ISLS Annual Meeting 2021

Reflecting the Past and Embracing the Future

Bochum, Germany, June 8-11

Workshops: June 1-7

Ruhr University Bochum (Online Event)

15th International Conference of the Learning Sciences (ICLS)

- Proceedings -

Edited by: Erica de Vries, Yotam Hod, & June Ahn

International Society of the Learning Sciences

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1st Annual Meeting
of the
International Society of the Learning Sciences (ISLS)

Editors:
Erica de Vries, Yotam Hod, & June Ahn

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Preface

With its 15th edition, the International Conference of the Learning Sciences (ICLS) has moved to being celebrated annually. Together with the International Conference of Computer-Supported Collaborative Learning (CSCL), it is part of the 2021 Annual Meeting of the International Society of the Learning Sciences.

As the first of its kind, the ISLS Annual Meeting 2021 is a milestone in the evolution of the Learning Sciences community. This meeting was envisaged to take place in Bochum, a location with a history that symbolizes the theme of the conference: Reflecting the past and embracing the future. Bochum lies in the heart of Europe in a region that has been historically shaped by the heavy industries but also by the solidarity and conviviality of workers with a variety of cultural backgrounds. After the decay of the old industries, this spirit of solidarity has become an important asset for embracing the present and future challenges. We hope this will inspire our growing international community, even though we do not have a chance to meet in place this time.

As part of the ISLS Annual Meeting, ICLS 2021 invited academics, researchers, professionals, and educators to share and embrace their diverse views with empirical, theoretical, conceptual, and design-based work. All papers, posters, and symposia were subject to a double-blind peer review. In total, 34% (62 out of 183) of long paper submissions, and 27% (40 out of 146) of short paper submissions were accepted in the category where they were submitted. In addition, a number of submissions were accepted in another category (short papers or posters). As a result, the ICLS Proceedings features 62 long papers, 72 short papers (work-in-progress), 153 posters, and nine symposia, with contributions coming from four continents: Asia, Europe, North America, and South America.

The content of the LS track covers a number of exciting contemporaneous topics, including computational thinking, teacher practices, STEM education, design-based implementation research, game-based learning, data visualization, epistemic practices, learning in virtual environments, equity and justice, knowledge building, emotions, and much more. We are proud of the way that scholarship within the learning sciences community reflects and explores the realities of our everyday world with an eye on making it a better place to live.

We would like to take this opportunity to offer a special thank you to the 315 reviewers who carried out over 1000 reviews, the 86 senior reviewers who greatly helped us in making the final decisions on each submission, as well as the numerous people around the process who have spent countless hours ensuring that the program is of high quality.

It is a great honor to edit this year's proceedings for the Learning Sciences community in ISLS. We hope all of you enjoy your participation in the conference and social activities designed online.

Erica de Vries, Yotam Hod, June Ahn
ICLS 2021 Conference Program Co-chairs

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Visual Cues in a Video-Based Learning Environment: The Role of Prior Knowledge and its Effects on Eye Movement Measures

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Abstract: This study examined the effect of prior knowledge on students' gaze behavior while studying in a video-based learning environment. A total of 23 participants took part in a lesson about electric circuits. Their learning was accompanied by visual cues that served as written explanations in boxes with arrows. The results showed (1) differences in cue utilization and the amount of visual attention on cued parts depending on different levels of prior knowledge, and (2) varying gaze patterns between experts and novices. Although both prior knowledge groups made use of the visual cues, they probably had different functions for them. In light of these variations, recommendations as a result are made for complex video-based learning that is accompanied by visual cues.

Keywords: multimedia, visual cues, prior knowledge, eye-tracking, gaze pattern

Introduction

Computer-based learning environments have become an important educational element. Digital instruction is on the rise, and in some cases is even replacing conventional schooling. This technology offers various multimedia learning opportunities that combine text and pictures (Mayer, 2014).

Combinations of external representations (e.g. graphics combined with textual information) can be beneficial for learning (Ainsworth, 2006). When learners work for instance with complex content having high element interactivity (e.g. electric circuit diagrams), additional external representations (e.g. instructional cues) are often necessary for understanding or solving tasks (e.g. Ertl et al., 2006; Suthers & Hundhausen, 2003). Computer-based learning environments such as videos or animations are a useful tool for implementing different ways of instructional support.

Learning with additional external support

Instructional (e.g. verbal- or text-based) cues help organize learning material content, and can emphasize the relationship between content-related aspects (de Koning et al., 2009). According to the signaling or cueing principle (van Gog, 2014), cues also help draw learners' attention to task-relevant information in a presentation. Cues furthermore help reduce visual searches within learning material (Chandler & Sweller, 1991) and guide learners' information processing (de Koning et al., 2009). They also assist learners who on their own might have difficulty identifying essential information (Alpizar et al., 2020).

The positive effect of cueing has been extensively examined, and is supported by several meta-analyses (Alpizar et al., 2020; Richter et al., 2016; Schneider et al., 2018). In particular, learners with low prior knowledge benefit from instructional support (e.g. Alpizar et al., 2020). Some studies (e.g. Richter et al., 2016, 2018) have contrastingly reported negative effects for learners with a high level of prior knowledge. This effect is known as the *expertise reversal effect* (Kalyuga, 2014) and suggests that additional aids obstruct the learning process because they present redundant content that is already known (Kalyuga, 2009; Kalyuga et al., 2003). In other words, the same information presented in multiple modalities is redundant for learners possessing high prior knowledge (Kalyuga, 2009), and imposes incremental processing of unnecessary materials (Kalyuga et al., 2003). Richter and colleagues (2018) pointed out that learners usually process both sources of information while learning with multimedia (i.e. text and pictures). This is supported by an instructional format where information is physically integrated (e.g. text is embedded within a picture) where attention does not have to be divided. Learners with low prior knowledge will benefit from this kind of instructional format because they do not need additional working memory resources for mental integration (Ayres & Sweller, 2014). In contrast, learners with high prior knowledge will be forced to process information that is likely to be redundant (Kalyuga et al., 1998).

Prior knowledge and its effect on visual attention

The effect of prior knowledge on visual attention is frequently discussed in multimedia research. According to the redundancy principle of multimedia learning, Richter et al. (2018) noticed that learners with high levels of expertise are unable to disregard redundant information. Other studies have however shown that skilled learners were in fact able to ignore irrelevant information and focus on the elements at hand (e.g. Jarodzka et al., 2010). According to the information-reduction hypothesis by Haider and Frensch (1999, p. 172), learners with a higher level of expertise are able "to become selective in their use of information, that is, to distinguish between task-relevant and task-redundant information." The authors pointed out that "redundant information is perceptually ignored whenever this is possible" (p. 188). This information-reduction process consists of two steps. First, learners basically identify task-relevant and task-redundant information. Second, they actively select and process task-relevant information, while neglecting unnecessary information thanks to strategic considerations based on practice.

As seen here, prior knowledge affects visual attention. In their meta-analysis, Gegenfurtner and colleagues (2011) examined different levels of prior knowledge and its effect on the visual attention of learners working with visual representations. For instance, they found that learners with a higher level of expertise experienced longer fixation durations on relevant areas, and expressed longer saccades. Similarly, in the domain of natural science, when working with external visual representations, novices relied more than experts on different visual features of the representations to guide their understanding (e.g. Lowe, 2003). Some of these findings were obtained using eye-tracking technology.

Eye-tracking to understand visual attention in learning

Eye-tracking has in recent years become an important tool for analyzing learning processes in educational science (Jarodzka et al., 2017). This technology provides information about learners' perceptions and interests in visual stimuli (Duchowski, 2003). Eye-tracking is furthermore used to optimize multimedia learning environments. Numerous studies have analyzed the visual attention determined by eye-tracking technology to understand cognitive processes such as selecting, organizing, and integrating while learning with multimedia (see Alemdag & Cagiltay, 2018 for an overview).

Key types of eye-movement measures included fixations and saccades (van Gog & Jarodzka, 2013). These are gathered on temporal, spatial, and count scales, and serve as reliable indicators of cognitive learning processes (Lai et al., 2013). Fixation duration and fixation counts generally display the amount of attention allocated to visual representations (Scheiter & Eitel, 2017). Longer fixation durations can report the depth of processing (Rayner, 1998), whereas a higher number of fixations can represent a measure of processing intensity (Glaser & Schwan, 2015). Saccades show learners' perceptual transitions between different external representations, and reveal the integration process (Scheiter & Eitel, 2017). Scan paths quantitatively allow successive fixation positions to be examined, and demonstrate attention sequences. So, these kinds of gaze parameters can provide insight into learning behavior, most notably while learning with visual cues.

Research questions

Generally positive effects of cueing on learning outcomes have been determined (e.g. Richter et al., 2016; Schneider et al., 2018). Based on these findings, our research interest is not on learning outcomes per se, but instead on further investigating the learning behavior of persons with different levels of prior knowledge as they learn with visual cues. Alemdag and Cagiltay (2018) in their study incorporated qualitative analyses obtained from measurements of scan paths. The present research contributes to understanding individual learning behavior while dealing with visual cues, and also aims to optimize computer-based learning environments. This study will additionally contribute to qualitative research on scan paths.

RQ1: *To what extent do people with high and low prior knowledge differ in their use of visual cues?*
Learners with low prior knowledge are likely to revisit visual cues more often than learners with high prior knowledge because they experience the cues as helpful in learning more effectively (cf. the signaling or cueing principle). Learners with high prior knowledge in turn might experience some of the cues as redundant, and as a result revisit the visual cues less frequently (cf. the redundancy effect).
RQ2: *To what extent do people with high and low prior knowledge differ in their visual attention to the cued parts?*
Learners with high prior knowledge are able to devote more attention to cued four electric circuits than learners with low prior knowledge (e.g. Jarodzka et al., 2010).
RQ3: *What differences occur in the gaze pattern of learners with high prior knowledge and low cue utilization (experts) compared to learners with low prior knowledge and high cue utilization (novices)?*

According to the information reduction hypothesis (Haider & Frensch, 1999), learners with high prior knowledge and low cue utilization are more selective in their information processing, and differentiate between task-relevant and task-redundant information.

Method

The data in this study was collected as part of a larger experiment (Ertl et al., 2020). Based on our research interest, we only focused on specific variables to investigate the role of prior knowledge during studying with visual cues in a complex physics learning environment. Twenty-three students from a German university participated in the computer-based experiment. The six female and 17 male participants were between 20 and 30 years old, and had a mean age of 22.34 (SD = 2.55). The participation was voluntary and rewarded with a €10.00 voucher or one course credit.

Procedure

Participants were tested during an individual session by a professional examiner. Before starting, every participant generated a personal code and completed a survey including their age and gender. The session lasted about sixty minutes and included both a pre- and post-test.

Prior to the experiment, participants were asked about their task-specific prior knowledge regarding the components of electrical circuits. This was followed by two learning phases: First, the participants refreshed their knowledge about electrical circuit symbols (e.g. switch or light source) with the help of illustrations. Second, they watched eight time-limited videos consisting of a task and four electrical circuits each. Some tasks added an additional electrical circuit (i.e. reference circuit) which was also accompanied by cues (i.e. reference cues). In this phase, participants applied physical concepts (application tasks) or a given electrical circuit (i.e. reference circuit) to identify an equivalent electrical circuit (comparison tasks). They obtained system-paced cues as external representational guidance in the learning material. These were presented as on-screen texts in boxes. The text boxes had arrows pointing to the corresponding object being explained (see Figure 1). The cues introduced the components of each electric circuit presented and their types of connections (serial vs. parallel).

Eye-tracking data was collected during the second phase of learning by using the SMI RED eye-tracker. Learners sat in front of a notebook with a 15” screen at a distance of about 60 cm. Their eye movements were recorded contact-free with a calibrated infrared sensor placed on the notebook. The participants then completed a test consisting of recall and transfer tasks.

Measures

Prior knowledge (pre-test) was scored on six self-constructed items (Cronbach’s α = .87). Elements of the electric circuits presented later were shown, and participants were asked to identify them. All six prior knowledge items were added to obtain a score between 0 to 6 points, indicating their overall prior knowledge of electric circuits. We then divided the participants into groups: low prior knowledge (between 0 and 3 points; 10 participants) and high prior knowledge (between 4 and 6 points; 13 participants).

Cue utilization (Eye movement measure) was operationalized as revisits to visual cues in the second learning phase. Revisits indicated how many times participants re-fixated on visual cues when they needed additional information. A revisit was counted when a fixation landed on the area of interest (AOI). To measure cue utilization, we first pre-defined an AOI for each cue of the eight learning tasks. Afterwards, we summed up all revisits to the overall 51 cues (Cronbach’s α = .92).

Visual attention (Eye movement measure) was measured during the second learning phase. We used a mixed-method approach to examine the attention allocation to the cued parts. Quantitatively, the distribution of visual attention over all cued electric circuits was expressed by the average fixation duration (Cronbach’s α = .87). First, eight AOIs were pre-defined, which consisted of the four circuits per task. The total number of fixations and the fixation time on each AOI were then calculated. The sum of total fixation times was divided by the number of all fixations, which resulted in the average fixation duration (in milliseconds). Scan paths were quantitatively used to show visual attention.

Results

SPSS Statistics version 26 was used for all analyses, with a pre-defined α-level of .05 for inference testing. All preconditions for statistical analyses were additionally tested and confirmed.

Treatment check. Figure 1 provides a scan path of a sequence of four images to show how the intervention was implemented. Furthermore, a qualitative analysis of all gaze behavior during the presentation of visual cues was conducted to examine whether the desired effect of attentional guidance was achieved. The sequence exemplarily shows the effect of cueing. Overall, the visual cues were utilized, guiding the learners’ core attention to the elements in the electrical circuits referenced in the cue.

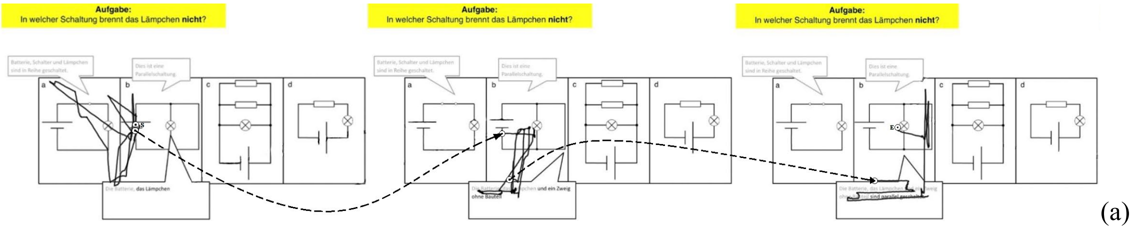

Figure 1. An exemplary sequence (a-c) during a presentation of a visual cue to show utilization and its effect on directing attention. Each panel demonstrates three seconds that confronted learners with cues.

RQ1: Differences in visual cue utilization

An ANOVA with high and low prior knowledge as the between-subjects factor, and number of revisits as dependent variable was conducted to examine the differences in cue utilization. No significant effect was found for the different levels of prior knowledge on cue utilization. The results merely indicated a statistical tendency towards lower cue utilization by high prior knowledge learners, $F(1, 21) = 2.99$, $p = .099$, $\eta_p^2 = .13$.

A MANOVA was additionally conducted with high and low prior knowledge as the between-subjects factor and revisits of visual cues in each task as dependent variables. The results revealed consistent differences between learners with high and low prior knowledge on cue utilization, as shown in Figure 2. A significant effect of prior knowledge on cue utilization was only found in Task 5.

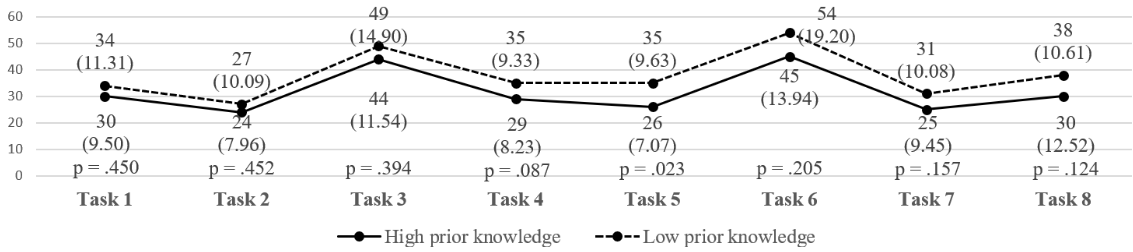

Figure 2. Mean values of the revisits on visual cues for high and low prior knowledge. The second number in parentheses indicates the standard deviation (SD).

RQ2: Differences in attention allocation on cued parts

An ANOVA was conducted with high and low prior knowledge as the between-subjects factor, and average fixation duration as dependent variable to investigate the differences in attention allocation on the cued parts across the eight tasks. A significant effect of prior knowledge was found for average fixation duration on different tasks, which indicates higher visual attention of learners with high prior knowledge, $F(1, 21)= 4.56$, $p = .045$, $\eta_p^2 = .18$.

In addition, a MANOVA was conducted with high and low prior knowledge as the between-subjects factor and the average fixation duration for each task as dependent variables. The results revealed consistent differences between learners with high and low prior knowledge of the cued parts, as shown in Figure 3. Significant effects of prior knowledge on average fixation duration were however only found for the first three tasks.

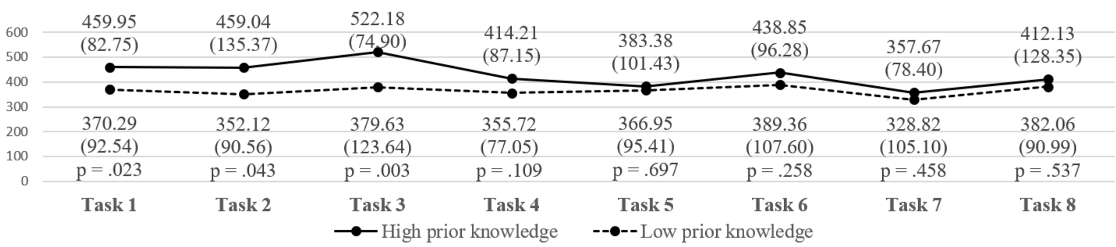

Figure 3. Mean values of visual attention in milliseconds on cued parts for high and low prior knowledge. The second number in parentheses indicates the standard deviation (SD).

RQ3: Differences in gaze pattern

A qualitative analysis of scan paths was conducted to investigate the gaze pattern of learners who differ in levels of prior knowledge and cue utilization. First, we split students based on their cue utilization into three groups using terciles. To analyze gaze patterns, we exemplarily selected one typical gaze pattern from learners of the lower and upper third (see Figures 4-5) as representatives of high and low cue utilization. We then analyzed ten-second sequences of their gaze patterns during two types of tasks: application tasks applying physical concepts, and comparison tasks using an additionally provided electrical circuit.

Application task. The focus on the learner with high cue utilization and low prior knowledge (Panels 1a-1c) was more directed to the cues and electrical circuits being described. Here the learner repeatedly jumped back to the cue presented, as indicated by vertical saccades between the visual cue and cued elements (Panels 1a-1c, A). In addition, the learner also jumped back to a cue which had already been presented (Panel 1c, B).

In comparison, the gaze behavior of the learner with low cue utilization and high prior knowledge (Panels 2a-2c) was initially scattered. First, the learner scanned all presented circuits and compared them with each other (Panels 2a-2b, C), as indicated by horizontal saccades between the four electric circuits. Later on, the learner fixated on the visual cue and did not frequently or repeatedly jump back to the cue presented (Panel 2c, D).

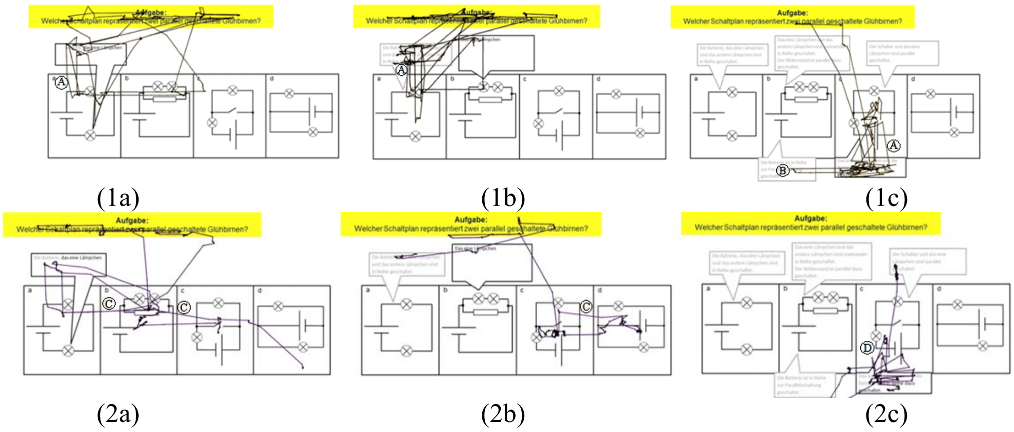

Figure 4. Ten-second sequences of gaze behavior during an application task. Panels 1a-1c show a common gaze pattern of a learner with high cue utilization and low prior knowledge. Panels 2a-2c show a common gaze pattern of a learner with low cue utilization and high prior knowledge.

Comparison task. Two cues were sequentially provided in Panels 3a and 4a over a span of ten seconds, i.e. the second part of the reference cue on the left (3a, E) and the first part of the cue to circuit (3a, F). In general, the focus of the learner with high cue utilization and low prior knowledge (Panels 3a-3c) was directed more to the cues as well as the electrical circuits being described. The learner also jumped back to the reference cue on the right, which had already been presented (Panel 3a, G). Furthermore, the learner repeatedly jumped back to the cue presented (e.g. Panels 3b-3c, H), as indicated by vertical saccades between the visual cue and the physics elements.

In comparison, the gaze behavior of the learner with low cue utilization and high prior knowledge (Panels 4a-4c) was initially scattered. Here the learner scanned all four presented circuits and compared them with each other (note the forward and backward jumps between the electric circuits, regardless of the cue being discussed (4a, I)). Later on, the learner also fixated on the visual cue, but did not often jump back to the cue presented (4b-4c, J).

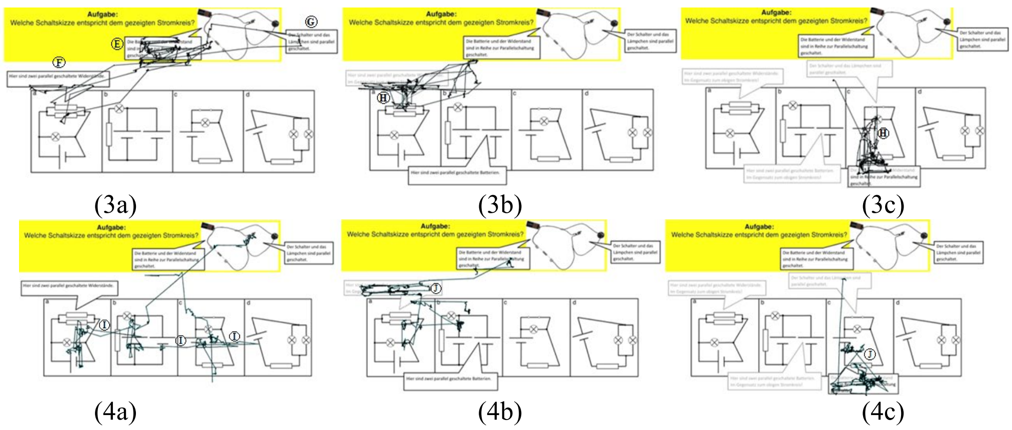

Figure 5. Ten-second sequences of gaze behavior during a comparison task. Panels 3a-3c show a common gaze pattern of a learner with a high cue utilization and low prior knowledge. Panels 4a-4c show a common gaze pattern of a learner with a low cue utilization and high prior knowledge.

General discussion

This study aimed to identify effects of prior knowledge on learning behavior while dealing with visual cues in a video-based learning environment of electric circuits. Although we found consistent differences between prior knowledge groups across the eight tasks, there was no significant difference between high and low prior knowledge learners with regard to their use of visual cues, even though there was a significant difference of average fixation duration on the cued parts. In addition, a distinct influence of prior knowledge on gaze behavior in perceiving two different types of tasks was qualitatively found.

According to the cueing or signaling principle (van Gog, 2014) and the redundancy effect (Kalyuga, 2009), we assumed that learners with low prior knowledge would be more likely to revisit visual cues than high prior knowledge learners. The consistent differences over all eight tasks between the groups may suggest that learners with low prior knowledge need more instructional guidance when dealing with schematic diagrams such as electrical circuits, whereas visual cues could be redundant for some high prior knowledge learners. Hegarty and colleagues (1991) stated that learners generally have difficulties interpreting schematic diagrams. This phenomenon might explain why it was difficult to find a significant difference in cue utilization between the two groups.

Furthermore, we could support our hypothesis that high prior knowledge learners were better able to devote their attention to the cued parts than low prior knowledge learners (Jarodzka et al., 2010). Our assumption was that learners with high prior knowledge would not lack information given in the visual cues, and could therefore spend more cognitive resources on active problem solving; they focused longer on the cued parts, which were the relevant areas for understanding the tasks. The result of longer fixation durations on the cued parts of learners with high prior knowledge is in line with the findings by Gegenfurtner and colleagues (2011). Our result is in turn closely related to our first finding of a smaller number of revisits to visual cues. A deeper focus on visual cues could potentially achieve a lower average fixation duration on the cued parts. When learners frequently revisit cues, especially in a system-paced format, study time might be lost for the cued parts, i.e. for areas relevant for understanding and solving the task. Thus, low prior knowledge learners in our study had less time to focus more deeply on the cued parts.

According to the information-reduction hypothesis by Haider and Frensch (1999), we assumed that high prior knowledge learners would be more selective in their information processing, differentiating between task-relevant and task-redundant information. Via qualitative scan paths analysis, we were able to support these assumptions for both types of tasks. In line with Gegenfurtner and colleagues (2011), higher expertise learners displayed longer saccades on the visualizations of the electrical circuits. This gaze pattern was often found at the beginning. They initially scanned the four electric circuits before focusing more deeply on information perhaps identified as task-relevant. This finding is consistent with the first step of the information-reduction process suggested by Haider and Frensch (1999). In the further course, learners with high prior knowledge fixed onto visual cues. With regard to the second step of the information-reduction process, high prior knowledge learners might aim to identify the visualizations of electrical circuits as redundant. This assumption appears consistent with previous studies (e.g. Jarodzka et al., 2010) where high prior knowledge learners were better able to ignore redundant elements. Their gaze pattern showed that they did not permanently try to focus on both information sources (i.e. cues and electrical circuits). In addition, it seems that they preferred learning with visual cues. One explanation for this might lie in the construction of coherent mental representations of the different electrical circuits. Due to their higher level of expertise, these learners are able to create the mental models they require for the task at hand while reading the written explanations in the cues. This assumption is supported by text processing research (e.g. Kintsch & van Dijk, 1978) which empirically shows that readers construct coherent mental models of texts (e.g. Myers et al., 1994). In addition, it might be that these learners expected new information to be provided they did not previously know. Perhaps they reviewed their body of knowledge and tried probably filling knowledge gaps while learning mostly with visual cues.

In sum, the qualitative results showed that high prior knowledge learners as well as low prior knowledge learners used the visual cues. Along with the quantitative results, we can also derive from the qualitative results that learners with low prior knowledge needed more visual cues when learning with different electrical circuits, as indicated by numerous vertical saccades between the visual cues and the corresponding elements. Low prior knowledge learners mostly fixated on the visual cues at the beginning of the presentation, suggesting their need for instructional guidance.

Limitations

This study is not without limitations. Its sample size of 23 participants is rather small, providing only low statistical power. And small, albeit remarkable effects identified within it were not significant. Eye tracking studies are in fact typically conducted with a low number of participants (Gegenfurtner et al., 2011) due to the time-consuming generation of each participant's eye-tracking data. They moreover require special hardware equipment and software, which limits the number of possible participants.

A further limitation is the restricted analysis of eye tracking parameters to investigate cue utilization. Visual cues generate additional gaze behavior, a natural result of having to read written explanations. Therefore, we only focused on the parameter of eye movement revisits on AOI, which were not directly influenced by reading skills.

Conclusion and implications

Although both high prior knowledge learners and low prior knowledge learners alike used the visual cues in this study, each group applied them differently. On the basis of the mixed-method approach, and with regard to the different levels of prior knowledge, our findings identified two different functions of visual cues. For learners with low prior knowledge, visual cues offer additional support, providing lacking information and guiding learners through complex tasks. For learners with high prior knowledge, the information in the visual cues offers the opportunity to control or check their knowledge. Cues also appeared helpful for both expertise groups. We suggest that future research should use mixed-method approaches to gain deeper and various insights into learning behavior that extend beyond statistical findings.

In terms of the different levels of expertise, practical implications for using visual cues in a computer-based learning environment can be drawn from this study. Complex computer-based learning environments should be individualized to the different levels of expertise. A learning environment offering a self-paced format to sufficiently study the instructional support and relevant areas for understanding and solving the tasks might benefit low prior knowledge learners. Learners with high prior knowledge seem to prefer working with visual cues. Learning environments should basically offer the opportunity to display cues for high prior knowledge learners. More research is however needed to understand the use of visual cues for learners of high expertise.

References

Ainsworth, S. (2006). DeFT: A conceptual framework for learning with multiple representations. *Learning and Instruction*, *16*, 183–198. https://doi.org/10.1016/j.learninstruc.2006.03.001

Alemdag, E., & Cagiltay, K. (2018). A systematic review of eye tracking research on multimedia learning. *Computers & Education, 125*, 413–428.https://doi.org/10.1016/j.compedu.2018.06.023

Alpizar, D., Adesope, O. O., & Wong, R. M. (2020). A meta-analysis of signaling principle in multimedia learning environments. *Educational Technology Research and Development*, 1–25. https://doi.org/10.1007/s11423-020-09748-7

Ayres, P., & Sweller, J. (2014). The split-attention principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 206–226). Cambridge University Press.

Chandler, P., & Sweller, J. (1991). Cognitive theory and the format of instruction. *Cognition and Instruction, 8*, 293–332. https://doi.org/10.1207/s1532690xci0804_2

De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). Towards a framework for attention cueing in instructional animations: Guidelines for research and design. *Educational Psychology Review*, *21*, 113–140. https://doi.org/10.1007/s10648-009-9098-7

Duchowski, A. T. (2003). *Eye tracking methodology: Theory and practice*. Springer.

Ertl, B., Fischer, F., & Mandl, H. (2006). Conceptual and socio-cognitive support for collaborative learning in videoconferencing environments. *Computers & Education*, *47*(3), 289–315. https://doi.org/10.1016/j.compedu.2004.11.001

Ertl, B., Watzka, B., Csanadi, A., Hoyer, C., & Girwidz, R. (2020). *Physics learning environment: The impact of auditive and visual cues on learning outcomes and cognitive load*. AERA online repository, San Francisco.

Gegenfurtner, A., Lethinen, E., & Säljö, R. (2011). Expertise differences in the comprehension of visualizations: A meta-analysis of eye-tracking research in professional domains. *Educational Psychology Review*, *23*, 523–552. https://doi.org/10.1007/s10648-011-9174-7

Glaser, M., & Schwan, S. (2015). Explaining pictures: How verbal cues influence processing of pictorial learning material. *Journal of Educational Psychology, 107*(4), 1006–1018. https://doi.org/10.1037/edu0000044

Haider, H., & Frensch, P. A. (1999). Eye movement during skill acquisition: More evidence for the information reduction hypothesis. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*, 172–190.

Hegarty, M., Carpenter, P. A., & Just, M. A. (1991). Diagrams in the comprehension of scientific texts. In R. Barr, M. L. Kamil, P. B. Mosenthal, & P. D. Pearson (Eds.), *Handbook of reading research* (Vol. 2, pp. 641–668). Lawrence Erlbaum Associates.

Jarodzka, H., Scheiter, K., Gerjets, P., & Van Gog, T. (2010). In the eyes of the beholder: How experts and novices interpret dynamic stimuli. *Learning and Instruction, 20*(2), 146–154. https://doi.org/10.1016/j.learninstruc.2009.02.019

Jarodzka, H., Holmqvist, K., & Gruber, H. (2017). Eye tracking in educational science: Theoretical frameworks and research agendas. *Journal of Eye Movement Research, 10*(1):3, 1–18. https://doi.org/10.16910/jemr.10.1.3

Kalyuga, S. (2009). *Managing cognitive load in adaptive multimedia learning.* IGI Global.

Kalyuga, S. (2014). The Expertise Reversal Principle in Multimedia Learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 227–246). Cambridge University Press.

Kalyuga, S., Chandler, P., & Sweller, J. (1998). Levels of expertise and instructional design. *Human Factors, 40*, 1–17. https://doi.org/10.1518/001872098779480587

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23–31. https://doi.org/10.1207/S15326985EP3801_4

Kintsch, W., & Van Dijk, T. A. (1978). Toward a model of text comprehension and production. *Psychological Review, 85*, 363–394. https://dx.doi.org/10.1037/0033-295X.85.5.363

Lai, M., Tsai, M. J., Yang, F. Y., Hsu, C. Y., Liu, T. C., Lee, S. W. Y., et al. (2013). A review of using eye-tracking technology in exploring learning from 2000 to 2012. *Educational Research Review, 10*, 90–115. https://doi.org/10.1016/j.edurev.2013.10.001

Lowe, R. K. (2003). Animation and learning: selective processing of information in dynamic graphics. *Learning and Instruction, 13*(2), 157-176. https://doi.org/10.1016/S0959-4752(02)00018-X

Mayer, R. E. (Ed.) (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 72–103). Cambridge University Press.

Myers, J. L., O'Brien, E. J., Albrecht, J. E., & Mason, R. A. (1994). Maintaining global coherence during reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20,* 876–886. https//doi.org/10.1037/0278-7393.20.4.876

Rayner, K. (1998). Eye movements in reading and information processing: 20 years of research. *Psychological Bulletin, 124*(3), 372–422. https://doi.org/10.1037/0033-2909.124.3.372

Richter, J., Scheiter, K., & Eitel, A. (2016). Signaling text-picture relations in multimedia learning: A comprehensive meta-analysis. *Educational Research Review*, *17*, 19–36. https://doi.org/10.1016/j.edurev.2015.12.003

Richter, J., Scheiter, K., & Eitel, A. (2018). Signaling text-picture relations in multimedia learning: the influence of prior knowledge. *Journal of Educational Psychology, 110*(4), 544–560. https://doi.org/10.1037//edu0000220

Scheiter, K., & Eitel, A. (2017). The use of eye tracking as a research and instructional tool in multimedia learning. In C. Was, F. Sansost, & B. Morris (Eds.), *Eye-tracking technology applications in educational research* (pp. 143–165). Information Science Reference.

Schneider, S., Beege, M., Nebel, S., & Rey, G. D. (2018). A meta-analysis of how signaling affects learning with media. *Educational Research Review*, *23*, 1–24. https://doi.org/10.1016/j.edurev.2017.11.001

Suthers, D. D., & Hundhausen, C. D. (2003). An experimental study of the effects of representational guidance on collaborative learning processes. *The Journal of the Learning Sciences, 12*(2), 183–218. https://doi.org/10.1207/S15327809JLS1202_2

van Gog, T. (2014). The signaling (or cueing) principle in multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (2nd ed., pp. 263–278). Cambridge University Press.

van Gog, T., & Jarodzka, H. (2013). Eye tracking as a tool to study and enhance cognitive and metacognitive processes in computer-based learning environments. In R. Azevedo, & V. Aleven (Eds.), *International handbook of metacognition and learning technologies* (pp. 143–156). Springer.

People, Places, and Pets: Situating STEM Education in Youths' Homes with their Pets

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Abstract: We facilitated a remote educational summer camp for teenage youth, with participants "sheltering in place" at home due to the COVID-19 pandemic. The summer camp was part of an initiative aimed at promoting STEM education for youth through learning about their pets' senses and engaging in a co-design project to enrich aspects of their pets' lives. We describe how situating scientific and design activities within the home and with pets engages participants in ethnomethodological practices such as field work, naturalistic observation, and in situ design that build upon their funds of knowledge. We discuss implications for the designs of learning environments that leverage the benefits of at-home science and design with pets.

Introduction

As part of a larger project (Kelly et al., 2020), we planned to hold a summer camp for teenage youth to engage adolescents and their pets in feminist-oriented science, design, and engineering during the summer of 2020. Due to the COVID-19 pandemic, we were forced to run the entire program with facilitators and participants staying in their homes. We designed the camp to make the most of participants' time at home with their pets and connect empathetic practices to engagement into science and engineering practices (National Research Council, 2012; NGSS Lead States, 2013). We structured the camp to engage participants to learn about their pets' senses and experiences at home, and to engage participants in week-long co-design projects with the goal of enriching their own pets' lives. Drawing inspiration from Hollan and Stornetta's (1992) paper on how researchers and designers should leave behind notions of simply using telecommunication to recreate the experience of "being there," we use this experience created by circumstance to examine aspects of location, timing, and mode in learning environment design that may be useful well beyond the pandemic. We present the design of our remote summer camp, identify several key advantages of this type of learning environment, and summarize implications for the learning sciences community

Camp design

Theoretical and conceptual background

Researchers have taken different approaches to the ways in which homes, classrooms, and other spaces can support learning. Learning environment design in both informal and formal settings tends to aim towards physically co-located and synchronous facilitation when possible, increasingly with CSCL tools to mediate productive interaction, shared inscriptions, and records (Tissenbaum & Slotta, 2019). Exceptions to co-location in formal and informal education programs tend to occur when participants are geographically distributed and cannot travel to be together, and exceptions to synchronous tend to be when time is desired for individual preparation, practice, or reinforcement, as in flipped classrooms (Akçayır & Akçayır, 2018), or when time is desired for reflection and development of products. Connected learning acknowledges that learning happens across spaces and relationships in people's lives (Ito et al., 2013, 2020). Oftentimes, the home is still a proxy of connected learning for further activities that are done in the classroom. In our work, we directly situate the scientific inquiry and discovery in the home. The usual preference for in-class learning over at-home learning limits opportunities for students' home-based funds of knowledge to inform, motivate, and contextualize learning (Moll et al., 1992). Rather than simply recreating the same kinds of in-class experiences with Zoom and other media spaces for collaboration, we aimed to go "beyond being there" and designed situated learning experiences that would take place within the context (including physical affordances and relations with other actors) of youths' homes (Gaver, 1992; Hollan & Stornetta, 1992). "Activity and setting are seen as mutually crafting" (Lave, 1982, p. 6). Situating scientific and engineering problems within youths' homes with their pets establishes students as independent researchers, and more importantly, as experts, as they can draw on their direct experience and prior knowledge of their pets. We aimed to create at-home activities ("homework"), but not in the traditional sense of homework that is done to reinforce or expand upon learning done in the classroom (Carr, 2013), but as ethnomethodological and CSCW-style field work that students do within their homes to inform in situ co-design projects (Dourish & Button, 1998). Observing organisms in the field through naturalistic observation is an invaluable practice for understanding an animal's behavior in its natural environment by recording its reactions to unmanipulated stimuli (Salkind, 2010). Ethnomethodologically-oriented inquiry and design inform one another. In the case of designing for non-human stakeholders, Animal-Computer Interaction researchers view co-design as a powerful method that gives animals more agency because of its integration of stakeholders into all phases of the design process (Sanders & Stappers, 2008; Hirskyj-Douglas et al., 2017). By establishing students' homes as valuable research and design sites, we counter the privileging of classrooms separated from homes as sites for learning; acknowledging students, and their pets, as equally valuable co-creators of knowledge using the physical places where they live, together.

Overview

We designed the camp to draw on the advantages of being at home, particularly the advantage of participants spending time with their pets while performing ethnomethodological activities and creating co-design projects. Placing science and engineering work in the context of the home situates participants' scientific inquiry and investigation within their pets' natural environment, amid all the normal stimuli and routines they encounter. We conjecture this learning environment design enables participants to draw upon funds of knowledge from their homes and relationships with their pets. We designed the first week of camp for participants to engage in scientific inquiry and investigation of their pets' senses, as well as to observe their pets' behaviors interacting with different stimuli. We designed the second week of camp for each participant to co-design a project with their pet to enrich some aspect of their pet's life. We distributed assignments and resources via Google Classroom and met weekday mornings as a group for one hour over Zoom. We designed a mix of asynchronous at-home activities, and synchronous activities to do as a group in our Zoom sessions.

Recruitment

We recruited middle and high school aged youths through a STEM mailing list of people who previously participated in a science or engineering summer camp. We used a flyer that described the virtual camp activities, including estimates of how participants would spend their time. The participation criteria were that participants were between the ages of 13–18, had at least one pet dog or cat at home, and had internet and computer access. 13 youths, 9 dogs, and 5 cats participated in our study with 11 youths completing the camp (see Figure 1).

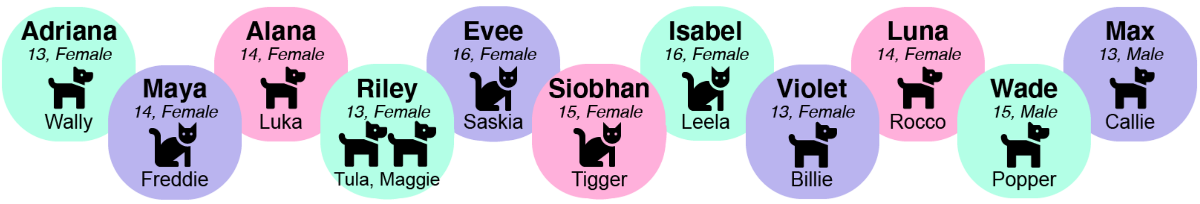

Figure 1. Participants' pseudonyms, ages, genders, and pet information.

Key asynchronous and synchronous activities

We shipped materials to participants to support their at-home activities and co-design projects. Each participant had a Pet Blog, which was a personalized Google Slides presentation where participants documented their at-home activities and co-design project. We orchestrated synchronous group share-outs over Zoom where participants reported their activity and project progress with the group. We also conducted group discussions (in full groups and smaller breakout groups) that helped participants generate ideas and questions for their later at-home activities. We used Google Docs and Slides, so participants could collaboratively comment on the document in real-time, post questions in the Zoom chat, or speak up verbally if they felt comfortable. For the first at-home activity, participants developed a mock social media profile for their pet and completed an ASPCA feline-ality or canine-ality assessment and reflected on their pet's personality type result (ASPCA 2007a; 2007b). Prior to this study, we developed two Snapchat lenses called DoggyVision and KittyVision (Kelly et al., 2020). These lenses simulate canine and feline visual differences: color perception, visual acuity, and brightness discrimination (Miller & Murphy, 1995). When users enable the lenses, they can see the effects in real-time on their phones' camera feeds and can capture photographs and videos of the scenes they are viewing—enabling participants to see their pets' home environments as they would. The day two activity was an at-home exploration with DoggyVision and KittyVision; participants viewed areas inside and outside of the house that their pets frequent using the lenses and took observational notes. On day three, participants designed an experiment using Doggy- or KittyVision to investigate a question they had about their pet's vision. On day four, participants observed their pet's reactions to different sound stimuli, and designed a wearable paper model of their pet's pinnae (outer ears) and made observations about their differences in their hearing and their pet's and wrote about sounds that stimulate or frighten their pets. Our day five activity (the last day of week one) was inspired by behavior tracking techniques from the animal sciences (Lehner, 1992). Participants observed their pets throughout the day and over the weekend and used their logs to make claims about their pet's emotional and mental states and the contributing environmental factors. Participants also used these techniques throughout week two for testing and evaluating their co-design projects with their pets. The week two activities guided participants through the process of creating co-design projects, including designing and building initial prototypes, and evaluating and iterating on their projects each day at home. At the beginning of week two (day six), each student wrote a proposal for a co-design project and developed a design persona ("pet-sona") to represent their pet as a co-design stakeholder (Hirskyj-Douglas et al., 2017). On days seven, eight, and nine (the penultimate day) participants provided daily project updates in class and in their Pet Blogs that included their project revisions, the methods they used to evaluate their project, and the results of their testing. Their results included successful aspects of their project and revision plans to address the unsuccessful aspects of their projects. On the penultimate day of camp, participants created a final video project presentation about their co-design projects. Participants presented their videos on the last day, while facilitators and campers asked questions.

Data collection and analysis

We saved participants' at-home Pet Blog work, in-class collaborative work, and recordings of all Zoom interactions. Additionally, we recorded exit-interviews with nine participants. We content logged and partially transcribed participants' exit-interviews, focusing on their experiences engaging in science and engineering at home. We performed a thematic analysis on the data, focusing on themes pertaining to participants' engagement in their at-home activities with their pets, and on how being at home shaped their practices and experiences regarding scientific experimentation and observation. As part of a larger analysis, we described in detail the links between science and engineering practices (NRC, 2012; NGSS Lead States, 2013), care, and empathy in participants' co-design work with pets. That work informed the analysis in this paper, where the emphasis is on how being situated in the home, with their pets, influenced the experience of doing science and engineering using the framework described in the Theoretical and Conceptual Background.

Findings and discussion

At-home activities as field work drawing upon funds of knowledge

The asynchronous camp activities promoted participants' enactment of ethnomethodological field work with their pets and in their homes. Situating this work in participants' homes with their pets enabled them to perform naturalistic observation, and to build on their funds of knowledge regarding their pets. One participant, Violet, reflected on the benefit of being able to participate at home with her dog from Texas (~950 miles distant from the facilitators' locations), saying, "this is [Billie's] environment and she knows it much better…her environment here is so much more different here than in Colorado." Violet's statement demonstrates the importance of place in this learning environment, particularly how participating somewhere other than their home would alter her and Billie's experiences of the camp.

Participants incorporated their and their pets' home environments and normal routines into their scientific work. For example, during the behavior tracking at-home assignment, participants logged their pets' behaviors and made arguments for what environmental stimuli in or outside the home were influencing these behaviors. Participants used this evidence, and drew on their funds of knowledge, to argue what their pets' emotional and mental states were. For example, Adriana's family had a visitor come over with a new puppy and she tracked Wally's interactions and behaviors around the puppy, writing observations such as, "If [the puppy] did something that Wally didn't like, he would growl at her. It was a low growl coming from the back of his throat." Based on Adriana's observations of Wally's growling, and engaging in behaviors such as "stalking her" and "try[ing] to stand up taller and appear bigger," she argued Wally was feeling territorial and therefore trying to assert his dominance over the puppy. In addition, when Adriana was evaluating Wally's interaction with her design project (a comfortable napping crate for Wally), she noted similar growling behavior. Adriana knew to associate growling with territorial behavior, therefore, Adriana noted this as a sign that Wally liked the napping crate. She wrote, "he was protective of the crate, and was thinking of it as his." The ability to observe Wally at home enabled her to see these territorial behaviors; had she and Wally participated in a different location Wally would not display the same ownership and comfort of the space.

In addition to the importance of *place*, the behavior tracking assignment displayed the importance of *relationships*; particularly, the value of participants' intimate knowledge of their pets. Adriana had knowledge of

Wally's sleeping preferences, saying "[Wally] loves resting in tight spaces...When he's napping, he'll often do it behind the dinner table, or up against the wall or couch." This knowledge of Wally's sleeping preferences is what led Adriana to choose to design a new, comfortable sleeping space for him for her project. This use of prior knowledge was also prevalent in one of Riley's behavior logs. Riley noted, unlike other dogs, Tula does not wag her tail when she is excited. She wrote, "[Tula] never really straightens her tail so this is just in its normal position...she is enjoying it too much to think about wagging it." Riley's assessment of Tula's mood required intimate knowledge of her behaviors. Whereas an outside researcher or other camper may have perceived Tula's lack of tail-wagging as a sign of discontent, Riley utilized her prior knowledge and relationship with Tula to explain why the opposite was true. To demonstrate the importance of participants' funds of knowledge, we offer a contrasting example; one participant, Maya, adopted her kitten Freddie only an hour before the camp started. Therefore, she lacked the prior knowledge about her pet that develops over time in a relationship. Maya could only perform on-the-spot naturalistic observation, which was also difficult because Freddie was nervous about his new home and tended to hide when she wanted to interact. In reference to this problem, Isabel said "[The feline-ality test] would be difficult for new animals because these animals may not have begun to form unique behaviors and figured out how they handle the world…[Leela] has become a little lazier and less social as she's aged."

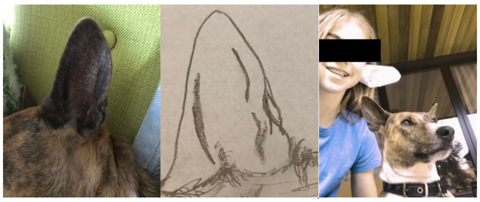

Figure 2. Alana's photograph of Luka's ear, a sketch, and her wearing the paper model she designed.

Situating the camp at home was beneficial towards participants' understanding how their pets' senses of sight and sound operated in their natural environments. Participants' use of DoggyVision and KittyVision in and near their homes allowed them to view their pets' natural environments with their simulated color perception firsthand. During Alana's initial explorations with DoggyVision in her home, she took a photograph of a view outside a window that her dog Luka often stares out. In her photo caption, Alana wrote, "this is the view out of a window that [Luka] likes to sit by. The colors are a lot less brilliant and the red flowers across the street blend in with the grass." Not only was Alana building a model of dogs' color perception, she was also viewing the world from her dog's day-to-day perspective—something impossible to do in a school classroom or at a centralized camp location. During the hearing activity, participants observed their pets' reactions to different sound sources and stimuli in and around their homes, as well as recalling prior knowledge of their pets. Alana wrote, "Whenever someone knocks on the door, [Luka's] head shoots up and he becomes very alert." Some participants made note of sounds related to feeding time, Isabel wrote, "We know that [Leela] knows the sound of her food cans opening, as she always runs when she hears it. We also see her react to my dad calling them to dinner." These observations required no manipulation of their pets' environments, and heavily relied on their prior knowledge. Participants' ability to work on the hearing assignment at home also enabled them to record up-close observations of their pets' ears and create detailed sketches of their appearance. This allowed them to design their paper models to more closely resemble the shape of their pets' unique ears, as opposed to a generic dog or cat model (see Figure 2).

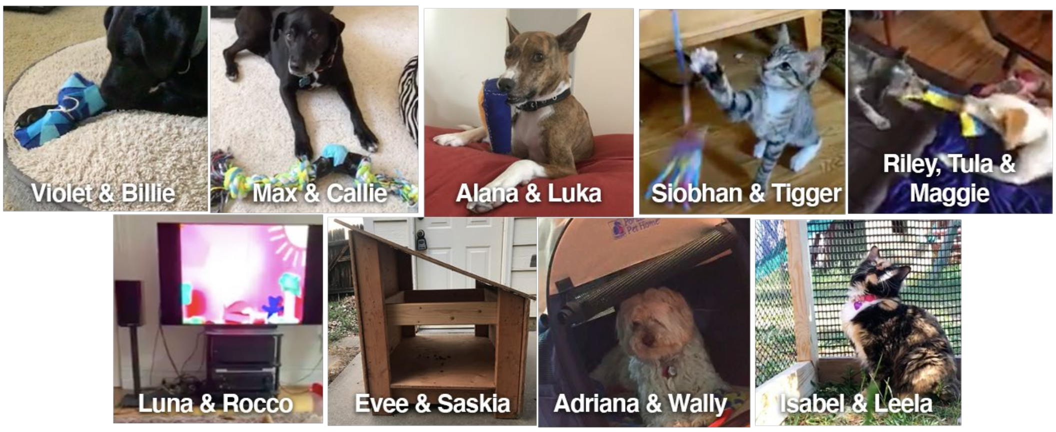

Figure 3. Participants' final co-design projects in use by their pets.

The ability for participants to engage in their experimental and observational activities with their pets at home enabled them to enact ethnomethodological practices and understand their pets' behaviors and senses in their natural environments (Dourish & Button, 1998). In addition, working from home allowed them to build on their funds of knowledge they have from their relationships and cohabitation with their pets. These practices helped participants produce more authentic data about their pets for them to develop hypotheses and to use in their co-design projects. Because each student's co-design project focused on improving their pet's quality of life, students' funds of knowledge helped provide empathetic motives for their design interventions. Students' co-design projects fell into two major categories: 1) new toys that were tailored to their pets' specific wants and needs and 2) spaces or environments that would make their pets feel comfortable and safe (see Figure 3).

In situ co-designing with pets

The ability for participants to work on their co-design projects from home allowed them to create projects that integrated seamlessly into their homes, and enabled participants to engage their pets in all stages of the design process, whereas participating in a classroom or camp location outside of their homes would create disjoint stages of iteration and evaluation. All phases of designing were situated in the context of theirs and their pets' natural lives: understanding stakeholder requirements (which we highlighted in the last section through examples of participants' at-home field work and observations), prototyping, evaluating, and revising.

As an initial stage of their co-design projects, participants developed design personas ("pet-sonas") for their co-design projects. Luna wanted to design a TV show for Rocco and wrote down her observations of how Rocco typically interacts with the TV, "Rocco loves to watch the tv when my family is sitting near it watching a show. He enjoys the sounds and visuals on the tv screen...when there is a loud or interesting sound his ears will perk up and he may run over to the screen." Luna's description captures both how Rocco interacts with the television, and also how his interest in the television is tied to spending time with the rest of the family. Isabel wanted to build an extension to her cat's current outdoor enclosure for her project, so she wrote about how Leela typically interacts with the current enclosure, "Leela mainly spends her time on the ground, eating grass, but she also enjoys the vertical shelves, which gives her a vantage point...she often claws at the fencing and clearly wants to be able to move around freely" (see Figure 4).

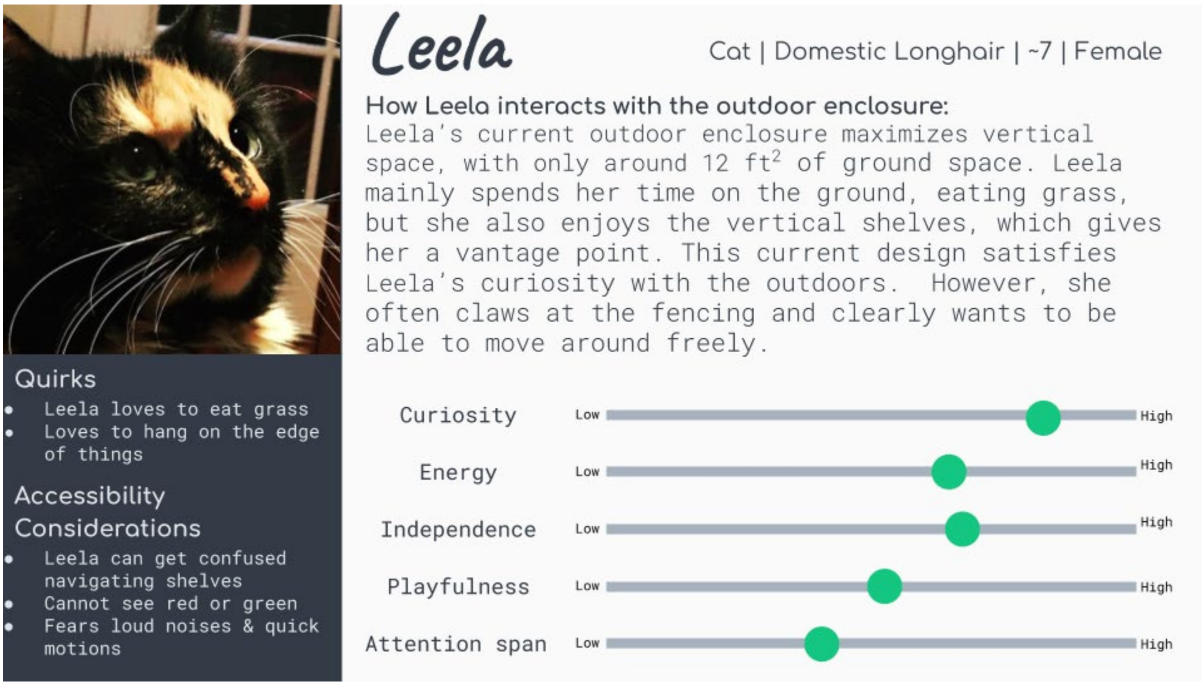

Figure 4. Isabel created this "cat-sona" to represent her cat Leela.

Conducting experiments and testing their projects at home with DoggyVision and KittyVision allowed participants to determine what colors were visually accessible for their pets in their natural environments, and to eventually evaluate what their prototypes looked like in their own homes. Figure 5 shows Violet's experiment she conducted with Billie to investigate whether she had a particular color preference in her toys. Being at home gave

Violet access to Billie's toys, as well as the ability to experiment in situ with Billie in an unmanipulated environment familiar to both dog and human. In her tests, Violet played with Billie in her normal habitat (the living room), and Violet collected DoggyVision photos to see how Billie's toys looked on their carpet. Based on her tests, Violet ascertained that bright blue was the most engaging to Billie, which led her to design a toy prototype that included varying shades of blue. Similarly, Riley used DoggyVision to observe how her toy prototype looked on different surfaces (grass, concrete, wood floor) to test if the colors would be visually accessible to her dogs. She wanted to compare the appearance of the new prototype against one of her dogs' old ratty toys to evaluate whether or not there was a visual improvement. Riley collected side-by-side photographic evidence of the old toy and new toy in three different locations: the backyard, the back deck, and a room in the house (see Figure 6).

Figure 5. Violet's documentation of her color preference test with Billie

Figure 6. Riley's side-by-side DoggyVision photos of her dogs' old toy and her new toy prototype.

Situating the co-design projects at home required participants to develop a sense of their pets' schedules and behaviors throughout the day. Many participants had to adapt their testing methods depending on the time of day. For example, Siobhan tried to keep her testing times consistent because Tigger was more active in the evenings and "his energy level also changed how he reacted to the toy." Similarly, Evee was worried that testing her prototype at night would cause her to have to force Saskia to interact with it because of the rushed timeline. To address this, she said "I made my changes and set it up in the late morning so that [Saskia] would have all day to explore it and get used to it if she wanted to." Sometimes, the pets were in control of when tests took place. One time, Riley was in a Zoom session and Maggie wanted to play with her and the toy prototype, "While I was on a zoom meeting she was chewing on the toy for a relatively long time. I think she liked the crinkling of the plastic and the smell of the treats and the sound of the rattle when it rolled." This ability for participants to adapt to their pets' needs and routines allowed for impromptu discovery and is a valuable skill for performing in-situ co-design work. In addition, participants who designed toys for their project were able to engage their pets in frequent "play tests" inside and outside of their homes, which situated the process of design and evaluation in a mutually enjoyable activity that established relationships and location as a valuable part of their design processes.

Another advantage of participants working from home was their ability to use at-home resources, and household materials relevant to their personal hobbies and interests. Although we supplied each participant with a box of supplies, all participants used at least one item from their own home for their project. In addition, participants explicitly designed their projects to be a part of the home. Isabel's co-design project was to extend her cat's outdoor enclosure which was attached to the house. Isabel and her cat, Leela, live in a small mountain community where outdoor cats can fall victim to larger predators. Isabel wrote, "[Leela] really likes going outside but it's not really safe for her to do here." Based on her prior knowledge and observations of her cat, she identified Leela wanted more space in her enclosure, saying, "she often claws at the fencing and clearly wants to move around more freely." Isabel's project involved several large pieces of plywood and power tools, which would have been cumbersome or even impossible to transport back and forth between home and school. Because participants worked on the entirety of their projects at home, they did not need to transport their project materials. In addition, participants could always test their projects in situ because of the constant access to their pets. For example, when Isabel finished sizing her initial extension, she wanted to make sure it accommodated Leela before the next step of putting it all together, "In order to test the revisions to my prototype, I laid out the materials for the extension outside...I will let Leela stand in the structure tomorrow, to ensure that she can fit comfortably" (see Figure 7). Prior to constructing the extension, Isabel built a prototype model using craft materials at home (see Figure 7), saying the experience "helped me realize how to use things in my house." To bring her prototype into fruition, Isabel's father supported her interest and drove her to the hardware store several times to buy materials, which was about an hour and a half round trip drive. Isabel had experience with woodworking at home and from a high school class, saying she "did as much of [the project] as possible on my own," but that her father taught her to use their saw and helped her drill, so she would not damage the house. Isabel's project shows how personal interests, family support, location, and funds of knowledge can connect to an at home co-design project with a pet. Isabel was not the only person whose project connected to a hobby; Riley described herself as being good at sewing and applied this skill to her project creation, "I will sew up my toy with a sewing machine but hand stitch on the smaller sections. I am a good sewer and like to sew clothing and other things in my free time." Riley's statement demonstrates her integration of a personal interest (sewing) into her design project.

Figure 7. Isabel's model prototypes (A and B), the materials Isabel laid out to test the enclosure size (C), and Leela enjoying the final enclosure (D).

Situating participants' co-design projects at home allowed for a cohesive process of design iteration and evaluation and enabled participants to perform authentic design interventions. Participants created projects specifically designed for their homes and pets, and even integrated their personal hobbies and interests to their projects. Participants developed adaptable testing procedures that worked around their pets' schedules and allowed for spontaneous discovery.

Conclusion

In contrast to Ann Brown's (1992) groundbreaking design experiments in the early days of the learning sciences which were radical in situating what used to be called "educational psychology" in the "blooming, buzzing confusion" of classrooms, we explored what could be gained by working in the blooming, buzzing context of learners' homes during a pandemic that made gathering in in-person groups for summer camp impossible. Facilitating a remote STEM summer camp enabled us to situate participants' scientific, design, and engineering activities within their own homes, building on their relationships with their pets and their funds of knowledge while participating in structured learning activities with a distributed group. Participants conducted activities with their pets at home; allowing them to engage in ethnomethodological fieldwork practices such as naturalistic observation and in situ design and draw on prior knowledge they have about their pets. The ability for participants to work in their free time, allowed them to test with their pets at optimal times, which involved learning to adapt to their pets' behaviors and schedules. This flexibility in designing in situ allowed for more authentic data for their co-design project iterations. Even though we applied an asynchronous, distributed learning model out of necessity, we believe this type of learning environment should always include some level of asynchronous at-home work due to the advantages we have highlighted. One downside of remote participation several participants mentioned was the lack of connection with other campers. To address this, future iterations could seek to enhance social interaction and community-building among campers, through additional in-person or online activities that foster interpersonal interaction and collaboration, while still situating the core experimental and observational work within participants' homes. Our experience points to a lesson for designing the location of learning experiences: changing the focus to what ethnomethodological fieldwork and design work makes sense to do remotely as asynchronous "homework" (in this case at home where learners lived with their pets), and what social and interactional work makes sense to do synchronously, with various inscriptional tools used to support either remote or face-to-face discussion.

References

Akçayır, G., & Akçayır, M. (2018). The flipped classroom: A review of its advantages and challenges. Computers & Education, 126, 334-345. Elsevier Ltd.

ASPCA. (2007b). Meet Your Match® Feline-ality™ Training Manual. American Society for the Prevention of Cruelty to Animals [PDF file]. New York, NY, USA. Retrieved from https://www.aspcapro.org/sites/default/files/Feline-ality%20Guide_PRO.pdf

ASPCA. (2007a). Meet Your Match® Canine-ality™ and Puppy-ality™ Training Manual. American Society for the Prevention of Cruelty to Animals [PDF file]. New York, NY, USA. Retrieved from https://www.aspcapro.org/sites/default/files/aspca-canine-ality-guide-2015.pdf

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. The Journal of the Learning Sciences, 2(2), 141–178.

Carr, N. S. (2013). Increasing the Effectiveness of Homework for All Learners in the Inclusive Classroom. School Community Journal, 23(1), 169-182.

Gaver, W. W. (1992, December). The affordances of media spaces for collaboration. In Proceedings of the 1992 ACM conference on Computer-supported cooperative work (pp. 17-24).

Hirskyj-Douglas, I., Read, J. C., & Horton, M. (2017). Animal Personas: Representing Dog Stakeholders in Interaction Design. In British Human-Computer Interaction proceedings, 3-6 July, 2017, Sunderland, UK. ACM, New York, NY, USA. https://doi.org/10.14236/ewic/HCI2017.37

Hollan, J., & Stornetta, S. (1992). Beyond being there. Conference on Human Factors in Computing Systems - Proceedings, 119–125. https://doi.org/10.1145/142750.142769

Ito, M., Gutiérrez, K., Livingstone, S., Penuel, B., Rhodes, J., Salen, K., Schor, J. Sefton-Green, J., & Watkins, S. C. (2013). Connected learning: An agenda for research and design. Digital Media and Learning Research Hub.

Ito, M., et al. (2020). The Connected Learning Research Network: Reflections on a decade of engaged scholarship. Connected Learning Alliance.

Kelly, A., Chang, C., Hill, C. N., West, M., Yoder, M., Polman, J. L., Kane, S. K., Eisenberg, M. & Shapiro, R. B. (2020). "Our Dog Probably Thinks Christmas is Really Boring": Re-mediating Science Education for Feminist-Inspired Inquiry. In M. Gresalfi & Seidel Horn, I. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS), Volume 2* (pp. 935-942). International Society of the Learning Sciences.

Lave, J. (1982). The Mature Practice of Arithmetic Problem Solving in the Daily Lives of Americans. Final Report.

Lehner, P. N. (1992). Sampling methods in behavior research. Poult Sci. Apr;71(4):643-9. https://doi.org/10.3382/ps.0710643

Miller, P .E. & Murphy, C. J. (1995). Vision in Dogs. Journal of the American Veterinary Medical Association, 207(12), 1623–1634.

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. The National Academies Press.

NGSS Lead States. (2013). Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Salkind, N. J. (2010). Encyclopedia of research design (Vols. 1-0). Thousand Oaks, CA: SAGE Publications, Inc. https://doi.org/10.4135/9781412961288

Sanders, E. B.-N. & Stappers, P. J. (2008). Co-creation and the new landscapes of design, CoDesign, 4:1, 5-18, https://doi.org/10.1080/15710880701875068

Tissenbaum, M., & Slotta, J. D. (2019). Developing a smart classroom infrastructure to support real-time student collaboration and inquiry: A 4-year design study. Instructional Science, 47(4), 423-462.

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Choose Your Evidence: Scientific Thinking Where It May Most Count

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Abstract: Schooling traditionally affords students more experience in learning and practicing procedures than in identifying what a situation calls for. When asked to choose appropriate numerical data to support their causal claims, college students perform surprisingly poorly. In one case we describe, almost all chose limited, inconclusive data as sufficient evidence, despite having available the more comprehensive data needed to support their claim, and despite their established competence to employ such data for this purpose. Our objective in highlighting this weakness is to make a case that choosing one's evidence warrants the status of an important metacognitive intellectual skill and educational objective, one central to but that extends well beyond the domains of scientific and mathematical reasoning and hence warrants greater attention both in and beyond the science curriculum. People may choose evidence to justify their assertions in an ill-considered way, with potential adverse effects in both private and public communication.

Keywords: judgment, reasoning, argument, evidence, discourse

Introduction

We live not only in a time of information proliferation (Hills, 2018) but a time that allows, even encourages us to "Choose your news," and from this news, to choose your facts. The latter implies our choosing the evidence to support those facts, should we need to do so. The following discussion illustrates some common possibilities in choosing evidence to substantiate a claim.

AL: The US tax system is unfair. It's rich people who are most likely to cheat on their taxes.
BEN: I know. Some of us should write a letter to the editor making people aware of this.
AL: Should we include anything to prove our point?
CLAY: I've known a lot of well-off people who cheat. We just need to point them out.
DON: But there are others who don't.
AL: But how many?
BEN: Maybe we could show there are more that do than don't. That should do it.
CLAY: I think it would be more convincing to focus on the cheaters and show they are most often rich.
AL: But there are lots of poor people. At least some of them must cheat.
BEN: Right. And there are a lot of rich people who don't cheat. So I think that kind of disproves our point. It's not clear-cut. Maybe we'd better forget this.
DON: But wait. There are probably a lot more rich cheaters and poor honest taxpayers, than there are poor cheaters and rich honest ones. So that would prove our point.
ED: Hold on, I've got a simpler idea. Why don't we just compare the percentage of rich people who cheat to the percentage of poor people who cheat?

Evidence in the form of Ed's final suggestion is appealingly simple. The form is also one seen very frequently in a wide variety of print or other media. Yet each of the other forms portrayed above are not uncommon and are based on responses we observed in recent work (Kuhn & Lerman, 2021). We think they are important because they highlight a form of everyday scientific thinking having serious consequences. Moreover, it is a form that science educators arguably have neglected to students' disadvantage.

Our objective here is to make a case that choosing one's evidence warrants the status of an important metacognitive intellectual skill and educational objective of broad relevance, one that is central to but extends well beyond domains of scientific and mathematical reasoning. Our focus in making this case is the common context in which people have a free hand in choosing what serves as sufficient evidence to support their own claims or to accept others' claims – hence a context that invokes disposition (rather than only procedural or strategic competence) and serves to identify the epistemological standards an individual subscribes to (Greene, Sandoval, & Braten, 2016; Mills, 2013; Metz, Weisberg & Weisberg, 2018; Moshman, 2015).

A rapidly expanding body of work now exists on argumentation and most recently in particular the role of evidence in argumentation – studies that highlight the complexities of different forms of evidence and the distinct roles they play in relation to a claim (Duncan, Chinn, & Barzilai, 2018; Hemberger et al., 2017; Iordanou

& Constantinou, 2015; Jiménez-Aleixandre & Puig, 2012; Macagno, 2016; Macagno & Walton, 2018; McNeill & Berland, 2017; Miralda-Banda, Garcia-Mila, & Felton, 2019; Monteira & Jiménez-Aleixandre, 2016; Sampson & Clark, 2008; Shi, 2019). These studies point to overall weakness in key skills of recognizing the critical role of and effectively using evidence to both support and weaken claims, in both individual written and verbal argument and in dialogic argumentation with others. Such skills do show improvement, however, with engagement and practice (Kuhn & Crowell, 2011; Hemberger et al., 2017; Iordanou, 2010; Iordanou & Constantinou, 2015; Rapanta, 2019; Reznitskaya & Wilkinson, 2017; Ryu & Sandoval, 2012; Shi, 2019). In general, progress in dialogic argument precedes that in individual argument (Kuhn, 2019; Kuhn & Moore, 2015; Mayweg-Paus & Macagno, 2016; Shi, 2019). Initially, the essays of novices consist largely of supporting arguments for a favored position. Later to appear are attention to and arguments seeking to weaken the opposing position. Only more gradually do essays begin to include mention of possible strengths of the opposing position or weaknesses of the favored position, and later still the "However" statements that serve to connect and weigh opposing arguments. Also gradually increasing is the use of evidence to weaken as well as support claims (Hemberger et al., 2017; Shi, 2019).

In the present discussion, our focus shifts from the one common to the body of research just cited – individuals' competence in making effective use of evidence in their arguments and argumentation – to a focus on their disposition to do so. Disposition becomes critical when people have a largely free hand in deciding whether and how to bring to bear evidence to support a claim they believe is correct, a situation we have suggested is a common one in natural conversational contexts. Yet it has been the subject of much less investigation, except perhaps less directly in research on epistemological understanding (Greene et al., 2016; Moshman, 2015), in which people are queried regarding how they know what to accept as true. Another related contemporary line of research examines how people react to "fake news" and the attributes of the source and of the receiver of such news in affecting whether such news will be accepted and whether it will be relayed to others (Barzilai, Tzadok, & Eshet-Alkalai, 2015; Barzilai & Zohar, 2012; De Keersmaecker, Dunning, Pennycook, et al., 2019; Lazer, Baum et al., 2018; Pennycook & Rand, 2018). In addition to the factors of source credibility and cognitive and personality characteristics of the receiver, however, is the form of the evidence one selects as bearing on the assertion and one's judgment regarding its sufficiency and strength. It is this epistemological dimension of understanding of evidence, and its significance in science education, that is our concern here.

One of us has written at length about mature epistemological understanding as a developmental achievement that many individuals do not complete (Kuhn, 2005, 2009, 2020). Its achievement is foundational to the disposition, as distinguished from competence, to think critically or to engage in what has been coined epistemic vigilance (Sperber, Clement et al., 2010; Settlage & Southerland, 2019). Early conceptions of knowledge as reflecting an objective reality evolve toward a more correct one of knowledge as constructed by human minds (Iordanou, 2017). Initially, however, this construction is understood as yielding only a multiplicity of subjective opinions that knowers are free to adopt at will in the form of personal possessions. This multiplist level of understanding offers a way of making sense of adolescents' discovery of the existence of multiple, often seemingly reasonable yet diverging claims. Only at a next level do subjective and objective dimensions become coordinated in an understanding of knowledge as judgment (rather than immutable fact or unconstrained opinion), based on evaluation in a framework of alternatives and evidence (rather than immutable fact or unconstrained opinion). The marshalling of evidence as a means of supporting or challenging claims thus assumes its key role, as an essential tool in distinguishing among conflicting claims.

An examination of evidence choice among college students

In the study we draw on here, 43 college students enrolled in the initial weeks of an introductory statistics course at a small liberal arts college in the Northeast US. Their ages were mostly in the early twenties, about two thirds female. Three quarters identified as White, with the remainder African American, Latino/a, and Asian. The college is selective in its admission and serves a largely homogeneous, upper-middle to upper class population whose families can afford to pay the high fees the institution charges. They served not as a convenience sample but as a sample of a population that are widely expected to hold standards higher than those of an unselected population with respect to their exercise of care in drawing unsupported inferences. Critical thinking, after all, is regarded as among the most highly valued achievements of a college-level education.

The main problem introduced in writing was this: A National Health Data Bank have identified children's obesity (excess weight) as a concern and want to determine the cause. They have collected information from a broad, representative sample of 200 American four-year-olds, these are the numbers they came up with. Each card shows the children they identified who fall into the category shown on that card. The Data Bank researchers now need someone to analyze the results and to write a summary report of what these findings show about the causes of young children's being overweight.

Students were presented a set of 19 cards ordered randomly, each containing a different kind of information pertaining to this sample of 200 four-year-olds. They were told they could examine and organize the cards in any ways they wished as preparation for writing their reports, and the cards remained available to them while they wrote their reports. The cards fell into two categories, those that contained numerical data and those that did not.

Of the 19 cards, 12 introduced numerical data – just a single number, identifying the number of children who did/didn't possess a binary attribute and who were/weren't overweight, e.g., "This card lists cases of CHILDREN WHO DO NO EXERCISE and ARE NOT OVERWEIGHT. NUMBER OF CASES: 30 [of 200 total children observed]." (See Figure 1.) The information each card contained is summarized in Table 1 (see below), one number per card. As reflected there, the information suggests a strong association between exercise and weight, a moderate association between diet and weight, and a negligible association between parent weight and child weight at age 4. (No information was available regarding cross-classification of individuals in multiple categories, of a sort that would allow assessment of additive or interactive effects of the three identified variables on the outcome variable.)

This card lists cases of CHILDREN WHO **DO NO EXERCISE** and ARE **NOT OVERWEIGHT**.

NUMBER OF CASES: **30** [of 200 total children observed]

Names of 30 cases: XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX XX

[names deleted for confidentiality]

Figure 1. Sample evidence card.

Table 1: Numerical values appearing on 12 individual cards (one value per card)

	Overweight	Not Overweight
Exercise	20	90
No exercise	60	30
	Overweight	Not Overweight
Regular diet	40	80
High-calorie diet	40	40
	Overweight	Not Overweight
Parent average	20	90
Parent overweight	60	30

Included in the 19 cards were seven that contained no numerical information, included to assess whether statements containing no or incomplete evidence would be regarded as evidence. Four were simply assertions made by a possibly authoritative source (e.g., "Dr. B. Marcy of Beacon clinic claims that parents' body type affects children's likelihood of being overweight"). The remaining three were assertions of prevalence of an outcome variable level (e.g.," Dr. F. Prentice sees a large number of children in his practice and reports that a majority of them are overweight or of a potentially causal variable level (e.g., "Dr. K. Lester reports a large number of children in her practice do not get enough exercise").

Most students organized the numerical cards and began by recording the information from them on a provided sheet, using various formats (typically simply a list, but occasionally in a branching chart form or as a histogram). In their reports most then showed numerical calculations followed by inferences, although some showed only calculations and others only inferences. Patterns of performance were categorized based on how many of the four cells in a cross-tabulation table (as shown in Table 1) a student utilized. A variety of patterns appear, but almost none reflect the correct comparison of two proportions. An illustration of the one that did appears in the final row of Table 2 (see below), striking in its simplicity. Descriptions of categories and their frequencies appear in Table 2 by category, with illustrations for each. As seen there, examples for each of the categories show that students in every category displayed little hesitation in advancing causal claims.

The categorization system in Table 2 is an objective one, based only on how many of the four cells were utilized. Categories are listed in order of number of cells utilized. Each participant is counted only once, based on highest performance level exhibited. (Performance patterns differed little when categorizing by modal strategies, which were of course slightly lower.) The majority of reports addressed two or more of the three factors. Among those who addressed at least two factors, most – 26 of 35, or 74% - used the same strategy in analyzing two or more of the three variables for which data were available.

Table 2: Patterns of performance on causal analysis problem (n=43)

Pattern	n	Examples
No data referenced but one or more inferences made	7	Based on the cards, obesity seems to be based on diet, exercise, & overweight parents.
No data referenced and no inference made	2	From this data we'd be able to crunch the numbers and compare percentages because of the sample size being consistent across the board.
One-cell referenced with causal inference	6	Because exercising and not-overeating has highest total – 90/200 – it is an indication that children who exercise more are at less risk of being overweight.
One-cell referenced without inference	4	This card shows the greatest number of cases who exercise and are not overweight, indicating it might be a key factor. However, no direct cause can be determined since there are multiple confounding variables that affect accuracy such as family income.
Two adjacent cells referenced with causal inference	7	Overweight children outnumbered not-overweight children in the do-not-exercise category. This tells me that the biggest factor in becoming overweight is not exercising enough.
Two adjacent cells referenced with noncausal inference	5	I found that a parent's weight does not play a part in a child's weight because there was a larger outcome of non-overweight children with overweight parents than overweight children with overweight parents.
Two non-adjacent (diagonal) cells referenced without inference	3	Some say children who exercise are overweight, some say they are not. They contradict one another. This shows there is no clear-cut answer to the question of factors that cause obesity.
Two non-adjacent (diagonal) cells referenced with inference	3	Out of 200 children, 75 had a parent who was not overweight and those children were also not overweight. On the other hand, 35 children out of 200 were overweight and had an overweight parent. So parent weight matters.
Four-cell reference with causal inference	5	Exercise matters. There are a high number of kids who exercise and are not overweight. Another high number who don't exercise are overweight. The other 2 cards have little number of cases.
Four-cell proportional reference with causal inference	1	The data show children who eat a low-calorie diet are less likely to become overweight – 80 aren't & 40 are. High-calorie shows an equal number on each side.

One might attribute such causal judgment weaknesses to limitations in skill in proportional reasoning. Long documented are the difficulties students exhibit in mastering proportional reasoning, even among those who have performed well in mathematics to this point (Tourniaire & Pulos, 1985; VanDooren, Vamvakoussi, & Verschaffel, 2018). (A weakness in employing all relevant frequencies has been referred to as neglect of base rates in the adult cognition literature; Kahneman, Slovic, & Tversky, 1982.) A second problem administered either before or after the main problem, however, made this interpretation less likely: "Susie and Sally are setting up lemonade stands. Susie is mixing 6 cans of lemon juice and 3 cans of water in her pitcher. Sally is mixing 4 cans of lemon juice and 1 can of water in hers. Whose lemonade will taste more lemon-y and why?" All but one student solved this problem correctly and provided appropriate reasoning, despite the problem structure encouraging an erroneous conclusion. A correct response incorporated all four values into the calculation and related them in terms of a ratio (2:1 vs. 4:1) or proportion (66% vs. 80%). Only two students failed to do so, comparing only the absolute amounts of water in each pitcher ("Sally's because she's using less water") in one case or in the other using a proportional strategy but incorrectly. Thus, an inability to reason proportionally does not explain students' challenges in the main problem. Nor did administration of the lemonade problem before rather than after the main problem serve as a prompt to improve performance.

What might students (and educators) be missing?

Wherein then lies the problem? At one level such data might be taken as a further cry of alarm regarding poor mathematics achievement of American students, up to and including students of college level. Mathematical proficiency at the level we examined extends well beyond mathematics itself. It is fundamental to science education (Hilton & Hilton, 2016), as well as foundational for numerous other fields within business, economics, engineering and beyond. The findings are consistent with lines of research in developmental psychology that have demonstrated early competence yet later weaknesses that become apparent at an older age. Proportional reasoning is one such case. Denison and Xu (2019) describe infants' abilities to make at least implicit judgments of proportion, and they offer the recommendation that proportion can be introduced profitably much earlier in the school curriculum, thereby weakening what has been referred to as the whole number bias that is reinforced by early mathematics instruction (Siegler, Thompson, & Schneider, 2011).

The evidence described here certainly supports the recommendation of earlier emphasis on proportion in the mathematics as well as science curriculum. At the same time, it suggests that more or better instruction on proportion is not the whole answer. Students were almost all able to execute a proportional reasoning strategy in a simple numerical context. Executing the strategy, however, did not in turn serve as a prompt to apply the strategy in the main problem, which offered three distinct opportunities to do so (for each of the three proposed factors possibly linked to outcome). Those who encountered and successfully solved the lemonade problem immediately before encountering the main problem did no better on the main problem than did those who encountered it only after the main problem. This finding highlights the broad and ubiquitous dilemma in educational psychology of failure to achieve transfer, and more specifically in the mathematical context it points to the need to maintain continuing interplay and coordination between procedural and conceptual knowledge (Rittle-Johnson, 2017).

Both elementary causal and proportional reasoning, in any case, should have been within the competence of college students. Children in the first decade of life commonly infer causal relations based simply on co-occurrence, but by late adolescence most have learned the control-of-variables strategy of holding other factors constant before inferring a causal relation between antecedent and outcome, even though they continue to struggle with multivariable causality involving multiple contributors to an outcome (Kuhn, 2012; Teig, Scherer, & Kjaernsli, 2020).

A further factor in participants' favor in the present task is the fact that the context in which students were asked to apply these skills was a favorable one, and context means a great deal in affecting the classroom behaviors students display (Jiménez-Aleixandre., Rodriguez, & Duschl, 2000; Kuhn, 2005; Settlage, & Southerland, 2019). The context was a statistics class in which students would have been aware that their mathematical skills were to be made use of.

If the context was supportive and skill in proportional and causal reasoning was not at stake, what then prevented college students from applying their skills in the main problem, where it would have been not just highly useful but essential? Why did they not recognize the need to do so? The answer to this question reaches beyond the realms of mathematics or science. We suggest it lies in an atypical degree of freedom the main task offers students in organizing a response to it. Research studies frequently present data to participants and ask them to analyze it and draw implications from it. What was uncommon in this case is that the student had to choose what data to call on. As noted earlier, the problem thus becomes one of epistemological standards: What constitutes relevant evidence and what constitutes sufficient evidence? This challenge is not only infrequent in research tasks but infrequent in most students' educational experience as well, in science or math classes as well as elsewhere. Especially in mathematics problems, students early on become aware that the numbers that appear in the problem are the ones to use, and the task is simply to figure out how to do so.

Students were able to choose appropriate evidence at least in the limited sense of categorizing the data points according to the potential causal variable being considered, but this achievement required little more than category-name matching. On the positive side, they did, however, largely ignore the cards that lacked numbers and contained only single-case assertions. Those who mentioned them did so only to comment that the assertion had been supported or contradicted by their data analysis. This contrasts with performance of middle-school students to whom we have given this problem, who frequently included reference to one or more of the non-numerical cards as support for one of their conclusions.

The performance college students displayed here, in selecting from and implementing procedural knowledge in mathematics to address a real-world problem, we believe bears on long-standing debates in science and mathematics education. Computational procedures like long division that students traditionally have learned to perform by hand are today increasingly seen as pointless by students, if not by their teachers as well. What should take their place? Should basic statistics replace the algebra and trigonometry for the great many students who find studying them tortuous as well as seemingly useless? These questions lack easy answers. Yet education science is now advanced enough to make clear that students need to find purpose in what they seek to learn or they are unlikely to succeed. Thus, coming to appreciate how mathematics addresses real-world problems is arguably an essential dimension of modern mathematics education.

A further objective arguably is the metacognitive development and practice that will allow students to recognize and apply effectively the strategic knowledge they do have in the wide range of contexts where it will serve a purpose. The college students described here showed little caution in making claims, almost all confirming causal (rather than non-causal) relations (and this applies across all the strategy categories identified). Only one expressed concern with potential interactions among the three variables, despite their likelihood, this student noting that the cards didn't provide cross-classification information that would be necessary to assess this possibility. Nor did many show understanding of the critical distinction between correlation and causality, even though a few used such language ("I've determined exercise and diet cause obesity…parent weight is just a correlation"), with only one correctly noting that all the provided data were only correlational, limiting conclusions. Finally, almost all took the three variables for which data were available to be the total set of potential causal contributors. The three who noted the potential contribution of additional variables (named or not) most often did so to explain cases that did not conform to the (diagonal) pattern of association between antecedent and outcome variable.

Our own further objective here has been to illustrate the implications of such data beyond achievement in mathematics to the broad realm of everyday reasoning and discourse. The students who participated in the work described here exhibited the epistemological failing of subscribing to very weak evidence standards for making causal inferences, leading to concern about their susceptibility to accepting without scrutiny similar unsubstantiated claims they encounter in both their academic work and outside of it. The sorts of incomplete data that these students chose as good evidence for a causal connection are ubiquitous in electronic and print media. The consequences for both personal and public discourse have of late become painfully evident.

What if anything can we point to as at fault in the pre-college educational experience of such students? The explanation we would propose has to do with weaknesses in the curriculum but of a particular sort. Students are not afforded the practice in autonomy that they would benefit from – autonomy affording them rich experience in deciding what to do, what information to consider, what additional information to look for, when multiple possibilities are available – in short, in taking charge of their own thinking and learning, in school as well as non-school contexts. Learning is now widely recognized by educators as more likely to be successful when learners experience what has been termed epistemic agency in conducting their own purposeful learning, learning directed toward sense-making (DiSessa, 2000; Elmore, 2018a,b; Rudolph, 2014; Scardamalia & Bereiter, 2015; Sikorski & Hammer, 2017), more than acquisition and retention of new information or procedures. Employers similarly now commonly express a wish for employees who can quickly make sense of new situations, determining what they need to know, learn it, and implement it appropriately as needed.

In short, cognitive self-regulation should be nurtured from an early age and is predictive of positive educational outcomes (Modrek & Kuhn, 2017; Modrek et al., 2019). Its importance becomes critical in scientific and indeed all higher-order thinking, where practice is key to its development, both with peers and in apprenticeship with more skilled others (Arvidsson & Kuhn, 2021; Kuhn, 2018, 2019; Mehan & Cazden, 2015; Mercer & Littleton, 2007; Papathomas & Kuhn, 2017; Rapanta, 2019; Reznitskaya & Wilkinson, 2017). However, individual cognitive weaknesses, of the sort highlighted by the data presented here, should not be overlooked by an exclusive focus on the study of thinking in social contexts (Kuhn & Modrek, 2018). In current work with middle-schoolers we are investigating ways to develop and strengthen the individual epistemological awareness and self-regulation that will improve performance on the kind of task discussed here.

We began this manuscript by suggesting the worrisome implications of adults in today's world becoming comfortable with choosing their evidence as a function only of their goals and needs (Mercier & Sperber, 2011), leaving their claims free to take whatever direction they wish. Potential remedies, however, lead us squarely back to education. Certainly, by college age, students need to be able to know what they need to know as they reason and learn. And they should be able to inhibit themselves and challenge others in advocating claims that lack the necessary evidence (Mills, 2013). In short, students must be equipped with needed knowledge and skills while prepared to assume responsibility and control over their own learning and knowing (Elmore, 2018a,b; Scardamalia & Bereiter, 2015). The eventual downside of their not doing so is arguably a contributing factor to the declining standards apparent in contemporary public and private discourse. This is certainly the case on topics that require attention to empirical evidence, as do all topics in the domain of science, and science educators are arguably in the best position to address them in educating the next generation.

References

Arvidsson, T.S., & Kuhn, D. (2021). Realizing the full potential of individualizing learning. *Contemporary Educational Psychology*.

Barzilai, S., Tzadok, E., & Eshet-Alkalai, Y, (2015). Sourcing while reading divergent expert accounts: Pathways from views of knowing to written argumentation. *Instructional Science, 43,* 737-766.

Barzilai, S., & Zohar, A. (2012). Epistemic thinking in action: Evaluating and integrating online sources. *Cognition and Instruction, 30*, 39-85.

De Keersmaecker, J., Dunning, D., Pennycook, G. et al. (2019). Investigating the robustness of the illusory truth effect across individual differences in cognitive ability, need for cognitive closure, and cognitive style. *Personality and Social Psychology Bulletin***.**

Denison, S., & Xu, F. (2019). Infant statisticians: The origins of reasoning under uncertainty. *Perspectives on Psychological Science, 14,* 499–509.

DiSessa, A. (2001). *Changing minds: Computers, learning, and literacy*. Cambridge MA: MIT Press.

Duncan, R., Chinn, C., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching.* DOI: 10.1002/tea.21468

Elmore, R.(2018).Beijing Academy: Innovation, design, and learning.*ECNU Review of Education, 1,*135-146. (a)

Elmore R. (2018) Design as learning, Learning as design. In R. Ellis & P. Goodyear (Eds.), *Spaces of teaching and learning. Understanding teaching-learning practice* (pp. 47-62)*.* Singapore Springer. (b)

Greene, J., Sandoval, W., & Braten, I. (Eds.) (2016). *Handbook of epistemic cognition.* New York: Routledge.

Hills, T. (2018). The dark side of information proliferation. *Perspectives on Psychological Science.*

Hilton, A., & Hilton, G. (2016). Proportional reasoning: An essential component of scientific understanding. *Teaching Science, 62,* 32-42.

Iordanou, K. (2010). Developing argument skills across scientific and social domains, *Journal of Cognition and Development, 11*, 293–327.

Iordanou, K. (2017). From theory of mind to epistemic cognition. A lifespan perspective. *Frontline Learning Research, 4,* 106–119.

Iordanou, K., & Constantinou, C. (2015). Supporting use of evidence in argumentation through practice in argumentation and reflection in the context of SOCRATES Learning Environment. *Science Education, 99,* 282-311.

Jiménez-Aleixandre M.P., Rodriguez, A., & Duschl, R. (2000). "Doing the lesson" or "doing science": Argument in high school genetics. *Science Education, 84,* 757-792.

Jiménez-Aleixandre M.P., & Puig, B. (2012) Argumentation, Evidence evaluation and critical thinking. In B. Fraser, K. Tobin, & C. McRobbie (Eds.), *Second International Handbook of Science Education*. Dordrecht: Springer.

Kahneman, D., Slovic, P., & Tversky, A. (Eds.). (1982). *Judgment under uncertainty: Heuristics and biases*. Cambridge: Cambridge University Press.

Kuhn, D., & Lerman, D. (2021). Yes but: Developing a critical stance toward evidence. International Journal of Science Education

Kuhn, D. (2020). Why is reconciling divergent views a challenge? *Current Directions in Psychological Science, 29*, 27-32. doi.org/10.1177/0963721419885996

Kuhn, D. (2019). Critical thinking as discourse. *Human Development, 62*, 146–164. DOI:10.1159/000500171

Kuhn, D. (2018). Building Our best future: Thinking critically about ourselves and our world. New York: Wessex Learning.

Kuhn, D. & Modrek, A. (2018).Do reasoning limitations undermine discourse? *Thinking & Reasoning,24*,97-116.

Kuhn, D. & Moore, W. (2015).Argumentation as core curriculum.*Learning: Research and practice, 1*(1), 66-78.

Kuhn, D. (2012). The development of causal reasoning. *Wiley Interdisciplinary Reviews: Cognitive Science, 3*(3), 327-335.

Kuhn, D. & Crowell, A. (2011). Dialogic argumentation as a vehicle for developing young adolescents' thinking. *Psychological science, 22*(4), 545-552.

Kuhn, D. (2009). Do students need to be taught how to reason?. *Educational Research Review, 4(*1), 1-6.

Kuhn, D. (2005). Education for thinking. Cambridge MA: Harvard University Press.

Lazer, D., Baum, M. et al. (2018). The science of fake news. *Science, 359,* 1094-1096.

Macagno, F. (2016). Argument relevance and structure: Assessing and developing students' uses of evidence. *International Journal of Educational Research, 79*, 180-194.

Mayweg-Paus, E., & Macagno, F. (2016). How dialogic settings influence evidence use in adolescent students**.** *Zeitschrift für Pädagogische Psychologie, 30,* 121-132.

Macagno, F., & Walton, D. (2018). Practical reasoning arguments: A modular approach. *Argumentation.*

McNeill, K., & Berland, L. (2017). What is (or should be) scientific evidence use in k-12 classrooms? *Journal of Research in Science Teaching, 54,* 672-689.

Mehan, H., & Cazden, C. (2015). The study of classroom discourse: Early history and current developments. In L. Resnick, C. Asterhan, & S. Clarke (Eds.), *Socializing intelligence through academic talk and dialogue*. Washington DC: American Educational Research Association.

Mercer, N., & Littleton, K. (2007). *Dialogue and development of children's thinking. A sociocultural approach.* London and New York: Routledge.

Mercier, H., & Sperber, D. (2011). Why do humans reason? Arguments for an argumentative theory. *Behavioral and Brain Sciences, 34,* 57-111.

Metz, S., Weisberg, D., & Weisberg, M. (2018). Non-Scientific criteria for belief sustain counter-scientific beliefs. *Cognitive Science.* DOI: 10.1111/cogs.1258

Mills, C. M. (2013). Knowing when to doubt: Developing a critical stance when learning from others. *Developmental Psychology, 49*, 404-418.

Miralda-Banda, A., Garcia-Mila, M., & Felton, M. (2019). Concept of evidence and the quality of evidence-based reasoning in elementary students. *Topoi.*

Modrek, A., Kuhn, D., Conway, A., & Arvidsson, T.S. (2019). Cognitive regulation, not behavior regulation, predicts learning. *Learning and Instruction, 60,* 237-244. DOI10.1016/j.learninstruc.2017.12.001

Modrek, A., & Kuhn, D. (2017). A cognitive cost of the need to achieve? *Cognitive Development 44*, 12-20.

Moshman, D. (2015). *Epistemic cognition and development: The psychology of justification and truth.* New York: Psychology Press.

Monteira, S., & Jiménez-Aleixandre, M.P. (2016). The practice of using evidence in kindergarten: The role of purposeful observation. *Journal of Research in Science Teaching, 53,* 1232-1258.

Papathomas, L., & Kuhn, D. (2017). Learning to argue via apprenticeship. *Journal of Experimental Child Psychology, 159*, 129-139.

Pennycook, G., & Rand, D. (2018). Lazy, not biased: Susceptibility to partisan fake news is better explained by lack of reasoning than by motivated reasoning. *Cognition*.

Rapanta, C. (2019). Argumentation as critically oriented pedagogical dialogue. *Informal Logic, 39,* 1-31.

Reznitskaya, A., & Wilkinson, A. (2017). *The most reasonable answer: Helping students build better arguments together.* Cambridge MA: Harvard Education Press.

Rittle-Johnson, B. (2017). Developing mathematics knowledge. *Child Development Perspectives, 11,* 184-190.

Ryu, S., & Sandoval, W. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education, 96,* 488-526.

Rudolph, J. L. (2014). Dewey's 'Science as Method' a Century Later Reviving Science Education for Civic Ends. *American Educational Research Journal, 51,* 1056-1083.

Sampson, V., & Clark, D. (2008). Assessment of the ways students generate arguments in science education: Current perspectives and recommendations for future directions. *Science Education*, 92, 447-472.

Scardamalia, M., & Bereiter, C. (2015). Education in an open informational world. In R. Scott & M. Buchmann (Eds.), *Emerging trends in the social and behavioral sciences.* Wiley Online Library.

Schustack, M., & Sternberg, R. (1981). Evaluation of evidence in causal inference. *Journal of Experimental Psychology: General, 110,* 101-120.

Settlage, J., & Southerland, S. (2019). Epistemic tools for science classrooms: The continual need to accommodate and adapt. *Science Education, 103,* 1112-1119.

Siegler, R., Thompson, C., & Schneider, M. (2011). An integrated theory of whole number and fractions development. *Cognitive Psychology*, *62*, 273–296.

Shi, Y. (2019). Enhancing evidence-based argumentation in a Mainland China middle school. *Contemporary Educational Psychology.*

Sikorski, T. R., & Hammer, D. (2017). Looking for coherence in science curriculum. *Science Education*, *101*, 929-943.

Sperber, D., Clement, F., Heintz, C., Mascaro, O., Mercier, H., Origgi, G., & Wilson, D.'(2010). Epistemic vigilance. *Mind and Language, 25,* 359-498.

Teig, N., Scherer, R., & Kjaernsli, M. (2020). Identifying patterns of students' performance on simulated inquiry tasks using PISA 2015 log-file data. *Journal of Research in Science Teaching.*

Tourniaire, F. & Pulos, S. (1985). Proportional reasoning: A review of the literature. *Educational Studies in Mathematics, 16,* 181-204.

VanDooren, W., Vamvakoussi,X., & Verschaffel, L. (2018). Proportional reasoning. *Educational Practices Series, 30,* vol. 8. International Academy of Education.

Rebuilding the Industrial Revolution: Using Minecraft in Teacher Education in Social Studies

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Abstract: This article discusses how Minecraft: Education Edition (MEE) can be used as a teaching aid in social studies and as a digital learning resource to facilitate the development of generic and subject-specific competencies. The study reports from an intervention in a teacher education program where student teachers recreated historical environments of the industrial revolution along the river Aker in Norway. The rebuilding of the industrial revolution in MEE was conducted through three phases: introduction, reconstruction and transformation. These phases are illustrated with empirical data. This approach to teaching student's history emphasizes active learning by making it more engaging.

Introduction

Engagement and motivation are often cited as justifications for using computer games in teaching (Callaghan, 2016). Research on the use of digital games shows that they provide opportunities for engagement and activity among students, but the learning outcomes have also been questioned (Kluge, 2016), and computer games as a digital learning resource are met with skepticism from both teachers and parents (Dikkers, 2015; Sigurdardottir, 2016). Minecraft appeals to children because the threshold for participation is low, while the opportunities for creativity and role-playing are many, and the game allows children to build and collaborate with others (Mørch, Mifsud & Eie, 2019). Our aim is to explore how Minecraft Education Edition (MEE) can be used as a digital learning resource to create learning contexts in which generic and subject-specific competencies can be developed in interaction.

Generic competencies, often called 21st-century competencies, play an important role in fostering analytical and critical thinking, creativity, and problem-solving in children (Binkley et al., 2012). Dolan (2020) points out that 21st-century competencies should not be an end in themselves but can act as a framework for teaching. Minecraft, often referred to as digital Lego, gives participants an unlimited number of building blocks to create buildings and other visual structures. MEE is a version of this game adapted for use in schools. The basis for this article is a project that started in autumn of 2017 at a City University in Norway in which student teachers with specializations in social studies for 5th–10th grade used MEE to reconstruct historical environments. The article addresses the following research question: How can Minecraft be used in teaching social studies to develop generic and subject-specific competencies?

Enabling historical empathy

To understand the actions of the people who lived in the past, we must have some knowledge of the framework and conditions within which they acted (Lund, 2020). Hatlen (2020) refers to the English tradition of history didactics and explains the concept of "historical empathy" as "understanding how the people of the past saw their world at different times, and why they acted as they did" (p. 147). Like the concept "historical empathy" is the concept "taking [a] historical perspective," described by Seixas and Morton (2013) as:

> [...] considering the different "things" that made up their everyday living – technologies, clothing, housing, food – as well as the landscape of their communities and settlements; [...] ideas and belief systems through which they made sense of it all (p. 138).

The people of the past, like us, acted on the basis of emotions, beliefs, and ideologies, so taking a historical perspective means taking on multiple perspectives. A core element of the Norwegian curriculum is historical empathy (DoE, 2020).

According to Yilmaz (2007), historical empathy can involve elements of emotion but is mostly an intellectual exercise of reconstructing the past through the systematic study of historical contexts. Creating micro-stories about people from a period of the past provides an opportunity to take multiple perspectives and can serve as a bridge to understanding the features of society in that period (Kvande & Naastad, 2020). Roleplaying games and simulations give students access to historical situations or, events as though they were still happening (Lund, 2020). With this roleplay, the historical actors have several possibilities for action within a structural and contextual framework. Lund claims there is "much to suggest that simulation is little used by history teachers, especially the large selection of computer simulations" (2020, p. 127). Probable reasons for this are that teachers find simulations time-consuming to use and difficult to adapt to the classroom (Lund, 2020). This paper will address this gap by using MEE for rebuilding a local context of the industrial revolution and experience it through a roleplay.

Minecraft as a digital learning resource

In the past five years, increased interest in the use of MEE in educational settings has been reported. MEE can increase motivation and creativity and provide opportunities for collaboration in the classroom (Lorence, 2015; Callaghan, 2016). Dikkers (2015) believes that Minecraft's popularity has great pedagogical potential and highlights its benefits in areas such as problem solving, motivation, and commitment in addition to learning academic topics (pp. 110–111). Jensen and Hangøj (2019) point out that MEE creates new ways of participating (p. 361) and changes teacher-centered activities to student-centered activities. Researchers have investigated the use of MEE in subject-specific competencies within language, mathematics, science, and social studies (Jensen & Hangøj, 2019; Lorence, 2015).

Games engage students in and out of school and contribute to flexible teaching, but competition and frequent trial and error approach within games can hinder reflection and learning (Kluge, 2016). Kluge (2016) states that computer games must have a high degree of pedagogical structure and give students opportunities to work with subject-specific concepts to turn commitment to play the game into learning outcomes. Gabriel (2016) points out the need to include digital game–based learning in teacher education to increase student teachers' competence in incorporating digital learning aids like games into their teaching (p. 35). Previous research has shown that few studies examine the use of MEE in teacher education (Egebert & Borysenko, 2019). Callaghan (2016) found that the teacher's active participation in the game is important for students' commitment and motivation. However, Kuhn and Stevens (2017) point out that many teachers are reluctant to use Minecraft because they know less about computer games than their students.

Common understanding through intersubjectivity

This article adopts intersubjectivity (Mead, 1910; Rommetveit, 1976) and dialectics (Vygotsky, 1986) as overarching theoretical concepts. Intersubjectivity can be described as a subprocess of collaborative learning (Stahl, Koschmann & Suthers, 2006; Fugelli, 2012). Rommetveit (1976) defined intersubjectivity as a psychological process that arises between individuals by creating a common understanding (Rommetveit, 1976). Creating a common understanding is essential for developing knowledge together (Fugelli, 2012) and is a central component of computer-supported collaborative learning, both among students and between students and teachers (Ludvigsen & Mørch, 2010). Through intersubjectivity, a group creates a common social awareness (Mead, 1910), which is developed through communication, collaboration, and negotiation (Rommetveit, 1976; Ludvigsen & Mørch, 2010). According to Mead (1910), we create history through communication with others, using a technique he referred to as reconstruction, a process that emerges in the present. Rommetveit stated that intersubjectivity is a social world temporarily shared between individuals, but which can never be completely shared because it is a generalization of different individuals' experiences (Rommetveit, 1976). The intersubjectivity partially developed in a student group needs a driving force to develop into a common knowledge object (Fugelli, 2012); for this driving force, we use the dialectical method (Vygotsky, 1986). In our case, this means setting up tensions between subject-specific and generic competencies and structuring the learning process into three steps. Mørch, Mifsud & Eie (2019) developed a model to apply processes in practice, focusing on the gradual, knowledge-based development of a common understanding (object of knowledge) through intersubjectivity. The three steps of this model are introduction, reconstruction, and transformation. In this work, we applied this model in three rounds of design-based research.

Method and case design: The industrial breakthrough in Minecraft

The main method used to organize this study was design-based research (Brown, 1992) with an emphasis on interventions over three-week periods in three semesters (autumn 2018, spring 2019 and autumn 2019). A total of 146 student teachers followed this topic during the study period. The student teachers were going to use MEE to teach in the classrooms. MEE was used to reconstruct buildings and events of the industrialization period as part of the in-depth study of the industrial breakthrough around 1840-1890, with emphasis on global history and location-specific knowledge of the Aker river area. Based on feedback from previous iterations, the intervention was readjusted several times. Data were obtained via, screen recordings of group work, qualitative interviews, and student-produced films of the roleplay in MEE. The informants were recruited on a voluntary basis. See Table 1 below for an overview of the data we report on.

Table 1: An overview of the data reported on in this article

Data sources	**Amount of data**
Interviews with student teachers	Total numbers of participants = 3
Screen recording of the groups' construction in MEE	2 hours of screen recording
Student-produced films of roleplaying games	25 movies (3–4 minutes per movie)

A thematic analysis (Reichertz, 2014) was conducted of the interviews. The screen recordings show the students' screens and speech while they built. When analyzing the screen recordings, we looked especially for the use of sources, collaboration, and problem-solving abilities. When analyzing the roleplay films, we looked particularly at how subject-specific knowledge of the industrial breakthrough, such as the living conditions of this period, was expressed through context (MEE staging) and conversation between the avatars. For the thematic analysis, we used a combination of data-driven and theory-driven approaches, also referred to as the abductive approach (Reichertz, 2014). The three phases of introduction, reconstruction, and transformation describe the teaching process: first, we (the teachers) introduced the knowledge domain (subject-specific knowledge), then the students created their own reconstructions in MEE and in a written script document, and finally, they transformed the reconstruction and events into a film.

Data and analysis

The data are presented and analyzed for each of the three phases described above: We use empirical data from the Canvas Factory along the river Aker to illustrate our findings. The Canvas Factory started producing canvas for sailing ships in the early phase of industrial breakthrough in Norway.

Introduction

The first phase was to introduce subject-specific knowledge. The students spent time orienting themselves in the subject matter about the industrial buildings and the business associated with them, which had changed over the years. On campus, the students received a more detailed lecture about the buildings' architecture and the events associated with them during industrialization. The teacher then prepared an excursion along the river Aker, in which the students were given the responsibility of presenting their respective buildings to the other participants. During the excursion, the student teachers had the opportunity to take pictures and explore the building and their surroundings (Figure 1). The students gained access to historical sources that dealt with living and working conditions in addition to their own online research. The student teachers were introduced to MEE at the beginning of the intervention period. However, at least one student in each group had previous experience with MEE.

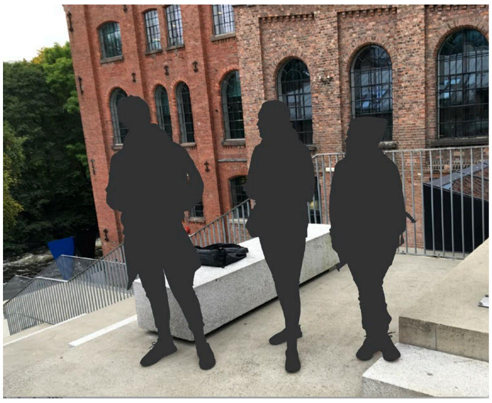


Figure 1. A picture of student teachers in front of the Canvas Factory during the excursion along the river.

The excerpt below is from an interview about how the student used different sources to learn about the Canvas Factory.

Student: We looked at old pictures and we just had to use our imagination to envision how we thought it [the Canvas Factory] was then [. . .]. We also looked in old books to get an overview. But it was difficult to find out, especially at the Canvas Factory, because it was much smaller before (in the industrial age), now it is much larger due to later extensions of the building [. . .] what it looked like in the very beginning, we found a picture that represented it quite nicely, so we got a pretty good overview [. . .]

The student elaborates on his use of different sources to gain knowledge of how the Canvas Factory looked in the industrial age. Next, the students listened to the subject teachers, searched for information on the Internet, distributed tasks among themselves, and planned the next phase. This can be understood as the beginning of the process of building intersubjectivity (common understanding); at this stage, the intersubjectivity is low or vaguely defined. We can see a parallel to Sfard's (1998) acquisition metaphor, as the students were concerned with acquiring knowledge of subject concepts, gaining knowledge of the building through historical sources, teaching, and going on the excursion. This work prepared the students for the later phases.

Reconstruction

In this phase, the student teachers were tasked with reconstructing the buildings as authentically as possible in MEE. Alongside the construction, the students developed scripts for roleplay about living and social conditions.

Reconstruction of buildings

The teachers developed an empty world (Figure 2a) with sites ready for construction along the river. Figure 2b shows how the students reconstructed and built the Canvas Factory in MEE.

Figure 2. Reconstruction of buildings in MEE: a) Empty world (site) made by the subject teachers (left) and b) the building constructed by a group of student teachers tasked with modeling Canvas Factory (right).

At the start of the reconstruction phase, an interesting pattern was revealed: group members experienced in MEE took initiative and control over the building process. The students with less experience received training from the more experienced, as revealed in the following interview excerpt:

Student: The other two I worked with had no experience with Minecraft, so it was in a way my job to teach them to play Minecraft and be leader for the construction in Minecraft and the organization of the activity. But they (the other student teachers) worked very hard to build things. I had to explain it for them, like that this area here should have this kind of stones, and you have to build using that kind of pattern, and things like that. It was very alright to work that way. During the roleplay and scriptwriting, it was the others who created the dialogue.

The students agreed on the dimensions, building materials, and design of individual elements in the building and then distributed the construction work. They often collaborated on the most complicated parts of the building, such as roofs and windows. The excerpt below illustrates the need for collaboration when reconstructing the more complex elements of historical buildings in MEE, in this case, the factory building roof.

Student: When we started building and shaping the roof, someone said: "The roof will be very high." So, we looked at it and agreed, because it got very high, so

> then we flattened it [the roof]. In the game [MEE], you have stair blocks, and when you use them on top of each other, it becomes a very pointed roof. As a result, instead we used flat half blocks and a regular block [. . .], and then it became a flatter roof. [. . .] and it matched better with the picture as well.

The following excerpt is from an interview with a student who reconstructed the Canvas Factory.

> Interviewer: How did you solve the task of building the Canvas Factory?
>
> Student: We had to find out information about the Canvas Factory, and we were on an excursion along the river. We had a presentation about the factory when we walked along the river, so then we got that prior knowledge there and talked about strikes and poor working conditions and things like that. We also saw the building there. [. . .] Later, we used Google Earth to zoom in on the building to see what it looked like, but there is an extension there [in the new Google picture] and a staircase on the side that was not there before. Earlier [during the industrial age], it was just a plain [staircase].

Figure 3. Reconstruction of the staircase inside Canvas Factory.

The two previous excerpts describe the reconstruction process, highlighting two typical situations in which generic competencies and subject-specific knowledge were applied. First, the students put great effort into searching the MEE inventory for the right building blocks to use, and they regularly checked their own buildings against sources, including historical images, floor plans, and digital maps. Second, when the groups encountered problems in the construction process, they searched for more information. To figure out how the Canvas Factory looked when it was founded in 1858, the students had to search for historical pictures and drawings in books and online. The students compared different sources of information and discussed them to come to an agreement of how the building might have looked. This process parallels the process of building intersubjectivity (Rommetveit, 1978), in which students enter discussions and develop a common ground.

The reconstruction phase facilitated the development of generic competencies, such as creativity, problem solving, collaboration, and division of labor. When reconstructing the building, the students discussed the different parts of the construction process. This parallels Sfard's (1998) participation metaphor, which foregrounds participation in the collaborative building process. In the data presented above we see a tension between generic and subject-specific skills: the students worked to develop parts of the building both in parallel and together. The students contributed with their parts (walls, windows, doors, etc.) to create a whole factory building along the river, which in turn set the framework for the individual parts. This tension is linked to the lack of subject-specific knowledge. When detailing the staircase in the building, which was not shown in the original pictures, the students had to be creative. Generic competencies were therefore more dominant in this phase, contrasting with the subject-specific knowledge driving the process forward (i.e., through the need for more detailed knowledge). The development of generic and subject-specific competencies is interdependent: the whole (which is a set of relationships among parts, Figure 2b) is related to the use of domain-specific knowledge, and the parts in isolation draw on generic skills, such as creativity and information seeking (Figure 3). The two types of competencies are in a dialectical relationship (Vygotsky, 1986), which is resolved in phase 3, transformation.

Reconstruction of historical events

To reconstruct historical events and develop a realistic script, the students sought historical sources that went into depth about working conditions, power relations, and living conditions. When researching working conditions, one student came across an interview with a former employee in one of the industrial buildings, in which the worker uses the term "black pudding on Fridays"—which the student connected to their present-day "Taco Fridays." Tacos are a typical Norwegian Friday dinner dish. The following excerpt elaborates on this connection:

> Student: We refer to the present and we called it black pudding Friday instead of taco Friday. We used humor. [. . .] When it comes to problem solving, such as reconstructing a building without having the correct measurements, but at the same time getting the whole of the structure to resemble the actual building, collaboration, problem solving, and creativity are fundamental.

In the literature, this is referred to as anachronism or prolepsis. In Rommetveit's (1976) work on intersubjectivity, such formulations are considered a technique for bringing past conversations and common understandings forward in time. This linking of black pudding and taco Fridays can be seen as an anachronistic or proleptic play on words, connecting the past, the present, and an anticipated future with the aim of increased intersubjectivity.

Historical empathy is not about free imagination but about developing an understanding of a historical context via sources (Hatlen, 2020). To achieve historical empathy, the historical context must be reconstructed. The student groups based their reconstruction on sources, but several students told us they also took artistic freedom, using their own knowledge to adapt the end result. Several students expressed personal empathy for the reconstruction as they began to feel a sense of ownership of the building's history. Data from the Canvas Factory indicates that the students activated both feelings and reasoning by taking on different perspectives and life experiences in the roleplay, such as gender and class membership, which is related to historical empathy.

In the reconstruction phase, the students became participants in a community in which collaboration skills, problem-solving abilities, and creativity paid off. In using trial and error in in the building process (placing, destroying and rebuilding blocks in MEE) the students negotiated towards a shared understanding of the historical building connected to different artefacts: the MEE building and the role play script, implying that intersubjectivity gradually materializes, but partly fragmented.

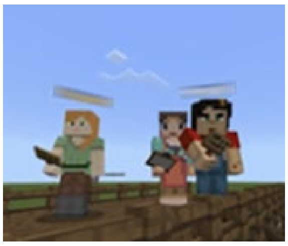
Transformation

In the third phase, the students used what they had made, the building and script, to make a film showing their learning in a compact format. Two main findings emerged in the transformation phase: 1) how the students co-created a shared object of knowledge through roleplay, and 2) how the students connected the historical knowledge in the film to their own lives. These two points will be elaborated in this section.

Below are stills from a student group's film of their roleplay in the historical context of the Canvas Factory in MEE. The film shown in Figure 4 is set in 1889 and begins with a dialogue between the female workers in the factory, the director, and a representative for the workers' rights. In the opening scene, the female workers receive a scolding from a male head worker who tells them to work faster. This frustrates the women, who complain to the factory manager. He dismisses their complaint and says they are easy to replace. In the second

Female worker: Mr. Director! The men in here do nothing but scold and picking on what we do. The work we do is heavier than theirs and the air we breathe actually makes us sick.
Director: That's actually how it is here. I have done nothing but take you under my wings. You can be replaced in no time.

Agitator: Mr. Director! It is so that these women have miserable working conditions. Their wages are much worse than those of men. They are not valued for the effort they actually put in.
Director: I stand by what I have said earlier in this case and am not at all interested in negotiating. I do not need them.



Female worker: Then we go on strike. All of us! Then we'll see how your factory production goes.

Figure 4. A series of screenshots and the corresponding dialogue from a film set inside the Canvas Factory.

scene, the female workers call upon a well-known agitator for workers' rights. In the last scene, we see the female workers go on strike:

The four-minute film demonstrates subject-specific knowledge about working conditions, class relations, gender relations, and agitation for workers' rights. The roleplay dives into a limited reality, in which the actors play out written scripts and have certain options for action that depend on the level of detail in the script and creative on-the-spot adaptation. The students' roleplay in MEE has the potential for generalization of experiences to others. The factory workers and factory owners' function as representatives of "many from the same place and conditions in the relevant period" (Kvande & Naastad, 2020, p. 186). The students' roleplay enables them to get closer to historical events, take on different perspectives, and imagine how past events were happening (Seixas, 2013).

In the transformation phase, subject-specific knowledge is foregrounded, while the generic competencies of creativity and adaptation stay in the background. Both competencies can be identified in the film, as illustrated by the dialogue sequences in Figure 4. A transition occurs between the two types of competencies when an actor plays out a prolepsis (Rommetveit, 1976), which shifts the dialogue and the group's common understanding away from subject-specific topics (e.g. blood pudding for industrial workers' dinner) to a generic competency (e.g. adaptation). This shift in turn drives the intersubjectivity forward in time, resulting in a common object of knowledge. Intersubjectivity at this stage is focused, combining a verbal component (the roleplay conversation) and a visual component (the MEE building staging the roleplay). Our data indicates that through phases 1–3, the students gradually developed a common, focused object that ended with the films used in plenum presentations.

Conclusion

This article discussed how MEE can function as a digital learning resource for developing generic and subject-specific competencies in tandem. In the introduction phase, the learners received a professional introduction to subject-specific knowledge and were given access to primary and secondary sources of information. The learners were given multiple opportunities to develop their subject-specific knowledge. In the reconstruction phase, historical buildings and events were recreated in MEE and the learners were given opportunities to develop generic competencies, such as creativity, collaboration, problem solving, design, and adaptation. In the transformation phase, the students' generic competencies and subject-specific knowledge were integrated and transferred to a common knowledge object, in this case, a film of roleplay in MEE. In this phase, the subject-specific knowledge came into focus, while the generic competencies were put in the background. Tensions between the two competencies drove forward the process of creating intersubjectivity. The student teachers dialectically switched between developing generic and subject-specific competencies when using MEE to rebuild the industrial age. This was partly facilitated by the model we used for teaching, but also aided by the tensions inherent in the knowledge domain (historical knowledge) as it is reconstructed using a new digital learning resource.

The implication of this paper is that Minecraft may be explored in an educational setting as a digital learning resource that facilitates active learning processes by making history more engaging. Learners are given the opportunity to contextualize the past and imagine how historical actors lived, often under very different conditions than those under which we live today.

References

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century skills. P. Griffin, B. McGaw, & E. Care (Eds.), In *Assessment and teaching of 21st century skills* (17–66). Chicago, IL, Dordrecht, Netherlands: Springer.

Brown, A. L. (1992) Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The Journal of Learning Sciences*, *2*(2), 141–178.

Callaghan, N. (2016) Investigating the role of Minecraft in educational learning environments, *EducationalMedia International*, *53*(4), 244–260.

Dikkers, S. (2015). *Teachercraft: How teachers learn to use Minecraft in their classrooms*. Pittsburgh, PA:ETC Press.

DoE. (2020). *Læreplan i samfunnsfag*. Retrieved from https://www.udir.no/lk20/saf01-04. (SAF01-04)

Dolan, A. M. (2020) *Powerful primary geography. A toolkit for 21st century learning*. New York: Routledge. Fricker, R. & Schonlau, M. (2002). Advantages and disadvantages of internet research surveys: Evidencefrom the literature. *Field Methods*, *14*(4), p. 347–367.

Fugelli, P. (2010). *Intersubjectivity and objects of knowledge: Making sense across sites in software development*. (PhD Thesis, Faculty of Educational Sciences, University of Oslo.)

Gabriel, S. (2016). Why digital game-based learning should be included in teacher education. *ReflectingEducation*, *10*(1), 26–36.

Hatlen, J. F. (2020). Historikerens kode. Veien til historisk forståelse. Universitetsforlaget: Oslo.
Jensen, E. O. & Hanghøj, T. (2019). Math in Minecraft: Changes in students' mathematical identities when overcoming in-game challenges. In 13th European Conference on Games-Based Learning (s. 355–362). Academic Conferences and Publishing International.
Kluge, A. (2016). Fra PC i skolen til læring med teknologi. Rapport fra prosjektet "Med ark og app. Bruk av læremidler og ressurser for læring på tvers av arbeidsformer" Universitet i Oslo.
Kvande, L. og Naastad, N. (2020) Hva skal vi med historie? Historiedidaktikk i teori og praksis. 2. Utgave. Oslo: Universitetsforlaget
Kuhn, J., & Stevens, V. (2017). Participatory culture as professional development: Preparing teachers to use Minecraft in the classroom. *TESOL Journal*, *8*(4), s.753–767.
Lorence, M. (2015). MinecraftEdu takes hold in schools. *School Library Journal*. Retrieved from http://www.slj.com/2015/04/technology/minecraftedu-takes-hold-in-schools/
Ludvigsen, S. R., & Mørch, A. I. (2010). Computer-supported collaborative learning: Basic concepts, multiple perspectives, and emerging trends. In P. Peterson & B. McGaw (Eds.), *International encyclopedia of education* (s. 290–296). Oxford: Elsevier.
Lund, E. (2020) Historiedidaktikk. En håndbok for studenter og lærere. 6. Utg. Oslo: Universitetsforlaget.
Mead, G. H. (1910). Social consciousness and the consciousness of meaning. *Psychological Bulletin*, 7(12), 397–405.
Mørch, A., Mifsud, L., & Eie, S. (2019). Developing a model of collaborative learning with Minecraft for social studies classrooms Using role-play theory and practice. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.). In Proceedings CSCL 2019, Vol. 1 (pp. 272-279). Lyon, France: International Society of the Learning Sciences.
Reichertz, J. (2014). Induction, deduction, abduction. In U. Flick (Ed.), *The SAGE handbook of qualitative data analysis* (pp. 123–135). London: SAGE Publications.
Rommetveit, R. (1976). On the architecture of intersubjectivity. In R. Rommetveit & R. M. Blakar (Eds.), *Studies of language, thought and verbal communication*, s. 147–161. New York: Academic Press.
Seixas, P., & Morton, T. (2013). *The big six historical thinking concepts.* Toronto: Nelson Education.
Sfard, A. (1998). On two metaphors for learning and the dangers of choosing just one. *Educational Researcher*, *27*(2), 4–13.
Sigurdardottir, H. (2016). *Concern, creativity, and compliance: The phenomenon of digital game-based learning in Norwegian education*. PhD dissertation, Norwegian University of Science and Technology.
Vygotsky, L.S. (1986). The development of scientific concepts in childhood: The design of a working hypothesis. In Vygotsky L. and Kozulin A. (Eds.), *Thought and Language*. Cambridge, MA: MIT Press.
Yilmaz, K. (2007). Historical empathy and its implications for classroom practices in schools. *The History Teacher*, *40*(3), s. 331–337.

The Role of Bridging Practices in Expansive Learning Processes

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Abstract: Increased accountability policies and pressures have forced teacher education programs in the United States and elsewhere to use various forms of outcome data in new and expanded ways. I employ an activity-theoretical framework for organizational learning known as expansive learning to examine how three "high data use" programs developed new work practices in order to both comply with external policies and also serve locally-constructed goals. Findings highlight similar and different ways these programs navigated organizational change by re-mediating their activity systems. This study extends previous work on organizational learning by illuminating relational *bridging practices* that facilitated expansive learning despite tensions, setbacks, and disturbances created as new work practices emerged in response to changing conditions. Through bridging practices, these programs developed co-constructed collective motives related to data use, common knowledge, distributed expertise, and a sense of collective agency and shared responsibility; these became cultural resources that supported expansive learning efforts.

Keywords: Organizational learning, teacher education, leadership, activity theory, case studies

Introduction

In teacher education and other programs in higher education in the United States, new and intensifying pressures surrounding data use for external accountability and program improvement are emerging from several directions, including escalating public scrutiny of teacher preparation, new federal and state mandates, and new Council for the Accreditation of Educator Preparation (CAEP) standards (Cochran-Smith et al., 2018; Wilson, 2014). As programs are expected to engage with outcome data in new and different ways, program leaders are tasked with balancing data use as required by accountability mandates and data use that willingly engages program members and is focused on locally-oriented goals constructed with input from various internal stakeholders (Davis & Peck, 2020; Cochran-Smith et al., 2018; Peck, Gallucci, & Sloan, 2010). Data use for compliance and, especially, for inquiry purposes requires motivating and engaging faculty, supervisors, and administrators to participate in collaborative inquiry, data analysis, and decision-making activities and to draw on those activities to make and evaluate program changes using multiple sources of evidence; in short, it requires organizational learning and change.

In order to better understand how teacher education programs (TEPs) situated within institutions of higher education undergo such collective learning processes, I studied three "high data use" TEPs with exemplary commitments to using data for program improvement (including what was necessary to comply with state and accreditation agencies, but moving beyond that to ensure that data use served locally-constructed goals). I drew from a conception of organizational learning based in activity theory known as expansive learning (Engeström, 1987, 2001; Engeström, Kerosuo, & Kajamaa, 2007; Engeström & Sannino, 2010) to examine how these three programs, located in diverse institutional and regional settings in the United States, navigated increasing data use policies and practices over the course of two years and learned in individual and collective ways in the process. Findings highlight both similarities and differences in how faculty and administrators in these TEPs re-mediated their activity systems and developed new data use processes that progressed beyond required accountability and accreditation policies to serve co-constructed local goals. While studies of expansive learning generally focus on structural and systemic changes (Engeström et al., 2007; Engeström & Sannino, 2010), this study extends this body of work by illuminating the role of interpersonal *bridging practices*—which are relational and organizational practices that help resolve tensions and disturbances created as new work practices develop in response to internal and external conditions—in continuing expansive learning. Over time, these bridging practices facilitated co-constructed collective motives related to data use, common knowledge, distributed expertise, and a sense of collective agency and shared responsibility; these became cultural resources that supported expansive learning.

Theoretical framework

In order to examine organizational learning processes, I drew on a framework of organizational learning called expansive learning, based in cultural-historical activity theory (CHAT). Expansive learning considers organizational learning to be an iterative, evolving process of development in which interrelated, interdependent elements of an activity system are re-mediated through collective activity in order to better serve a collective motive, known as the *object* (Engeström, 1987). As a sociocultural theory of learning with roots in Vygotsky's (1978) work, CHAT attends to the roles of a system's participants, cultural norms, policies, social structures, and conceptual and material tools in object-oriented learning (Engeström, 1987, 2001; Roth & Lee, 2007). This is a particularly helpful theoretical framework for understanding organizational learning related to data use for program improvement and accountability, as such data use requires attending to the context, including organizational routines of data interpretation and use, individuals within the system, and the tools used to mediate interpretation of data (Spillane & Miele, 2007).

In CHAT, individual and collective action and learning within an activity system is understood in relation to the system's collective motive (i.e., *object*) and the participants (i.e., *subjects*) who are motivated by this object. Material and conceptual *tools* and resources also mediate the system's activity, as do the *rules* and *division of labor* within the system's *community*. These interactive components of an activity system guide analysis of learning and development within a focal system (Engeström, 1987; Roth & Lee, 2007); in this case, a TEP aiming to use data for program improvement and accountability.

CHAT highlights the role of contradictions, which are historically-laden tensions within and between components of the activity system, in driving change and learning (Engeström, 2001). These contradictions manifest through disturbances, innovations, dilemmas, conflicts, or double binds in the activity system (Engeström & Sannino, 2010). Development and learning occur as individuals and groups attempt to resolve contradictions through the development of new tools, practices, or social relations aimed at better aiding an evolving object. These developments and new practices lead to changes or expansions of the object through a process of *expansive learning*. In processes of expansive learning, contradictions unsettle existing practices and potentially motivate and guide re-mediation of the activity system in ways that further collective learning and development. However, contradictions do not necessarily lead to expansive learning; expansive learning cycles may be broken or abandoned (Engeström, Keruso, & Kajamaa, 2007). Engeström and colleagues (2007) found that there were some times when efforts to "bridge" the discontinuities leading to "breaks" in a cycle of expansive learning were successful in continuing organizational development towards an expanding object, while at other times these attempts were not successful. In these cases, expansive learning processes were abandoned and an alternative object was embraced.

CHAT's conception of expansive learning provides a lens that facilitates examination of collective goal-oriented activity and learning. I drew on the expansive learning framework to analyze how three TEPs situated in different state, local, and institutional contexts within the United States experienced and responded to new policies and pressures around data use, including whether and how contradictions in these systems led to new work practices or a new, expanded collective object and new activities aimed at that object. See Davis (2021a) for an extended expansive learning analysis of these three programs. In this paper, I provide an overview of this analysis in order to focus on what these findings suggest about the process of expansive learning, and the organizational and relational practices that leaders and others who care about collective development towards a particular object can do to support individual and collective learning and development through expansive learning processes. This investigation was guided by the following research questions:

1. What is the role of contradictions in expansive learning?
2. What practices and resources serve to bridge or support expansive learning efforts?

Research design and methodology

I employed a qualitative multiple case study design (Merriam, 2009; Stake, 2006) in order to analyze individual and collective practices supporting or constraining expansive learning. A multiple case study design facilitated in depth data collection and analysis while also supporting contextually-rich comparative analyses (Merriam, 2009; Stake, 2006). This study's three focal cases were strategically chosen for their organizational commitments to data use, as well as the diversity of their contexts within the United States (see Table 1). The cases were situated in different institutional and state contexts; they all faced national and accreditation-related accountability demands, with some differences in the pressures coming from state and institutional levels.

Table 1: The three cases

Institution (Pseudonym)	**Institutional Size**	**Institutional Type**	**Region**	**Annual TEP Graduates**	**Outcome Measures Used**
Glenville State University (GSU)	28,000	Doctoral Universities: Higher	Southeast	800	Value-added measures; edTPA; graduate

		Research Activity			satisfaction; employer satisfaction
Milford College (MC)	5,000	Master's Colleges & Universities: Medium Programs	Midwest	90	edTPA; employer satisfaction; graduate satisfaction
University of Longview (UL)	20,000	Public Doctoral Universities: Highest Research Activity	West	120	edTPA; employer satisfaction; graduate satisfaction

In order to address my research questions, I analyzed data from two to four site visits conducted at each focal institution over the course of two years. This data included: 82 interviews and focus groups; five day-long observations of collaborative data use activities; and variety of artifacts from each program, including job descriptions, compensation policies, and meeting minutes. Data analysis was ongoing and iterative. I started with an initial round of open coding of all relevant data. Next, I developed a code list based on my initial reading of the data as well as a "start list" of codes from my literature review and theoretical framework. I engaged in multiple rounds of open and focused coding of all data (Miles & Huberman, 1994). The final coding scheme had 21 categories, including categories such as "individual motive/goal", "collective motive/goal", "relational agency", "division of labor/personnel", and "shared responsibility". Shared responsibility was an example of an emerging theme from data analysis, as I noted the ways in which various stakeholders expressed an understanding of joint, rather than solely individual, responsibility for improving the program and better preparing novice teachers in interviews and observations. For example, in a focus group, a faculty member at GSU said, "People are starting to see, going from the style of 'Oh, I know how to do it. I know how to do it better' to: 'You know what? I think *we* can do it best.'" Both during and after the coding process, I employed clustering techniques to consider patterns in the data, compare cases, triangulate data sources, and identify disconfirming evidence or outliers (Miles & Huberman, 1994). I also conducted member checks (Merriam, 2009).

Findings

I employed a cultural-historical conception of organizational learning known as expansive learning (Engeström, 1987, 2001; Engeström & Sannino, 2010) to examine the similarities and differences in the ways in which the three cases experienced and responded to increased pressures around data use (see also Davis, 2021a). Activity systems undergo expansive learning when confronting contradictions leads the collective to a new, expanded object and related new work practices (Engeström, 1987). In a cycle of expansive learning, an activity system grapples with four levels of contradiction:

1) The *primary contradiction* involves tensions between an activity's use value (i.e., the inherent value) and exchange value (i.e., the commercial value)
2) *Secondary contradictions* are concrete manifestations of the primary contradictions that occur between two or more nodes of the activity system (e.g., between the system's rules and the division of labor), which may lead individuals to question or change their practices
3) *Tertiary contradictions* occur with the introduction of new patterns of activity as people attempt to resolve secondary contradictions
4) *Quaternary contradictions* occur between the focal activity system and neighboring activity systems (e.g., between a TEP and local K-12 schools) as the focal activity system innovates and changes their practices (Engeström, 1987; Foot & Groleau, 2011).

This expansive learning analysis highlighted not only salient challenges most, if not all, US TEPs face under the current accountability climate, but also the important role of specific types of organizational and relational practices that served as bridging practices in the process of expansive learning. I first give an overview of the role of contradictions in the expansive learning processes at these three sites, and then describe the bridging practices that fostered expansive learning.

The role of contradictions in expansive learning

Despite significant differences in the three cases' sociohistorical contexts and data use practices, there were also marked similarities in the types of contradictions each program faced and the new activities that were developed to help relieve those contradictions and evolve organizational work practices related to the object of data-informed program improvement. I focus my analysis primarily on the systemic disturbances accompanying the introduction of standardized teacher performance assessments (edTPA) in each program to illustrate some of the most salient similarities and differences among these cases. While all three programs were undergoing numerous changes related to data use during the period of data collection, all three programs had recently begun piloting edTPA.

The primary contradiction: Internal vs. external accountability

The three TEPs in this study were situated in the context of increased competition from alternative route programs, fiscal scarcity, public accountability based on candidate outcomes, and criticism of traditional university-based teacher education. This played out through a primary contradiction (Engeström, 1987) between the object of internal accountability (guided by local values and goals) and that of external accountability (guided by the expectations of state and accrediting agencies, federal entities, and the public). Program leaders and members articulated tensions between the need to comply with accountability policies related to data use in order to prove their (exchange) value, and their desire to use program outcome data (including new sources of data often mandated by state regulatory bodies or national accreditation bodies) for internal program improvement purposes.

Interviews with program leaders at all three sites illuminated how tensions between internal and external accountability goals revealed a double bind. A dean at MC articulated this double bind as "the difference between proving and improving." Program leaders in all three programs exhibited commitments to using data to improve their programs based on local values, but at the same time, they also needed to use data to "prove" their worth to accrediting bodies, state regulatory bodies, prospective and current students, and the general public.

Secondary contradictions: Evolving object related to data use vs. data sources (tools)

As the accountability climate intensified, tensions developed in each of these three TEPs between implementing state and accreditation-related data use policies, which required using many sources of program outcome data to prove program effectiveness, and using data in an inquiry-oriented manner to improve their candidates' learning and their program outcomes. This manifested as a secondary contradiction between an evolving object related to data use for program improvement over data use for accountability and the available data sources (tools) that would support this object. Program members found that some data sources, including performance assessments, were more conducive to inquiry-oriented data use efforts than other data sources, such as value-added measures, which were difficult to interpret at the program or course level (Davis & Peck, 2020).

This tension between the object and available tools was influenced by pressures to use edTPA as it gained increasing popularity as an assessment tool in the field. All three programs began piloting edTPA before it was required by their states, motivated at least in part by their desire to learn how to best use edTPA to serve program improvement goals before the performance assessment potentially became required by external accountability mandates or consequential for candidates. This proactive approach helped maintain a sense of agency and internal accountability as external accountability pressures increased (Davis, 2021a). While the three programs had different relationships with the development of edTPA, their involvement piloting edTPA and providing feedback to the creators fostered a "sense of dialogue" (Faculty/Program Coordinator, UL) and collective agency.

Tertiary contradictions: New vs. old tools and practices

Tertiary contradictions occur as new activities and practices potentially clash with previous versions of those activities and practices (Engeström & Sannino, 2010). As programs began implementing edTPA, tertiary contradictions manifested as conflicts between existing work practices and the demands of this new tool. For example, each program experienced contradictions between new data sources and existing capacities and routines associated with other tools in the activity system used to conceptually and logistically manage data, including data platforms. The programs managed these tensions in ways that depended on their available structures and resources. GSU drew on financial and human resources to create and use a new data platform, MC began researching ways to expand or replace their existing data platform, and UL managed the tension primarily by shifting the division of labor around data sharing and analysis (e.g., creating a new edTPA Coordinator position). Each of these solutions addressed a common issue in ways that worked given their contextual differences. However, any time a new element is introduced in an activity system, even when created to address a contradiction, there are unintended consequences within the system. For example, the introduction of a new shared data platform at GSU precipitated further tensions, including the need for additional human and technical supports that allowed students, faculty, supervisors, and administrators to be able to *use* the data platform for both accreditation reporting and programmatic research and development.

Quaternary contradictions: Managing tensions with other activity systems

Each program experienced contradictions not only within their activity system as new practices conflicted with existing practices, but also between their activity system and neighboring activity systems (Engeström & Sannino, 2010; Foot & Groleau, 2011). These programs experienced quaternary contradictions between their emerging practices and their relationships with state policymakers and accrediting bodies, the K-12 systems they worked with (e.g., schools that candidates did fieldwork in), the makers of edTPA, and with Pearson, who was contracted to do the external scoring of edTPA and support scale-up efforts. These contradictions, particularly with state policymakers, accrediting bodies, and edTPA/Pearson, manifested in concerns about institutional autonomy and their ability to challenge a "powerful… bandwagon" (Faculty, GSU).

In order to maintain collective agency and autonomy, members of all three programs (particularly program leaders) acted as "watchdogs" (Faculty, GSU), advocating within and outside their program for their own longstanding and emerging beliefs about the role data and assessments have to play in defining and evaluating teacher quality, especially for credentialing purposes. These programs were determined to be part of larger state- and national-level conversations about teacher education and evaluation of teacher quality. They were deeply committed to internal inquiry about how to best serve their own students and to improving their own programs towards locally developed and articulated goals.

Bridging individual and collective development in activity: Developing relational practices for expansive learning

Engeström and colleagues' (2007) identified the role of bridging actions as attempts to resolve contradictions in ways that continue rather than abandon expansive learning processes when there is a threat to their persistence. They primarily identified bridges as systems-level decisions and actions (e.g., adopt a new training system); the authors did not examine or define the role of individual or interpersonal practices in maintaining a cycle of expansive learning. Institutional structures and resources do not create change on their own; change and learning also depend on people's engagement in actions and activities. In activity theory, there is a crucial but undertheorized relationship between individual agency and organizational development and change. Theoretical and empirical research in activity theory and expansive learning has primarily focused at the level of collective and systemic phenomena, often ignoring or underspecifying the role of individual learning, identity, agency, and motivation (Billett, 2006, 2008; Edwards, 2007, 2010; Engeström & Sannino, 2010). My analysis of expansive learning processes in these three TEPs suggests that relational bridging practices played a key role in addressing tensions and conflicts that came up during the process of organizational change and expansive learning.

In these programs, shifting the allocation of structural resources and program policies was helpful but insufficient in motivating and sustaining engagement in data use. Program members also needed to see the value of data use work for themselves and the program before participating. It was particularly important for program members to see the utility of data use *beyond* its necessity for external accountability. This required relational practices that attended to and reinforced "the human factor… [that] drives us to do our best work" (Program Administrator, GSU). Relational *bridging practices* that linked and supported individual and collective motives, agency, knowledge, expertise, and responsibility encouraged and sustained program members' engagement in data use work that furthered programmatic goals. These bridging practices are described in detail in Davis (2021b) and summarized below.

Bridging individual and collective motives

Program members only engaged in data use and related decision-making processes in authentic and sustained ways once they believed in its utility for themselves and the program. In order to broaden participation, leaders at all three programs attended to the ways in which individual motives might align with collective, programmatic goals. One strategy program leaders employed was the construction and articulation of organizational narratives (Edwards, 2010) that *reframed accountability* by emphasizing how data use practices could help evaluate and improve internally defined, co-constructed program goals rather than externally defined, compliance-oriented goals (Davis, 2021b; Davis & Peck, 2020).

Over time, with continued articulations of these inquiry-focused organizational narratives, people became more invested in the evolving, increasingly collectively-constructed program goals. Most program members found ways to work collaboratively "together with a common goal" (Supervisor, UL). This did not necessitate that all program members participate in exactly the same ways, or hold the same views about data use. At UL, participants noted how the program director trusted faculty, supervisors, and staff to "decide their agendas" (Faculty, UL) within the context of shared, co-constructed program goals.

Bridging individual and collective agency

The shifting political environment for teacher education threatened a potential loss of individual and programmatic agency. Tensions also arose between the desire for individual agency (for example, wanting authority over all aspects of a particular course) and collective agendas around data-informed program improvement. As program leaders worked to address these tensions and related individual resistance to change by listening and responding to individual needs and concerns, program members began to see and appreciate a growing sense of collective agency.

In a focus group at GSU, faculty discussed the "tsunami of expectations" associated with external accountability pressures and articulated how alone, one person would "get knocked over in a heartbeat," but "when you're all in it together" they don't get "battered around by myself". Collective action allowed them to "stand up to that wave" (Faculty focus group, GSU). The emergent collective strength resulting from collaborative, goal-oriented data use work motivated continued participation and fostered a proactive stance towards accountability. This facilitated a sense of collective agency despite increasing external regulations.

Bridging individual and collective knowledge

Increased inquiry-oriented collaboration around data use, including cross-role collaboration (e.g., tenure-track faculty, instructors, supervisors, and administrators working together, including across disciplinary boundaries), resulted in the development of co-created common knowledge (Edwards, 2010) and a common language of practice (Peck et al., 2010) among program members. The TEP director at UL argued that "one of the things that makes us really strong is that we do capitalize on the knowledge that… exists within the program. It's collective knowledge. It's not my knowledge."

Bridging individual and collective expertise

Program leaders and members also worked to identify individuals' strengths and areas of expertise and find ways for them to constructively contribute to collective data use work. This led to a network of distributed expertise that encompassed program members across roles. A supervisor at UL stated, "Each of us has our own strengths… there's really a web, a network [of program members], that is continually moving."

Networks of expertise grew not only within the three TEPs, but also across activity systems. For example, programs across the Southwest state GSU was situated within, including GSU, began engaging in cross-institutional discussions and research related to data use and accountability policies.

Bridging individual and collective responsibility

Study data indicated a growing sense of shared responsibility for program outcomes. Through cross-role, cross-disciplinary collaboration, stakeholders began to understand and develop "an ownership of the program and the product in the program." This involved looking "beyond your piece of the pie to what's coming out in the end." (Program administrator, GSU). There was ample evidence across cases that faculty, supervisors, and administrators were increasingly connecting their individual work and role in the program to how prepared graduates were at the end of the program based on program outcome data. Despite some faculty members' initial resistance to edTPA, the vast majority found that the holistic nature of edTPA (i.e., an assessment that wasn't tied to a particular course, but rather a candidate's overall learning in the program) allowed them to see and appreciate their own role in the bigger picture and feel increasing individual and collective ownership for program outcomes.

Cultural resources built by bridging practices

The co-constructed collective motives, collective agency, common knowledge, distributed expertise, and sense of shared responsibility that interpersonal bridging practices fostered over time became important cultural resources that program members could increasingly draw on to improve collaborative data use efforts and further organizational learning.

Figure 1 articulates the relational strategies and resources that supported organizational change efforts. The overall context is an activity theory framework. The components of the activity system and the relationships among those components provide structural and organizational supports for expansive learning. Within the activity system's expansive learning process, the bridging practices described above mediate and connect the subjects and the object of activity. Over time these bridging practices, along with the structural resources that support individual subjects' engagement in joint work within the activity system, have the potential to lead to cultural resources that include: the co-construction of collective motives related to the object of activity, collective agency, common knowledge, distributed expertise, and a sense of shared responsibility. These cultural resources further support expansive learning efforts.

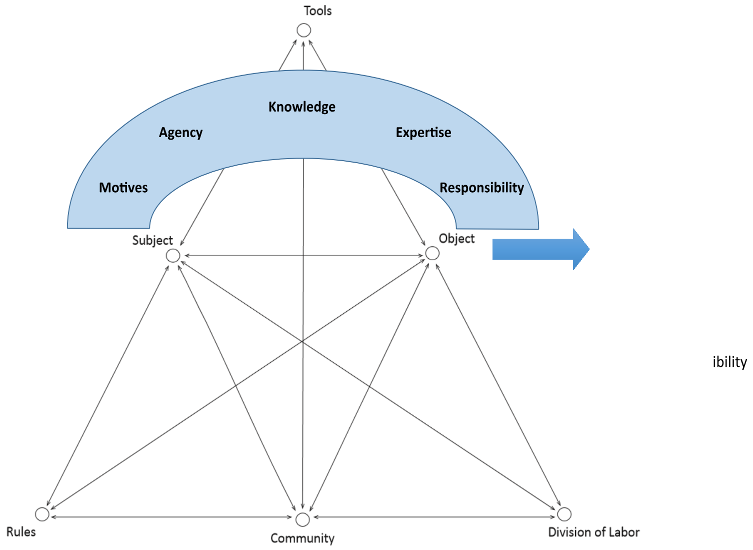

Figure 1. The role of bridging practices in expansive learning

Discussion and implications

Findings from this study suggest that the process of developing and sustaining collaborative data use practices through expansive learning required simultaneous attention to interpersonal, organizational, and cultural dimensions of the change process. This included practices such as articulating how individuals and programs might benefit from the collective agenda; reframing accountability by emphasizing data use for internal program improvement goals; strategically involving program members in cross-role collaboration; creating ways for individuals to co-create a collective vision for data-informed program improvement; setting up collaborative structures to facilitate data use and decision-making activities; developing incentives and concrete supports for individuals to participate in those collaborative activities; adjusting program norms to emphasize and reify the value of collective work; and continuously revising programmatic data use practices based on continually co-constructed collective goals.

While these are complex and demanding processes, these findings can offer guidance to leaders within and beyond teacher education facing similar challenges. This study offers new insights about managing motivational and interpersonal aspects of organizational change and expansive learning. While this study includes a relatively small number of programs, the fact that thematic findings were consistent across programs that vary significantly in size, mission, and state policy context suggests that they may be of relevance and value to others interested in facilitating individual and organizational learning within educational programs and institutions (Merriam, 2009; Patton, 2003).

Most research on organizational change from an activity theory perspective focuses primarily at the level of collective activity as it relates to organizational structures and resources. These studies contribute important insights about processes of organizational change, but often ignore or underspecify the important role and contribution of individual learning, identity, agency, and motivation (Billett, 2006, 2008; Edwards, 2007, 2010; Engeström & Sannino, 2010). This study expands on the undertheorized role of individuals and relationships within processes of expansive learning (Engeström et al., 2007). In this study, I connect institutional structures and resources that support organizational change with relational strategies and actions (bridging practices) that motivate engagement and foster co-constructed joint goals, collective agency, common knowledge, distributed expertise, and shared responsibility. These bridging practices and the cultural resources they created became the driving force of expansive learning for these programs as they navigated a changing accountability landscape. As learning scientists increasingly partner with organizations to address persistent problems of practice (Fishman, Penuel, Allen, Haugan Cheng, & Sabelli, 2013), these findings provide insight into practices that facilitate individual engagement and learning in processes of organizational learning and development. As TEPs and other educational institutions become more adept at managing the relational as well as the structural aspects of organizational change, they will be better able to motivate and facilitate both individual learning (of, in the case of teacher education, faculty, teacher candidates, and, ultimately, students) and collective organizational learning.

References

Billett, S. (2006). Relational interdependence between social and individual agency in work and working life. *Mind, Culture, and Activity*, *13*(1), 53–69.

Billett, S. (2008a). Learning throughout working life: A relational interdependence between personal and social agency. *British Journal of Educational Studies*, *56*(1), 39–58.

Cochran-Smith, M., Cummings Carney, M., Burton, S., Chang, W.-C., Fernández, M. B., Miller, A. F., … Baker, M. (2018). *Reclaiming accountability in teacher education*. New York: Teachers College Press.

Davis, S. C. (2021a). *Reclaiming accountability in practice: Developing shared internal accountability in teacher education through expansive learning*. [Manuscript in preparation].

Davis, S. C. (2021b). *Engaging faculty in data use for program improvement: How leaders bridge individual and collective development*. [Manuscript submitted for publication].

Davis, S. C., & Peck, C. A. (2020). Using data for program improvement in teacher education: A study of promising practices. *Teachers College Record*, *122*(3), 1–48.

Edwards, A. (2007). Relational agency in professional practice: A CHAT analysis. *Actio: An International Journal of Human Activity Theory*, *1*, 1–17.

Edwards, A. (2010). *Being an expert professional practitioner*. Dordrecht: Springer.

Engeström, Y. (1987). *Learning by expanding: An activity-theoretical approach to developmental research*. Helsinki: Orienta-Konsultit Oy.

Engeström, Y. (2001). Expansive learning at work: Toward an activity theoretical reconceptualization. *Journal of Education and Work*, *14*(1), 133–156.

Engeström, Y., Kerosuo, H., & Kajamaa, A. (2007). Beyond discontinuity: Expansive organizational learning remembered. *Management Learning*, *38*(3), 319–336.

Engeström, Y., & Sannino, A. (2010). Studies of expansive learning: Foundations, findings and future challenges. *Educational Research Review*, *5*(1), 1–24.

Fishman, B. J., Penuel, W. R., Allen, A., Haugan Cheng, B., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *National Society for the Study of Education*, *112*(2), 136–156.

Foot, K. A. (2001). Cultural-historical activity theory as practice theory: Illuminating the development of a conflict-monitoring network. *Communication Theory*, *11*(1), 56–83.

Foot, K., & Groleau, C. (2011). Contradictions, transitions, and materiality in organizing processes: An activity theory perspective. *First Monday*, *16*(6), 1–18.

Merriam, S. B. (2009). *Qualitative research: A guide to design and implementation*. San Francisco: Jossey-Bass.

Miles, M. B., & Huberman, A. M. (1994). Focusing and Bounding the Collection of Data. In *Qualitative data analysis: A sourcebook of new methods* (2nd ed., pp. 16–39). Beverly Hills, CA: Sage.

Patton, M. Q. (2003). *Qualitative research and evaluation methods* (3rd ed.). Thousand Oaks, CA: Sage Publications.

Peck, C. A., Gallucci, C., & Sloan, T. (2010). Negotiating implementation of high-stakes performance assessment policies in teacher education: From compliance to inquiry. *Journal of Teacher Education*, *61*(5), 451–463.

Rennert-Ariev, P. (2008). The Hidden Curriculum of Performance-Based Teacher Education. *Teachers College Record*, *110*(1), 105–138.

Roth, W.-M., & Lee, Y.-J. (2007). “Vygotsky’s neglected legacy”: Cultural-historical activity theory. *Review of Educational Research*, *77*(2), 186–232.

Spillane, J. P., & Miele, D. B. (2007). Evidence in practice: A framing of the terrain. In P. A. Moss (Ed.), *Evidence and decision making* (pp. 46–73). Malden, MA: Blackwell.

Stake, R. E. (2006). *Multiple case study analysis*. New York: The Guilford Press.

Vygotsky, L. (1978). *Mind in society.* Cambridge, MA: Harvard University Press.

Wilson, S. M. (2014). Innovation and the evolving system of U.S. teacher preparation. *Theory Into Practice*, *53*(3), 183–195.

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Thousand Oaks, CA: Sage Publications.

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Teachers' Aesthetic Judgments of Classroom Events

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Abstract: This paper introduces and articulates the contours of a novel component of teacher noticing and thinking—teachers' *aesthetic judgments* of classroom events. By aesthetic judgments, we refer to teachers' rapid recognition of particular classroom events as having a certain character or quality, such as students being highly engaged or having a "good" conversation. Drawing on a definition from diSessa (1993) of an aesthetic as a loose knowledge system that operates in a data-driven manner, we highlight how such judgments appeared and functioned in the context of teachers selecting video clips from their own classrooms to share in an online professional development course. We describe a range of aesthetic judgments evident in this context to illustrate what aesthetics may involve and sound like in practice and to highlight domains in which teachers may draw on influential aesthetics. We conclude with consideration of related empirical and theoretical issues.

Keywords: aesthetics, teacher noticing, teacher thinking, video-based professional development

Introduction

Over the last two decades, research on teacher noticing has been concerned with how teachers parse and make sense of complex classroom events (Schack et al., 2017; Sherin et al., 2011). Accounts of teacher noticing commonly emphasize at least two key dimensions of noticing, often considered and analyzed as distinct dimensions—what teachers attend to within classroom interactions, and how teachers interpret or reason about what they attend to (see van Es & Sherin, 2021, for a recent review). However, studies continue to explore and debate how these dimensions relate to each other and the extent to which they are separable (e.g., Barnhart & van Es, 2015; Sherin & Star, 2011; Walkoe et al., 2020), particularly if conceptualized as cognitive processes. A range of research and teacher learning efforts have sought to both understand the nature of teacher noticing and support its development through intentional work with video recordings of classrooms, such as having teachers write analyses and reflections about videotaped classroom events (e.g., Barnhart & van Es, 2015; Superfine & Bragelman, 2018; Walkoe et al., 2020) or watch and discuss videos in arrangements like video clubs, in which groups of teachers meet to examine videos recorded in the classroom of one of the participating teachers (e.g., Sherin & van Es, 2009; Stockero et al., 2017; Walkoe & Luna, 2020).

The work reported in this article departs from prior work on teacher noticing by focusing on a unique aspect of teachers' workflow with respect to video. Namely, we looked closely at teachers' noticing processes as they selected clips from video that they captured in their own classrooms. This was done in the context of an online professional development course, for the purpose of sharing and discussing with other teachers.

Working within this novel context drew our attention to phenomena that we believe are not well-captured by prior research on teacher noticing—phenomena that we now call *aesthetic judgments*. In brief, when engaged in selecting clips, teachers seemed to make rapid judgments about what they saw in their classroom videos, highlighting particular parts as reflecting particular characteristics or qualities (e.g., where students were really engaged, where the conversation was "meaty"). These judgments blurred the lines between attending and reasoning, in that the very "noticed-things" (Sherin & Star, 2011) integrated inferences and characterizations. These rapid judgments were instrumental in understanding teachers' selections and selection processes in this video-based professional development opportunity in which teachers had agency over what to share. Further, we have come to believe that teachers' selection processes provided a window into an important, underspecified component of teacher thinking.

The purposes of this paper are to introduce the idea of an aesthetic judgment as applied to teachers' parsing of classroom events, and to provide the reader with a sense for the kinds of aesthetic judgments displayed in the context of our course. We do this with illustrations drawn from our data corpus. We discuss this corpus and the context in which it was collected in the next section. Then, we explain what we mean by an aesthetic judgment, situating this new construct. After that, we present, with examples, a range of types of aesthetic judgments seen in our corpus. We finally conclude with a discussion of empirical and theoretical issues, questions, and next steps with respect to the study of teachers' aesthetics as a focus of research.

Study context

Our study of teachers' aesthetic judgments occurred in the context of a short, online course on mathematical argumentation in kindergarten through second grade, adapted from a longer course designed by Lomax et al. (2017). In the course, participating teachers were asked to try a series of argumentation activities with their students, videotape the conversations that occurred, and select a 3-4-minute portion of each conversation to share and analyze with peers in the course. For instance, one argumentation activity involved showing a set of four images that differed in multiple respects and inviting discussion of "which one doesn't belong" and why. A second argumentation activity (reflected in the example in Figure 1 below) asked teachers to lead their students in discussing whether a somewhat ambiguous equation, such as $3 + 2 = 5 + 1 = 6$, was true or false. Instructions for selecting a video clip consistently specified the time limit and invited teachers to focus on what they noticed about their students' thinking but were otherwise fairly non-specific. Teachers shared and discussed video clips in a discussion board-like setting as shown in Figure 1.

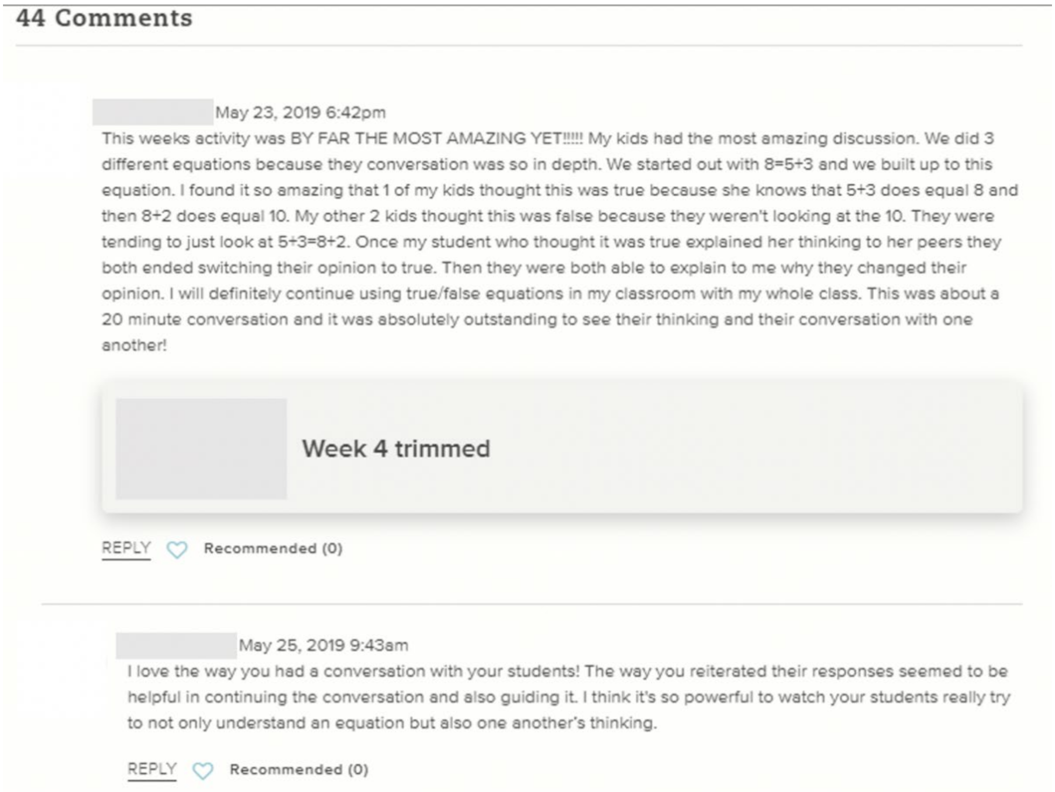

Figure 1. Example of selected video clip discussion.

Ten teachers from two well-resourced, predominantly white suburban school districts in the United States participated in the course in the spring of 2019, and we collected several sources of data to gain insight into participating teachers' selecting processes and associated reasoning. First, we conducted two short interviews with teachers just after they videotaped argumentation conversations in their classes, where we asked them how they anticipated selecting clips and whether there were any particular portions they would want to make sure to include. Second, we asked teachers to perform at least two think-alouds while selecting video clips, in which they were to describe what they were doing and thinking as they interacted with their recorded video and made selections. Third, we conducted a final end-of-course interview with each teacher, where we asked them to reflect on what they tended to select in their video clips and why.

In prior work with this data corpus, we engaged in systematic coding of teachers' considerations while selecting (Richards et al., 2021), which allowed us to survey, at a high level, the types of thinking observed. In that work, we noted the existence of aesthetic reasoning as one component of that thinking. Here, we extend our theoretical and analytical work with this construct, focusing on data assembled from five of the ten participating teachers who had a) complete selecting datasets and b) particularly rich think-alouds, the latter of which we felt provided unique insight into the varied aesthetic judgments teachers made about videotaped classroom events.

These five teachers had a mean of seven years of teaching experience (with a range from three years to 15 years); all identified as female and white, and one teacher identified as Hispanic or Latina. We describe more about how we approached the data after introducing key aspects of what we mean by aesthetics as a teacher thinking construct.

Aesthetics, the idea

We begin with an example drawn from an interview with a first-grade teacher, Allison (1), used to introduce the idea of aesthetic reasoning in prior work (Richards et al., 2021) and further unpacked here. This particular example is taken from our second interview with Allison, just after she filmed an argumentation discussion with her class and before she had selected a portion of the video to share online. During these interviews, we always asked whether a teacher had any initial thoughts about what parts of the recorded activity they might choose to share. When asked this question, Allison responded:

> So, I probably will leave out—usually I go for the ending because I feel like that's where like *the meatiest conversations* come from, but I feel like this one, the last [equation] I'll probably leave out and more skim towards like the middle to the beginning, and I feel like at the beginning the kids were more on track with like 3 + 5 = 5 + 3. (*emphasis added*)

Allison reported that typically she selects clips from the latter portions of activities since those portions are usually the "meatiest" (though that pattern did not hold in this particular instance). She did not elaborate on what she meant by "meaty," though one could infer a potential relation to where conversation was "more on track." The interviewer then asked her to say more about what she meant by "meaty."

> I: Mhmm. Yeah, and when you say meaty, like what do you—what counts as meaty?
>
> A: So, like the more in-depth conversations where they're like really able to explain their thinking, and then the opportunities where when it does make sense, and I have other kids like, "Can you repeat what so and so said"? Like those teachable moments.

Allison's noticing of "meaty" conversations is an example of the sort of *aesthetic judgments* that are our focus, and it has many features that typify these judgments. It is our intention to use the term *aesthetic* in a particular, technical sense—as a particular kind of knowledge system—that may be unfamiliar to some readers. In some loose respects, our usage does reflect everyday usages of the term; in other respects, it does not. Most fundamentally, our description of a system of knowledge as constituting an aesthetic is meant to describe features of the *form* of the knowledge—its structures and processes that act on those structures. In this respect, we closely follow the usage of the term proposed by diSessa (1993). In his account of the nature of intuitive physics knowledge and how it arises, diSessa provided a formal definition of a type of knowledge system that he called an *aesthetic*, explaining:

> The term is meant to be evocative of the functional characteristics of rich but structurally limited knowledge systems, which, notwithstanding their richness, appear fluid, data driven, and involve situation-specific reasoning (as opposed to plans and general methods) and idiosyncratic justification. (p. 187)

In diSessa's definition, an aesthetic is a knowledge system that consists of a collection of elements that are not highly organized. An aesthetic is activated and applied through a process of recognition, strongly driven by the data at hand. Further, since aesthetic judgments are undergirded by "structurally limited," less formalized knowledge systems and terminology, we should expect teachers to use variable ideas and language to express what they have in mind; in particular, we should expect them to draw on language that is somewhat specific to the situation currently under consideration.

Although diSessa's (1993) definition of an "aesthetic" is quite technical, it nonetheless aligns with some aspects of more everyday usages of the term. Consider, for example, the aesthetic judgments of wine connoisseurs. They might use words such as "complex" and "balanced" to describe a particular wine, with some consistency, and they would draw on a rich range of knowledge elements and experiences in doing so. Nonetheless, such judgments are simultaneously "fluid" and "data driven"; they are in-the-moment responses to particular sensory experiences. And a wine connoisseur might use varied language, perhaps cued by the particularities of a given wine, to explain what it means for a wine to be "complex."

We see the characteristics of an aesthetic reflected in Allison's judgments in the example above. Allison seemed to treat "meatiness" as something that could be recognized—perhaps relatively unproblematically, as she did not initially think to describe it further. However, when pressed, she applied a range of descriptors, suggesting that the bases of this judgment may involve a range of elements, some of which are more or less salient in particular situations. Indeed, although she used the word "meaty" throughout all of our interviews, the ways in which she unpacked this term varied. Here, for example, she described meaty conversations as "in-depth" and as "opportunities where when it does make sense." Across other data, depth was a relatively consistent descriptor associated with "meaty," but Allison also associated meaty with an "aha moment" (interview 1) and with being able to see diverse student thinking (final interview). These observations lead us to believe that for Allison, "meaty" is more than just a word—it reflects an aesthetic with some consistencies and complexities, and its application in particular situations may be nuanced and fluidly connected to a variety of considerations and inputs.

As emphasized above, diSessa's (1993) definition of an aesthetic is intended to be only structural. For him, an aesthetic is a system of weakly connected knowledge elements applied in a data-driven manner. But the aesthetic judgments in our own data do have some characteristics that are reminiscent of more everyday usages of the term. Though this was not always the case, the aesthetic judgments in our data were sometimes value-laden (as are those of a wine connoisseur). Here, for instance, Allison did not simply notice and characterize something that occurred; she positioned meaty conversations as desirable. Strictly speaking, in these interviews, teachers were responding to a question about which parts of a video were desirable for a particular purpose—the purpose of sharing in an online course with their colleagues. But, in actuality, their judgments often did not seem limited to this context; Allison's judgment that a portion of the discussion was meaty seemed to be naming an intrinsically positive attribute of that part of the conversation, regardless of the video-based task at hand.

It makes sense to us to think of the systems of knowledge that produce aesthetic judgments—systems that we call simply "aesthetics"—as part of the underlying machinery of teacher noticing. They produce readouts and evaluations that are, in a fundamental and important sense, "just seen" in classroom events. They become raw "noticed-things" (Sherin & Star, 2011) that are often treated as inputs to teacher reasoning and decision-making (e.g., Schoenfeld, 2008). Yet with respect to the noticing literature as described in the introduction, we note that an aesthetic seems to be a particular *kind* of noticed-thing that blurs distinctions between what teachers attend to and how they interpret or reason about objects of attention. For instance, noticing a "meaty conversation" embeds interpretations or evaluations within the noticed-thing itself. This contrasts with noticed-things that require little in the way of inferences, such as noticing that a particular student spoke in class today.

Aesthetics in teachers' video selecting work

As we looked across our data corpus of teachers' selecting processes, we noted a range of aesthetic judgments that teachers made with respect to what occurred in their classrooms. Briefly, the first and second authors independently identified all instances in the data corpus in which a teacher seemed to rapidly recognize and characterize a classroom occurrence, noting both what the teacher was naming (e.g., "meaty conversation") and descriptors or observations used by the teacher that may be part of the locally applied knowledge system. We then discussed and refined our collective understanding of each instance and discussed patterns and potential categories of aesthetics across the dataset. The first author then constructed analytic memos synthesizing instances into descriptive categories and examining prevalence across teachers.

Here, we elevate and characterize aesthetics that arose across multiple teachers. We do not put these forth as any kind of firm typology; rather, we frame these aesthetics as initial evidence-based characterizations that illustrate what an aesthetic (as a teacher thinking construct) may involve and sound like in practice, suggest varied domains for which teachers may have operational and potentially influential aesthetics, and form the basis for future work in this area. We also broadly acknowledge that focusing on aesthetic judgments is only one way of making sense of teachers' judgments that foregrounds their common structure and character; one could alternatively foreground other aspects of teachers' judgments, such as their epistemic underpinnings.

Student state-oriented aesthetics

We begin with a set of aesthetics that focused on different aspects of students' states—how students were participating, feeling, understanding, etc. As with most aesthetic judgments, these were often positioned as things one could "see" or "tell" directly from observational cues. Unlike some other aesthetic judgments, however, they at times incorporated language that suggested degree, in that students could demonstrate more or less of a given state.

We call one common student state-oriented aesthetic *engagement*, following from teachers' language. We believe that, even in everyday interactions, it is a common assumption that it is possible to tell when someone is "engaged" with us or with an activity—though it might be challenging to define what we mean or say why we think so. Four of the five teachers demonstrated evidence of judging whether and to what degree students were engaged in the classroom activity at different times in their video work, often via declarations without further explanation. For instance, a kindergarten teacher, Deb, described a week in which she filmed two argumentation activities and selected one to share in part based on her perception of students' engagement. She noted that "they were just so blah" (final interview) in relation to one of the activities, but they were highly engaged in the other: "I did this one just on a whim one day and I'm like, 'Oh, we need to stop and record this' because they got so into it" (final interview). Such judgments—of students collectively getting "so into it," or of other descriptors teachers used such as "more engaged," "so distracted," or "checked out"—likely involved complex, synthetic work across a range of sensory inputs, but they were framed as fairly direct read-offs of the data at hand. As first-grade teacher Allison noted, "You can kind of see like the engagement, you can see the kids who are kind of like zoned out" (interview 1).

Another emergent student state-oriented aesthetic across teachers was *understanding*—whether and to what degree students understood something or not. Here, teachers described whether students "realized" something, or were "confused" or "lost," often making such judgments based on observational cues (e.g., "they'll show if they're confused or they're not quite sure… just through their facial expressions" (Vicky, interview 1)). Again, these are complex judgments that are far from unproblematic; they require ascribing to students a cognitive state, based on their facial expressions, postures, tones of voice, etc. Furthermore, in the moment of teaching these judgments are not incidental; they are likely to have an impact on teachers' actions and interactions with students.

Contribution-oriented aesthetics

Teachers also made aesthetic judgments with respect to specific contributions from students. Here, the aesthetics were more explicitly valenced in nature, elevating and depicting particular contributions as "good" or "interesting" from the teacher's perspective. For instance, multiple teachers drew on a *good contribution* aesthetic, in which they demarcated particular contributions or segments of contributions with positive evaluative language: "She does a nice job using math vocabulary" (Dorothy, think-aloud 1); "This is where I got some really good observations" (Kendra, think-aloud 2); "That's a really important point" (Vicky, think-aloud 2); "I love that they were connecting across the subjects" (Deb, think-aloud 3). These sentiments were most common during selecting think-alouds, suggesting that they were activated for teachers in response to specific pieces of video data, and they at times shaped teachers' selections.

What we call the *interesting part* aesthetic was also a contribution-oriented aesthetic that teachers used to demarcate particular contributions, but these judgments had a different tenor. Here, teachers were reacting to contributions that intrigued them, sometimes because they were surprising or reflective of times when students posited ideas that teachers had not contemplated or showcased abilities that teachers had not expected. This aesthetic was distributed across data sources, suggesting that teachers identified parts that were interesting to them during their interactions with students while capturing video, as well as while selecting portions to share. Further, while teachers on occasion simply cited something as "interesting," they tended to also name *what* was interesting, and at times *why.* They added this specificity more often with the *interesting part* aesthetic than with others. For instance, a kindergarten teacher, Dorothy, described a line of thinking she found "interesting": "He wanted it to look like 2 + 5 = 2 + 5 [rather than 2 + 5 = 5 + 2] and then it would be true, and then at the end he realized that it still is the same, which I think is- it's interesting" (think-aloud 2). At the end of the course, Dorothy noted that she made selections partly based on parts that she "found really interesting or different or that were surprising" (final interview). When pressed to unpack what "interesting comments" meant, Dorothy replied:

> I kind of had in my mind, things that they were going to say, and things that they would notice, and sometimes they said something completely different that I was like "Wow, I didn't even think of that," so I thought that was awesome… Things that surprised me that I didn't really think they could do, or that I didn't think they would notice (final interview).

Other teachers also depicted students' approaches or understandings as "interesting," "fascinating," or "compelling" and made sure they were included in their selections (e.g., "I think it's so fascinating that she's- when she talked about flipping it around. She's just doing it completely backwards… okay, so I'm keeping that" (Vicky, think-aloud 2)). In another example, kindergarten teacher Deb noted how a "whole video" in which her class discussed an equation with variables was "very fascinating. I just thought it was so interesting talking about variables with kindergartners" (think-aloud 3). Deb reiterated her interest in this particular discussion and how it influenced her selections several times throughout her final interview:

> I was just like so intrigued by their understanding… there were times when I trimmed the video more on something that I just found really like compelling that a student had said… I'm remembering it was something [student] said… where she shocked me in understanding what "a" could stand for… their thinking on that one was just so fascinating to me (final interview).

Here, Deb used varied language—"intrigued," "compelling," "shocked," and "fascinating"—to depict the part she found interesting and specified that while the "whole video" was fascinating, she was most tuned into a particular student's understanding of how to work with a variable that she found surprising.

Interaction-oriented aesthetic: Good conversation

A third category of aesthetic that arose across multiple teachers focused on the nature of interactions among students. In our course context, three of the five teachers drew on what we call a *good conversation* aesthetic, which had several characteristics. First, it was often used as a descriptor without much further specification—teachers noted where the conversation was "good," "better," or "best," often positioned in contrast to where the conversation was "slow" or "not argumentative" (given the content of the course). Contrasting "good conversation" with what teachers deemed to be less good conversation seemed unique to this aesthetic.

Second, when teachers did specify what made a conversation "good," they focused on specific ways that students interacted with each other. For instance, Dorothy described that students "were actually listening to each other," in contrast to portions where she perceived that "once one kid was talking, the other two were not listening at all" (interview 1; note here that this aesthetic also seems tied to the *engagement* aesthetic in Dorothy's judgment of when students were listening). Other teachers noted that "good conversation" was where "there was kind of a back and forth between other students" (Kendra, final interview) or where students explicitly disagreed with each other (Vicky, final interview).

Story-oriented aesthetic: Completeness

Finally, four of the five teachers demonstrated aesthetic judgments that seemed to be more about the holistic nature of the classroom event or video clip, judgments that we link to a *completeness* aesthetic. Here, teachers considered and judged whether a given event or clip seemed to reflect a "complete" or "whole" story.

Take the following think-aloud example from Kendra, a second-grade teacher, who had filmed her students' discussion of whether two pairs of images were the same or different and was considering what to include in her selected clip. She watched how students discussed both pairs of images and noted that in one discussion, a particular student took over and "it wasn't really, um, argumentative" (the *good conversation* aesthetic). She noted, "I'm just gonna eliminate the second conversation and, um, my video will now capture the complete conversation on our first same or different… picture" (think-aloud 5). Note here that while the *good conversation* aesthetic seemed to drive which conversation to include, Kendra also made a *completeness* judgment—that the video would "capture the complete conversation" she selected.

Kendra returned to this *completeness* aesthetic on multiple occasions. She sought to reflect "the conversation as a whole" (think-aloud 3), and this consistently led her to trim at what she deemed to be natural boundaries, such as after a spot where a student was "finishing a thought" (think-aloud 4). Other teachers drew on similar judgments of what made something complete. For example, Allison explained, "if I could include the whole part of the last person talking I would, but always that beginning part I felt like it was important to like capture the whole conversation" (final interview). Similarly, Deb made sure to "get to the end of [the student's] thought" (think-aloud 1) before trimming. While there were some commonalities in what made an event or a clip feel complete, such as starting and stopping at natural boundaries in talk or tasks, these judgments were also situation-specific in that what felt "complete" to a teacher for one argumentation activity did not always match what felt complete for another activity. Returning to Kendra's examples, what felt "complete" in the same or different discussion described above was showing the entirety of students' discussion of one pair of images; what felt "complete" in another argumentation activity in which students discussed what would make particular equations true (e.g., 1 x __ = 2 x __) was showing portions of how students discussed two equations back-to-back, to be able to showcase the whole trajectory of their reasoning.

Discussion

This paper is our first extended attempt to articulate our ideas concerning what we believe to be an underexplored component of teacher noticing and thinking—teachers' aesthetic judgments. To recap, these are rapid, at times value-laden judgments that we saw teachers make about, and in response to, classroom events. Drawing on diSessa's (1993) notion of an aesthetic as a rich but loosely organized knowledge system, we argued that aesthetics that are "just seen" by teachers are likely to be an important part of teacher noticing. Specifically, they reflect what teachers intuitively notice in classroom events in a way that seems to merge attention and interpretation, blurring dimensions often treated as separable in studies of noticing.

With respect to teacher learning and learning to notice in particular, we believe that the prevalence and ease with which teachers made aesthetic judgments while selecting video clips in our course context suggest that such judgments are likely at play for teachers even if they are not made explicit through professional development activities. Furthermore, we believe aesthetic judgments can reflect substantial professional expertise. Indeed, precisely because an aesthetic is a largely informal kind of knowledge system, we anticipate that aesthetics may be largely built up from experiences observing and leading classrooms, in addition to other sources of knowledge. Teachers' aesthetic judgments likely constitute some of the raw "noticed-things" (Sherin & Star, 2011) that can be built on, and/or critically investigated with respect to how relational positionalities and lived experiences shape noticing, in professional development contexts.

However, we are aware that much work remains to be done to more fully investigate and articulate the idea and its implications. We conclude here with a discussion of what we see as the most pressing empirical and theoretical issues. First, from an empirical point of view, an important next step is to investigate teachers' aesthetics in contexts beyond video selection. In some respects, teachers' video selection processes provided an ideal context within which to see aesthetics, as they involved teachers judging segments of classroom activity and choosing some segments over others. But again, our argument for the importance of aesthetics hinges on our belief that they are also active throughout other teaching activities. We believe there is a strong prima facie case to be made that aesthetic judgments play an important role when teachers, for example, lead a classroom discussion. Even fine-grained models of teacher decision making, such as the one developed in Schoenfeld (2008), include what are essentially black boxes in which teachers must make complex and important judgments, such as whether a particular student question is generative to pursue or reflective of a broader lack of understanding in the class. Thus, one concrete next step is to study how and when aesthetic judgments are made across multiple teaching activities, including within situated classroom events.

Another contextual consideration has to do with the specific focus of the course as related to the specific aesthetics activated among teachers. For example, the fact that teachers were to engender and capture student "argumentation" likely provoked a focus on interaction-oriented aesthetics, in which teachers judged whether and how students interacted with each other's contributions. Similarly, the prevalence of story-oriented aesthetics in our data corpus was likely dependent on the particular context of selecting video clips that would be comprehensible to share with peers (though we believe that a focus on discussion features such as "closure" is likely not unique to this context). Further work could explore which kinds of aesthetics are commonly activated in which kinds of contexts, as well as potential patterns across contexts and relations among aesthetics in action. For instance, we noted above how judgments of the quality of a discussion might be linked to judgments of engagement. We anticipate, as we expand the study of teacher aesthetics across contexts, that we will find aesthetics that tend to be employed together, and in characteristic ways.

A different empirical question concerns the degree to which there is individual and/or cultural variability in teachers' aesthetics and their use. On the one hand, multiple teachers in this study's context showed some focus on student engagement and the quality of student ideas. However, there was also a great deal of fine-grained texture to these judgments. Just as a wine connoisseur might employ a rich vocabulary of terminology to describe the flavor of wines, so did teachers use varied language to talk about the flavor of student ideas and student conversation. Future research could examine commonalities and variations in readouts and language across teachers and instructional contexts.

There also remain a variety of questions about teachers' aesthetics and aesthetic judgments that are more theoretical in nature. As a novel construct with respect to teacher thinking, the definition and posited characteristics of teachers' aesthetics will benefit from ongoing refinement in relation to additional teacher thinking constructs, related interdisciplinary perspectives, and other examples of aesthetic judgments among teachers. As with many constructs, we anticipate that refinement of the construct itself and associated heuristics for identifying aesthetics in data will co-evolve. Further, understanding teachers' complex judgments of classroom events through the lens of aesthetics is only one way of exploring what is happening—a way that affords attention to the structure of the judgments. Additional work in this area may help to clarify how the structure of aesthetic judgments relates to other interpretive lenses that instead focus more directly on content or context. There is also work to do concerning the relationships that may exist among aesthetics. For example, can they be nested one inside the other, similar to schemata (e.g., Rumelhart, 1980)? When considering an aesthetic, such as the *interesting part* aesthetic described above, in what ways does it make sense to conceptualize its counterfactual (i.e., a part that is not very interesting) as *part of* the aesthetic versus its own aesthetic? Finally, there are also dimensions of variability across aesthetics that deserve attention. For example, some aesthetic judgments seem to be more tacit than others, and some seem to have a stronger valence. We hope that the existence of these questions is suggestive that this is a worthwhile area for further research.

Endnotes

(1) All names are pseudonyms.

References

Barnhart, T., & van Es, E. (2015). Studying teacher noticing: Examining the relationship among pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education, 45*, 83-93. http://dx.doi.org/10.1016/j.tate.2014.09.005.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*(2-3), 105-225.

Lomax, K., Fox, A., Kazemi, E., & Shahan, E. (2017). *Argumentation in Mathematics*. An online course developed in partnership with the Teaching Channel.

Richards, J., Altshuler, M., Sherin, B. L., Sherin, M. G., & Leatherwood, C. J. (2021). Complexities and opportunities in teachers' generation of videos from their own classrooms. *Learning, Culture and Social Interaction, 28*. https://doi.org/10.1016/j.lcsi.2021.100490.

Rumelhart, D. E. (1980). Schemata: The building blocks of cognition. In R. J. Spiro, B. C. Bruce, & W. F. Brewer (Eds.), *Theoretical issues in reading comprehension* (pp. 33-58). Hillsdale, NJ: Erlbaum.

Schack, E. O., Fisher, M. H., & Wilhelm, J. A. (2017). *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks*. Switzerland: Springer International Publishing AG.

Schoenfeld, A. H. (2008). Chapter 2: On modeling teachers' in-the-moment decision making. *Journal for Research in Mathematics Education. Monograph 14*, 45-96.

Sherin, B., & Star, J. R. (2011). Reflections on the study of teacher noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 66-78). New York, NY: Routledge.

Sherin, M. G., Jacobs, V. R., & Philipp, R. A. (2011). *Mathematics teacher noticing: Seeing through teachers' eyes.* New York, NY: Routledge.

Sherin, M. G., & van Es, E. A. (2009). Effects of video club participation on teachers' professional vision. *Journal of Teacher Education, 60*(1), 20-37.

Stockero, S. L., Rupnow, R. L., & Pascoe, A. E. (2017). Learning to notice important student mathematical thinking in complex classroom interactions. *Teaching and Teacher Education, 63*, 384-395. http://dx.doi.org/10.1016/j.tate.2017.01.006.

Superfine, A., & Bragelman, J. (2018). Analyzing the impact of video representation complexity on preservice teacher noticing of children's thinking. *EURASIA Journal of Mathematics, Science and Technology Education, 14*(11), em1650. https://doi.org/10.29333/ejmste/99501.

van Es, E. A., & Sherin, M. G. (2021). Expanding on prior conceptualizations of teacher noticing. *ZDM*. https://doi.org/10.1007/s11858-020-01211-4.

Walkoe, J. D. K., & Luna, M. J. (2020). What we are missing in studies of teacher learning: A call for microgenetic, interactional analyses to examine teacher learning processes. *Journal of the Learning Sciences, 29*(2), 285-307. https://doi.org/10.1080/10508406.2019.1681998.

Walkoe, J., Sherin, M., & Elby, A. (2020). Video tagging as a window into teacher noticing. *Journal of Mathematics Teacher Education, 23*, 385-405. https://doi.org/10.1007/s10857-019-09429-0.

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Computational Thinking Unplugged for Science: Unplugged CT Professional Development for Inservice Science Teachers

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Abstract: Computational thinking (CT) is a fundamental skill for 21st Century work. Historically, CT instruction has existed primarily in computer science courses that lack both racial/ethnic and gender diversity. Scholars argue for broadening CT access for K-12 students by integrating CT in core curricula, however, CT/content integration remains uncommon. A major barrier to widespread CT integration is limited CT professional development (CT-PD). Given that, we drew on teacher professional development research to design and implement a fully unplugged CT-PD with inservice secondary science teachers that focused on unplugged strategies for integrating CT in core science curricula. We examined the influence of the CT-PD on teachers' CT understanding and CT integration self-efficacy, as well as, program components that participants identified as particularly beneficial to their CT understanding and self-efficacy in CT/science integration. This study provides important insights for the development of future CT-PD offerings for inservice teachers.

Keywords: computational thinking, CT unplugged, science education, teacher professional development

Introduction

Many scholars assert that computational thinking (CT) is a fundamental component of preparing students for the complex future of work, and that all students must have opportunities to build proficiency with these practices during their K-12 education (Grover & Pea, 2018; Ketelhut et al., 2020). Unfortunately, opportunities to engage with CT practices have, historically, been confined to elective computer science courses which lack racial, ethnic, and gender diversity (Gallup Inc. & Google Inc. 2016). Integrating CT into core curriculum is the most promising strategy for exposing diverse groups of learners to these critical practices (e.g., Grover & Pea, 2018; Yadav et al., 2016). While efforts to integrate CT with subject-area curriculum have been ongoing for more than a decade, CT/content integration (CTCI) is not yet commonplace; Shute and colleagues (2017) identify a lack of consensus about the framing of CT and few research-supported best practices for CTCI as a potential reason. Other scholars point to challenges that include teachers' concerns about access to and proficiency with technology (Israel et al., 2015), teachers' low levels of CT understanding (Kite et al., 2020), teachers' low CT self-efficacy (Bower et al., 2017), and limited CT professional development (CT-PD) support for inservice teachers (Sands et al., 2018).

Low levels of teacher CT understanding and self-efficacy in CT/science integration are particularly concerning because teachers are unlikely to integrate CT with their existing curriculum if they lack either sufficient understanding of CT or confidence in their ability to create quality CT learning experiences for their students (Ketelhut et al., 2020). Bower and colleagues (2017) demonstrated that teachers' CT understanding and self-efficacy can be enhanced by short-term, high-quality PD opportunities, however, Ketelhut et al. (2020) and Sands et al. (2018) both note that much CT-PD work has focused on preservice teachers and that research on CT-PD experiences for inservice teachers is in its infancy. Additionally, given the relative newness of CT-PD research, the community is still working to identify highly-effective components of CT-PD interventions. Nonetheless, ensuring that all students engage with CT practices in their K-12 STEM classrooms depends upon adequately-trained teachers who understand CT and feel confident in infusing it into their curriculum (Yadav et al., 2017).

Bearing in mind technology-related barriers to CT integration and the need for CTCI, we designed, implemented, and examined a week-long CT-PD called Computational Thinking Unplugged for Science (CTUPS), which focused on non-technological (Unplugged) approaches to integrating CT with secondary science content. This proposal presents an overview of CTUPS and its theoretical underpinnings, and reports its influence on teachers' CT understanding and self-efficacy in CT/science integration, as well as, components of CTUPS that teachers identified as uniquely beneficial. Our work was guided by the following research questions: (1) What is the effect of the CTUPS program on inservice secondary science teachers' CT understanding and self-efficacy in CT/science integration? (2) What elements of CTUPS do participants identify as most impactful on their CT understanding and self-efficacy in CT/science integration?

Theoretical background

The design of CTUPS is based on three lines of scholarship in the fields of CT, computer science (CS), and teacher education. First, in the decade since Jeanette Wing (2006) first described her conceptualization of the practices that comprise CT, many groups have forwarded definitions and frameworks for CT without reaching consensus (Grover et al., 2020). Lacking a common understanding, we adopt Fraillon et al. 's (2019) definition of CT (Table 1) as the conceptual foundation of our work because we believe it provides a vision of CT that can be operationalized in K-12 science classrooms. Specifically, Fraillon and colleagues' description of two distinct phases of CT (Conceptualizing problems and Operationalizing solutions) provides a useful framework for walking teachers and students through the process of developing an algorithmic solution to a complex problem.

Table 1: The 2018 ICILS computational thinking assessment framework (Adapted from Fraillon et al., 2019)

Strand	Aspect
Conceptualizing problems	Knowing about and understanding digital systems. Formulating and analyzing problems. Collecting and representing relevant data.
Operationalizing solutions	Planning and evaluating solutions. Developing algorithms, programs, and interfaces.
Definition	*Computational thinking refers to an individual's ability to recognize aspects of real-world problems which are appropriate for computational formulation and to evaluate and develop algorithmic solutions to those problems so that the solutions could be operationalized with a computer (pg. 27).*

Second, computer programming is the dominant tool of CT education (Kite et al., 2018; Moreno-León et al., 2018). However, multiple scholars identify restricted access to technology, teacher discomfort with technology, and teachers' lack of programming experience as barriers to CT/content integration (Kite et al., accepted; Bower et al., 2017; Israel et al., 2015). As an alternative to technology-focused CT practices, Lu & Fletcher (2009) and Caeli and Yadav (2020) argue that students and teachers could benefit from an unplugged-first approach that builds foundational CT skills. In 1998, Bell and colleagues published the first CSUnplugged collection of games and puzzles for teaching CS concepts without a computer. Over time, the term "Unplugged" has expanded to encompass any CT or CS activity that does not use technology. Though Peel et al., (2019) demonstrated the potential for unplugged approaches to fusing CT with science curricula, Moreno-León and colleagues (2018) highlight the lack of research in this arena. Given that, to address tech-related barriers, and in response to the need for research on unplugged strategies for integrating CT in disciplinary content, we adopted a fully-unplugged approach to the implementation of CTUPS.

Lastly, the design of CTUPS was guided by Darling-Hammond et al.'s (2017) and Desimone's (2009) frameworks for effective teacher PD. Drawing on the work of these scholars, we designed the main features and activities of CTUPS around the following essential elements of effective PD: 1) A focus on subject-area content. 2) Active learning strategies. 3) Opportunities for collaboration between teachers in similar grades/content areas. 4) Thirty contact hours. 5) Coherence with both teachers' existing beliefs about teaching and school/district policies. 6) Modeling of effective teaching practices by facilitators. 7) Time for teachers to reflect on what they have learned and to receive feedback on products and implementations. Consequently, each day followed an experience, collaborate, plan, reflect structure.

Methods

This study employs mixed methods to collect, analyze, and interpret both quantitative and qualitative data to answer the research questions.

Overview of the Computational Thinking Unplugged for Science (CTUPS) program

CTUPS is a weeklong CT-PD for secondary science teachers that focuses on unplugged strategies for integrating CT practices into existing science curriculum. This CT-PD operationalizes the Fraillon et al. (2019) framework as a structure for moving teachers through the unplugged process of developing an algorithmic solution to a complex problem; in this case, human disturbance of an ecosystem. Each day of the program was split into two halves; experience and plan. In the morning, teachers acted as students to engage in activities that led them through the process of, first, identifying a human disturbance to an ecosystem, then, developing an unplugged algorithmic solution to the disturbance (Table 2).

Table 2: CTUPS activities that allowed teachers to experience CT-infused science learning

CT Practice	CTUPS Activities
Day 1: Systems Thinking	Teachers selected an ecosystem and associated human disturbance; identified system inputs, outputs, and emergent phenomena; created a concept map to visualize relationships in the ecosystem; and defined boundaries of the system and rules that govern its operation.
Day 2: Problem Decomposition	Teachers selected a human disturbance that functions as a system input (e.g., Fertilizer runoff in waterways), identified its associated output (e.g., Eutrophication), and used a "5 Whys" protocol to decompose the root causes of the human activity.
Day 3: Data Practices	Teachers identified multiple sources of data that could be used to understand the problem, developed strategies for obtaining the data, and created sample tables and visualizations that could be used to organize and display the gathered data.
Day 4: Algorithm Creation	Teachers brainstormed a list of possible elements of a solution to their problem, then organized the elements into an algorithm for solving the problem. Algorithms were required to included loops and conditional statements.
Day 5: Abstraction	Teacher teams were paired to combine their individual algorithms into a single, more general algorithm that could be used to address both teams' problems.

In the afternoon, teachers translated their experiences into adaptations of their existing science curriculum. Table 3 provides an overview of the key features of CTUPS and their alignment with the features of effective professional development as described by Darling-Hammond et al. (2017) and Desimone (2009).

Table 3: Key features of CTUPS and their alignment with the elements of effective teacher PD

Element	Description	CTUPS
Content Focused	A focus on subject knowledge and associated pedagogical knowledge.	Teachers engage in CT practices in the context of subject matter that they will teach (i.e., human disturbance of ecosystems). Teachers are provided time to align CT practices with their content standards and write curriculum. Each day of CTUPS is devoted to building CT understanding and efficacy by engaging in unplugged practices that focus on one of the CT aspects described by Fraillon et al. (2019).
Active Learning	Engaging in the process of constructing knowledge rather than passively receiving knowledge through lectures.	Teachers participate as learners in unplugged CT-infused science activities. All knowledge dissemination occurs via collaborative groupwork protocols (i.e., no lecture).
Collaboration	Providing opportunities for teachers to share knowledge while engaged in learning and writing curriculum.	All learning activities occur in teams. Curriculum alignment and lesson planning occurs in teams. Teams provide one another with feedback on curriculum products.
Collective Participation	Collective participation from teachers in the same school, grade, or district.	Teachers placed in teams of 2-3 based on their grade level, subject area, and district.
Sustained Duration	Twenty or more contact hours.	CTUPS consists of 30 contact hours over 5 days.
Coherence	Coherence to curriculum, student needs, teacher knowledge and beliefs, and school, district, and state reforms and policy.	Teachers are teamed based on grade level and district to allow teachers to write curriculum that aligns with both state standards and district reforms and policies.

Modeling	Facilitators model effective pedagogical strategies.	The facilitator models effective instructional practices while implementing "student" activities.
Feedback and Reflection	Participants receive peer and facilitator feedback on work products and are given opportunities to reflect on their learning.	Teachers keep a reflection journal where they are asked to respond to daily prompts that encourage them to reflect on the day's activities, curriculum alignment, implementation barriers, and the state of their own knowledge and confidence.

Participants
Eleven secondary science teachers in a Southeastern state in the U.S. participated in CTUPS. Their demographics are provided in Table 4.

Table 4: Demographic characteristics of CTUPS participants ($N = 11$)

	n (%)		*n (%)*
Male	1 (9)	Teaching Experience	
Female	10 (91)	3-5 Years	4 (36)
Race/Ethnicity		6-15 Years	3 (28)
African American	4 (36)	20 or More Years	4 (36)
Asian	1 (9)	Middle School	6 (55)
White	6 (55)	High School	5 (45)
		Low Income (Title 1) School	6 (55)

Data sources
Data sources for this study include pre, post-, and three-month-delayed-post surveys investigating qualitative and quantitative CT understanding (Sands et al., 2018) and a modified Computer Technology Integration Survey (Wang et al., 2004), as well as, daily "exit tickets" and reflection journals completed during the program, and an end-of-program evaluation questionnaire. All quantitative items on the CT understanding and self-efficacy instruments were 5-point Likert items with 1 representing low levels of understanding/self-efficacy and 5 representing high levels. Teachers' qualitative understanding of CT was investigated via two open ended questions on the pre, post, and delayed-post surveys that asked teachers to define CT and describe the role of CT in science learning. Daily "exit tickets" asked teachers to record three things they learned, two comments, and one question on a Post-it. Reflection journals asked teachers to reflect daily on two to three prompts relating to their CT understanding and thoughts pertaining to integrating CT in their science classrooms.

Data analysis
Quantitative data analysis was conducted using descriptive statistics and paired-sample t tests to identify differences between teachers' pre/post, and delayed-post scores on measures of CT understanding and self-efficacy and Cohen's d was used to calculate the direction and magnitude of the effect of the PD. To provide richer insights into the development of teachers' CT understanding and CTCI self-efficacy, as well as particularly beneficial program elements, triangulation of multiple data sources (Patton, 1999) and the constant comparative method (Corbin & Strauss, 2015) were used to qualitatively analyze teachers' written artifacts. Specifically, all qualitative data was, first, open-coded to capture the essence of each quotation, with quotations expressing similar sentiments given the same code. Axial coding was then used to identify trends in the data by aggregating open codes into categories. Finally, common themes in teachers' responses emerged through the process of selective coding. To check the reliability of the coding scheme, 25% of the data was randomly selected for coding by a second coder; an intercoder agreement level of 90% and Krippendorff's alpha of 0.98 were calculated. Additionally, to understand the alignment of participants' understanding of CT with that of the broader CT community, we classified teachers' CT definitions into two categories: basic and informed. Using the work of Weintrop and colleagues (2016) as a guide, teachers' definitions of CT or descriptions of CT that include the following (or similar) practices were identified as informed: (1) Using computers to solve complex problems, (2) Structured problem solving, (3) Data creation, analysis, and visualization, (4) Systems thinking, and (5) Creating or using models or simulations. Readers will see the codes *Canonical definition* and *PRADA* (Pattern Recognition, Abstraction, Decomposition, Algorithms) *to solve problems* referenced. A *Canonical definition* of CT includes using a specific CT practice and technology to solve problems. *PRADA to solve problems* includes a specific CT practice and problem solving but does not include the use of technology.

Results

Effects of CTUPS on Participants' CT Understanding and CTCI Self-efficacy

Quantitative analysis of teachers' pre, post, and 3-month-delayed-post surveys of CT understanding and integration self-efficacy reveal that CTUPS significantly enhanced participants' understanding of CT and CTCI self-efficacy. As shown in Table 5, teachers' mean CT understanding improved by 0.983 points (on a five-point scale) at the conclusion of CTUPS. Three months after the program, their understanding remained elevated by 0.739 points. Paired-sample t tests indicate that the change measured at each milestone was significant (t (10) = 5.567, t (9) = 4.792, p < .001) and Cohen's d values of 1.866 and 1.515 reveal a large effect on teachers' understanding. Regarding teachers' feelings of CTCI self-efficacy, following CTUPS, teachers' mean self-efficacy score improved by 1.976 points (on a five-point scale); enhanced self-efficacy persisted three months after the program (Δ = 1.646). Paired-sample t tests reveal the significance of the changes at both times (t (10) = 6.741, t (9) = 7.689, p < .001) and Cohen's d reveals large effect sizes of 1.866 and 1.980, respectively.

Table 5: Effects of the CTUPS program on secondary science teachers' CT understanding and CT integration self-efficacy

	Mean	Standard Deviation	Change	Cohen's *d*
Pre-Understanding (n = 11)	2.983	0.294		
Post-Understanding (n = 11)	3.965	0.508	0.983	1.866
Delayed-Post-Understanding (n = 10)	3.721	0.586	0.739	1.515
Pre-Efficacy (n = 11)	1.987	0.957		
Post-Efficacy (n = 11)	3.963	0.507	1.976	2.033
Delayed-Post-Efficacy (n = 10)	3.633	0.684	1.646	2.432

Qualitative analysis of changes in teachers' CT understanding

Qualitative analysis of teachers' definitions of CT as provided on the three surveys and in their reflection journals reveal a rapid and durable shift in teachers' conceptualization of CT. Table 6 presents changes in the proportion of teachers' definitions that were assigned to five categories that emerged from our qualitative analysis.

Table 6: Qualitative changes in teachers' definitions of CT

Category	Pre *n* (%)	End Day 1 *n* (%)	Post *n* (%)	Delayed Post *n* (%)
Solving problems with computers or specific CT practices	5 (29)	12 (75)	10 (91)	9 (82)
Related to math or data	5 (29)	4 (25)	1 (9)	1 (9)
Generic problem solving	3 (18)	0 (0)	0 (0)	1 (9)
A specific type of thinking	2 (12)	0 (0)	0 (0)	0 (0)
Other	2 (12)	0 (0)	0 (0)	0 (0)

Prior to the beginning of the CTUPS program, the majority of teachers' definitions (59%) revealed basic understandings of CT. While several initial definitions were identified as informed, these definitions only referenced single CT practices (e.g. Pattern Recognition) and none of the teachers provided what would be considered to be a complete, *Canonical definition* of CT. Further, teachers frequently qualified their pre-survey definitions with phrases like "*I think*" or "*I imagine.*" At the end of the first day of the program, teachers were again asked to define CT. In contrast to their definitions at the beginning of the day, this set of definitions shows that 75% of the teachers provided informed understandings of CT, and three teachers gave full, *Canonical definitions* of CT. For example, one teacher stated that CT is "*A problem solving method using data to find patterns in order to create algorithms to solve a problem.*" Of the 11 definitions of CT provided on the post-survey, 91% were labeled informed and four teachers provided *Canonical definitions* of CT. The number of open codes used to analyze teachers' definitions decreased from 12 on the pre-survey to four on the day five post-survey; indicating that over the course of the five-day program, teachers' understandings of CT refined and coalesced around academically-accepted CT conceptualizations. Three months after the conclusion of CTUPS, teachers were, again, asked to define CT. Eighty-two percent of teachers' responses were identified as informed. As with the immediate-post-survey results, teachers' responses on this survey most frequently described CT as *PRADA to solve problems.* For example, one teacher defined CT as "*A process for conceptualizing problems and designing solution algorithms.*" Unsurprisingly, we do note some degradation in teachers' understanding of CT over the intervening three months between the conclusion of CTUPS and the delayed-post survey, and hypothesize that the decay stems from a lack of ongoing professional support.

Qualitative analysis of changes in teachers' CT integration self-efficacy

Sixty-one quotations gleaned from teachers' exit tickets and daily reflection journals were open-coded and categorized according to whether they demonstrated *Low efficacy, Growing efficacy,* or *High efficacy.* Considering the proportion of quotations housed in each of these categories for each of the days reveals that teachers' perceptions of their CTCI self-efficacy steadily improved over the course of the CTUPS initiative (Figure 1). Characteristic of statements written at the end of the first day were remarks such as "*This broad concept makes me uncomfortable*" and "*I feel much more prepared for the rest of the week.*" By the end of the second day, teachers' hinted at their growing efficacy through statements in the vein of "*CT is becoming clearer and clearer now.*" By the third and fourth days of the program teachers' efficacy had undergone a significant transition. Their writings from these two days are replete with statements like "*I am seeing ways to integrate CT in already created materials that middle schoolers can use and understand*" and "*I am a believer in CT!!! I cannot wait to use it in my classroom.*" One teachers' remark in her reflection journal from the first day may provide some insight into why teachers' self-efficacy changed over the course of the program. On day one, this teacher stated that "*I am starting to see that it is more of me starting to feel comfortable so that my students will be able to benefit from me introducing CT into my lessons.*" Other similar statements sprinkled across the four days indicate that teachers' felt that they, first, needed to become comfortable with CT before they had confidence that they could bring CT to their students. We hypothesize that presenting CT as a process and focusing on one Fraillon et al. (2019) practice each day may have allowed teachers to progressively build their understanding and comfort as we moved through the process of understanding a problem and developing a solution.

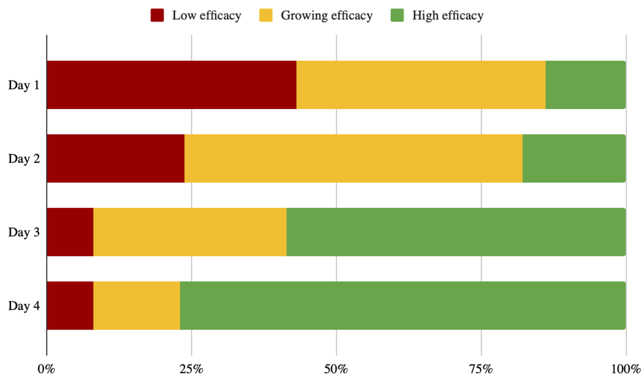

Figure 1. Change in teachers' statements of CT integration

Key elements of the CTUPS program

Qualitative analysis of 76 quotations gleaned from teachers' "exit tickets" and post-surveys resulted in 34 codes that were organized into four categories; three identifying particularly beneficial program elements and one identifying an element that should be changed. Thirty-one of the teachers' quotations about elements of CTUPS that they believed enhanced their CT understanding and CT integration self-efficacy fell under the theme *Practicing CT in the context of my content.* Within this theme, there were three categories of quotations, *CT-specific activities, Working through the process,* and *Contextualized practice.* In particular, teachers called out *Working through the process* and *Creating algorithms* as the most specific elements that enhanced their understanding and efficacy. The following quotation captures both of these sentiments "*The first three activities* [concept mapping, problem decomposition, data identification] *most impacted my understanding of CT because my thinking had to be restructured before getting to the algorithm.*"

In addition to practicing CT in the context of their curriculum, 22 of the teachers' quotations focused on the value they found in *Dialoging and collaborating with other teachers.* Teachers' writing across the documents are filled with statements that reflect the value that they found in working through the process of learning CT and developing CT-infused curricula with a group of like-minded teachers. One teacher noted that "*The true gift of our week this summer was having two other 8th grade science teachers to collaborate with. We all knew our standards, and were able to share our current labs, projects, and assignments. Integrating computational thinking in our curriculum was a natural next step.*" Along with collaborating with teachers in similar teaching circumstances, teachers emphasized the benefits that they found in the group debrief sessions that took place following each of the model CT activities and the peer feedback that they received on curriculum products developed throughout the program. In addition to the two above-mentioned themes, teachers also identified the *Program progress*, *Good model teaching,* and *Time to plan* as beneficial elements of CTUPS. Finally, with regards to program improvement, 11 of the teachers' quotations centered on the theme of *Beginning with a preview of the process and product.* The CTUPS program was designed using an explicitly constructivist approach, whereby teachers constructed their knowledge of CT by working through the practices of CT identified by Fraillon et al. (2019) as a process for producing an algorithm to solve a manmade environmental problem. The act of creating the algorithm was the culmination of the process and did not occur until day four. As a result of the constructivist design, participants were not provided with a vision of the final product (an algorithm) at the beginning of the program. While there was one teacher that appreciated this approach, most comments were in the vein of "*Do the algorithm as early as Tuesday so teachers will have more chance to digest what they needed to do at the end.*"

Discussion and implications

The results of this study point to the potential of fully-unplugged CT-PD programs for building inservice science teachers' CT understanding and CTCI self-efficacy, while providing them with CTCI strategies and addressing tech-centric CT concerns. Accordingly, we offer three implications for CT researchers and educators. First, our work, along with the work of Peel et al. (2019), demonstrates that unplugged CT activities like systems mapping, problem decomposition through tree maps, planning for data collection and analysis/visualization, and creating unplugged algorithms can effectively build teachers' and students' CT proficiency while supporting science content learning and practice as outlined in the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). Though some (e.g. Denning, 2017) will argue that CT education must include programming, we contend that programs like CTUPS can provide teachers with rich experiences that provide foundational CT understandings upon which later coding-centric CT instruction can build (Caeli & Yadav, 2020). Given that our program is a first attempt at a fully-unplugged approach to integrating multiple CT practices in science curricula, further research is needed to identify best practices for the design and delivery of unplugged CT-PD and to compare the affordances of unplugged CT-PD to its plugged counterparts with regards to CT/science integration.

Second, in line with the work of other teacher PD scholars (e.g. Darling-Hammond et al., 2017; Desimone, 2009), the results of our study demonstrate the importance of engaging teachers in learning experiences that they find to be relevant, applicable, and meaningful to them. In the case of CTUPS, involving teams of teachers in the collaborative task of using CT practices to produce a solution to an environmental problem was central to both building teachers' CT understanding and increasing their CTCI self-efficacy. The value that CTUPS participants found in practicing CT in context and collaborating with other teachers underscores the work of Ketlehut et al. (2020) and Sands et al. (2018), which both discuss the need for CT-PD partnerships whereby teachers provide subject-area and pedagogical knowledge and CT-PD providers provide CT content and learning experiences. Recognizing and leveraging teachers' expertise would appear to be emerging as a best-practice for future CT-PD offerings. Additionally, our findings accord with the work of others in demonstrating that CT-PD should be contextualized in teachers' discipline/curriculum (Yadav et al., 2017) and include time for teachers to identify CT/curriculum alignment and to write lessons for their classrooms (Ketelhut et al., 2020).

Finally, our work demonstrates the potential of operationalizing the Fraillon et al. (2019) CT framework as a guide for moving teachers and students through the process of developing computational solutions to complex problems. As far as the authors are aware, the CT education community has not previously presented individual CT practices connected as a coherent and systematic problem-solving process. This study, however, indicates that progressively moving teachers through the process of (1) understanding and mapping a natural system, (2) identifying and decomposing a problem, (3) identifying potential data sources and visualizations, and (4) creating an unplugged algorithmic solution, effectively scaffolded progressive construction of teachers' CT understanding. Further research on the affordances of operationalizing this framework as a process may illuminate the benefits of teaching CT as a coherent and interconnected set of practices for solving complex problems.

References

Bell, T., Witten, I., & Fellows, M. (1998). *Computer Science Unplugged: off-line activities and games for all ages.*

Bower, M., Wood, L. N., Lai, J. W., Howe, C., Lister, R., Mason, R., ... & Veal, J. (2017). Improving the computational thinking pedagogical capabilities of school teachers. *Australian Journal of Teacher Education, 42*(3), 4.

Caeli, E. N., & Yadav, A. (2020). Unplugged Approaches to Computational Thinking: a Historical Perspective. *TechTrends, 64*(1), 29–36. https://doi.org/10.1007/s11528-019-00410-5

Corbin, J., & Strauss, A. (2015). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA. Sage.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017*). Effective Teacher Professional Development*. Palo Alto, CA: Learning Policy Institute.

Denning, P. J. (2017). Remaining trouble spots with computational thinking. *Communications of the ACM, 60*(6), 33-39.

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181-199.

Fraillon, J., Ainley, J., Schulz, W., Duckworth, D., & Friedman, T. (2019). *IEA International Computer and Information Literacy Study 2018 assessment framework*. Springer.

Gallup Inc. & Google Inc. (2016). *Diversity gaps in computer science: Exploring the underrepresentation of girls, Blacks and Hispanics.* Retrieved from http://goo.gl/PG34aH

Grover, S., & Pea, R. (2018). *Computational Thinking: A competency whose time has come. Computer Science Education: Perspectives on teaching and learning in school*. London: Bloomsbury Academic, 19-37

Grover, S., Sengupta, P., Gunckel, K. L., & Wendell, K. B. (2020). Integrating STEM & Computing in PK-12 : Operationalizing Computational Thinking for STEM Learning & Assessment. *International Conference of Learning Sciences*. Nashville, TN. Retrieved from https://www.researchgate.net/publication/-342365849.

Israel, M., Pearson, J. N., Tapia, T., Wherfel, Q. M., & Reese, G. (2015). Supporting all learners in school-wide computational thinking: A cross-case qualitative analysis. *Computers & Education, 82*, 263-279

Ketelhut, D. J., Mills, K., Hestness, E., Cabrera, L., Plane, J., & McGinnis, J. R. (2020). Teacher change following a professional development experience in integrating computational thinking into elementary science. *Journal of Science Education and Technology, 29*(1), 174-188.

Kite, V., Park, S., & Wiebe, E. (2018). *From coding to computational thinking in science education.* Presentation to the American Education Research Association annual meeting. New York City, NY.

Kite, V., Park, S., McCance, K., & Seung, E. (2020). Secondary science teachers' understandings of the epistemic nature of science practices. *Journal of Science Teacher Education,* 1-22.

Kite, V. Park, S., & Wiebe, E. (Accepted pending minor revisions). The code-centric nature of computational thinking education: A review of trends and issues in computational thinking education. *Sage Open.*

Lu, J. J., & Fletcher, G. H. (2009, March). Thinking about computational thinking. In *Proceedings of the 40th ACM technical symposium on Computer science education* (pp. 260-264).

Moreno-León, J., Román-González, M., & Robles, G. (2018). On computational thinking as a universal skill: A review of the latest research on this ability. In *Global Engineering Education Conference (EDUCON), 2018 IEEE* (pp. 1684-1689). IEEE. doi:10.1109/educon.2018.8363437

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. The National Academies Press. Washington, DC.

Orton, K., Weintrop, D., Beheshti, E., Horn, M., Jona, K., & Wilensky, U. (2016). Bringing Computational thinking into high school mathematics and science classrooms. *ICLS 2016 Proceedings*. Singapore: International Society of the Learning Sciences.

Patton, M. Q. (1999). Enhancing the quality and credibility of qualitative analysis. *Health services research, 34*(5 Pt 2), 1189.

Peel, A., Sadler, T. D., & Friedrichsen, P. (2019). Learning natural selection through computational thinking: Unplugged design of algorithmic explanations. *Journal of Research in Science Teaching, 56*(7), 983-1007.

Sands, P., Yadav, A., & Good, J. (2018). Computational thinking in K-12: In-service teacher perceptions of computational thinking. In *Computational thinking in the STEM disciplines* (pp. 151-164). Springer, Cham.

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review, 22*, 142–158. doi:10.1016/j.edurev.2017.09.003

Tanenbaum, C. (2016). STEM 2026: A vision for innovation in STEM education. US Department of Education, Washington, DC.

Wang, L., Ertmer, P.A., & Newby, T.J. (2004). Increasing preservice teachers' self-efficacy beliefs for technology integration. *Journal of Research on Technology in Education, 36*(3), 231-250

Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33-35.

Yadav, A., Hong, H., & Stephenson, C. (2016). Computational Thinking for All: Pedagogical Approaches to Embedding 21st Century Problem Solving in K-12 Classrooms. *TechTrends*. doi:10.1007/s11528-016-0087-7

Yadav, A., Gretter, S., Good, J., & McLean, T. (2017). Computational thinking in teacher education. In *Emerging research, practice, and policy on computational thinking* (pp. 205-220). Springer, Cham.

Turn-usurping in dialogic collaborative problem solving

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Abstract: Dialogic collaborative problem solving (D-CPS) emphasizes the equal rights of group members. Turn-usurping is one approach of turn-taking where a student usurps the floor which has been offered to another person by the last speaker. It reflects speaker's strong agency in seeking for participation opportunities and hasn't been fully explored in literature. The present explorative study adopted a mixed-method approach to examine major features and functions of turn-usurping in D-CPS. Participants were 168 primary school students who were assigned into 42 four-person groups to solve three open-process mathematical problems. Results showed that turn usurpers tended to have low intellectual status, low confidence in mathematics and high social anxiety. Turn-usurping had positive impact on maintaining participation equity and moving forward and complexifying group discussions. The findings suggested that it is practically meaningful to promote an equitable interaction environment where each member is encouraged to freely jump in.

Introduction

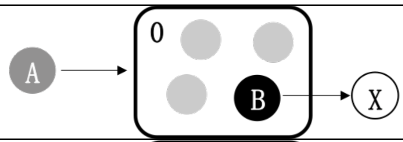
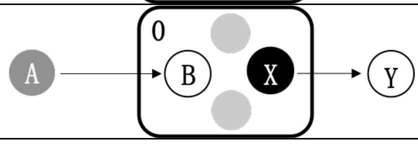
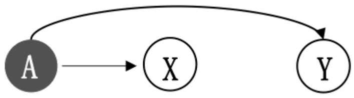
Following the epistemological assumptions of Bakhtin's dialogism (1929/1984), the present study defines dialogic collaborative problem solving (D-CPS) as a complex dynamic process whereby two or more consciousnesses, with equal rights and each with its own world, combine but are not merged in the unity of solving a shared problem. Students' verbal engagement is an essential end in D-CPS. Joint solutions emerge from and only exist in the dialogue whereby group members open themselves to each other's voices and augment their own.

Students verbally engage in D-CPS through taking the conversational floor, an evolving, socially negotiated space where individuals are allowed to make contributions (Engle, Langer-Osuna & McKinney de Royston, 2014). Turn-taking describes the process whereby the conversational floor transmits among speakers. It affects the amount of opportunities that different individuals have for influencing group discussions through verbal and accompanied non-verbal contributions (e.g., Lemke, 1990). Thus, examining turn-taking structure is essential for understanding the interanimation of various voices in a group.

Gibson (2005) proposed the participation-shift (P-shift) framework to describe "the way in which people move themselves and one another onto and off the floor" (p.1,566). This framework differentiates between the various speakers, targets and third parties in human interactions, and it further identifies four categories of participation shifts (see Table 1). Turn-receiving happens when a target takes the floor offered by a speaker. Turn-claiming happens when a speaker addresses the whole group, and a third party responds to this open invitation. Turn-usurping happens when a third party usurps the floor assigned to the target by the speaker. Turn-continuing occurs when a speaker continues to occupy the floor while talking to various other individuals. These participation shifts cover all possible micro turn-taking motifs, and they can thus describe how dynamic turn shuffling gives rise to participation equity and inequity in the process.

Regarding the degrees of freedom people have to participate, both turn-receiving and turn-continuing tend to reduce the diversity of participation by limiting identity shuffling. Both turn-claiming and turn-usurping, however, strengthen the diversity of the participation structure, and thus they tend to increase the complexity of turn-taking patterns. Individuals who prefer different types of turn-taking may have different individual characteristics. Little research has been done on this issue. Tsvetkova, Garciá-Gavilanes and Yasseri (2016) did one similar study on how individual characteristics affect their reverting behavior patterns on Wikipedia. The authors identified six two-event temporal motifs to describe various behavioral patterns among the reverters and the reverted users. These researchers found that the reciprocal motif (A reverts B, and B reverts A back, AB–BA) usually happened between participants of equal status. Senior Wikipedia editors tended to perform continuous reverts (A reverts B, and A reverts C, AB–AC), and were likely to be reverted by either low-status editors or by others of equal status (A reverts B, and C reverts A, AB–CA).

Table 1: Participation shifts as defined by Gibson (2005).

Participation shift	Formula[a]	Illustration	Description
Turn-receiving	AB-BX		A talks to B, then B talks to X (X could be A or the group).
Turn-claiming	A0-BX		A talks to the group, then B talks to X (X could be A or the group).
Turn-usurping	AB-XY		A talks to B, then to X (X is not B or A) talks to Y (Y could be A, B or the group).
Turn-continuing	AB-AX		A talks to X (X could be the group), then A continues to talk to Y (Y could be the group).

a. The formula denotes the following: (speaker) (target) – (third party) (target of third party). The group is denoted as 0. X and Y represent people other than the neighbouring speaker and target.

The present explorative study tries to shed light on turn-taking approaches by first focusing on turn-usurping. Turn-usurping involves stronger agency than turn-claiming due to the usurper's self-nomination as well as the overlook of last speaker's nomination. It is an approach that an individual actively create participation opportunity rather than passively take a given one. Therefore, it represents a seemingly disruptive turn shuffling approach in D-CPS. However, to the best of my knowledge, this turn-taking approach hasn't been sufficiently explored in existing literature. I did not find relevant studies in addressing how turn-usurping might affect the process of group discussion and whether individuals who prefer usurping turns might have some specific characteristics. Therefore, the present study particularly aims to explore:

1. How does turn-usurping affect the social structure of D-CPS?
2. Who is likely to usurp a turn in D-CPS?
3. What are the intentions for students to usurp a turn?
4. How does turn-usurping shape the flow of group discussion?

Method

Participants and procedures

This study was conducted in a primary school in a city of mainland China. Participants were 168 fourth graders from five classes (41% females, 59% males, aged from 8 to 12). The teachers helped organize the students into groups of four, making gender and prior mathematics grades as balanced as possible. To ease the effect of task structure on individual participation modes, the present study designed three structured, open-process mathematical problems with various difficulties levels. Each group was given 30 minutes to collaboratively solve these three problems in a normal classroom setting. During the test, teachers or the researcher did not moderate group discussions except for clarifying task instructions or maintaining classroom discipline.

After the test, students independently completed a questionnaire concerning their demographic information, mathematics learning enjoyment, mathematics self-concept, and social anxiety. Both measurements on self-concept and learning enjoyment were measured through four-point Likert scales adapted from the TIMSS 2015 questionnaire for fourth graders in Taiwan (Mullis & Martin, 2013) (1 = *strongly agree*, 2 = *somewhat agree*, 3 = *somewhat disagree* and 4 = *strongly disagree*). Social anxiety was measured using the 10-item Chinese version of the Social Anxiety Scale for Children–Revised (La Greca & Stone, 1993). The students were asked to indicate the frequency of specific behaviors on a three-point Likert scale (1 = *always do this*, 2 = *sometimes do this*, 3 = *never do this*). The measures had a relatively high internal reliability, as indicated by Cronbach's alpha values for social anxiety (α = .835), mathematics enjoyment (α = .734) and mathematics self-concept (α = .882) (Tavakol & Dennick, 2011).

Data analysis

Written solutions submitted by the groups were graded according to a standard scoring criteria which considered the correctness of the final solution first and then awarded partial credit for solution steps informed by group discussion audios if the final answer was wrong.

Group discussion audios were transcribed turn by turn. If a speaker paused and then continue to speak, her utterances were viewed as happening in one turn. Therefore, turn-continuing is not considered in the present study. All transcripts of group discussions were coded according to the participation shift framework by two trained coders. The decision tree for identifying the target interlocutor was as follows:

Does the speaker explicitly name the target interlocutor?

Yes, code it as the named interlocutor.

No. Does the speaker use *you* in the utterance?

Yes, code it as the last speaker.

No. Does the speaker use *we* in the utterance?

Yes. Is there any clue indicating *we* not representing the whole group?

Yes, code it as the inferred target.

No, code it as Group.

No. Does the utterances belong to a flow of discussion with one specific interlocutor?

Yes, code it as the specific interlocutor.

No, code it as Group.

Participation shift type was automatically generated through Excel after target interlocutors were determined (see Table 2). Two coders separately coded three groups randomly selected from participants and achieved an acceptable level of inter-rater agreement (*Kappa* = 0.692; Landis & Koch, 1977). All disagreements over coding were resolved through negotiation. One coder then finished the coding of all the left groups.

Table 2: Sample data coding

Turn	Speaker	Target	Content	Participation shift type
42	Gan	Group	8 divided by 2 equals 4.	
43	Gu	Gan	Why? Their prices may not be the same.	Claim
44	Gan	Gu	8 divided by 2 equals 4. Listen to me (5.0), 8 yuan …	Receive
45	Xun	Gan	Gan, I wanna ask a question (…) ((in a muffled sound))	Usurp
46	Gan	Xun	It means 8 equals one popsicle and one ice cream.	Receive
47	Gu	Group	So, how can we calculate the prices of one popsicle and one ice cream?	Usurp
48	Gan	Gu	One popsicle …	Claim
49	Si	Group	I think we can calculate like this.	Usurp
50	Gan	Si	Say it.	Claim
51	Si	Gan	2, 8, 16. That is two popsicles and two ice creams. Then 22 minus 16 equals two popsicles. Then divide by 2. It is one popsicle.	Receive

The present explorative study adopted a mixed method approach. Quantitative analysis was used to address the first two research questions; qualitative analysis was used for the last two questions. The qualitative analysis only targeted three representative groups to examine major intentions for students to usurp a turn and the impact of turn-usurping in D-CPS. This study adopted a grounded-theory informed coding process to identify talk moves involved in usurped turns and further extract major functions of turn-usurping in shaping group discussion structure. There was only one coder (the author) for the qualitative analysis part.

Results

Quantitative results

Quantitative analysis was conducted to examine how turn-usurping shifts affect the social structure of D-CPS and who are likely to participation through usurping turns.

There were 42 groups in total in this study. Each group produced an average of 286 turns (*SD* = 116, *min* = 104, *max* = 522) within the half hour testing period. Turn-receiving was the most common type of participation shift within the groups. Around 43% (*SD* = 10.3%) of turns shift by the current speaker receiving the floor offered by the last speaker. The percentage of turn-usurping (M = 29%, SD = 8.1%) and turn-claiming is similar (M = 28%, SD = 7.5%).

Regarding group level analysis, the incidence of turn-usurping shifts was found to be correlated with the total number of turns one group produced ($r(42) = 0.459$, $p < .01$). Furthermore, turn-usurping is significantly negatively correlated with the standard deviation of individual participation rates ($r(42) = -0.534$, $p < .001$). That is, the higher percentage of turn-usurping in a group, the more equal of individual participations.

At an individual level, the higher degree that an individual participated by usurping turns, the higher level of her social anxiety ($r(144) = -0.204$, $p < .05$), the lower of her prior mathematics grade ($r(144) = -0.281$, $p < .01$), the lower of her prior Chinese grade ($r(144) = -0.332$, $p < .001$) and the lower level of her self-concept in mathematics ($r(146) = -0.225$, $p < .01$). That is, turn-usurpers were more likely to be those with low intellectual status, low self-concept and high social anxiety.

Qualitative results

Qualitative analysis was conducted to examine underlying intentions and the impact of turn-usurping shifts through the scrutiny of three concrete groups. The three groups were selected based on their representativeness of interaction intensity and final solution quality: groups that discussed a lot and achieved a good solution (Talkative-Good), groups that discussed few and achieved a good solution (Quiet-Good), and groups that discussed few and achieved a bad solution (Quiet-Bad) (see Table 3).

Table 3: Characteristics of three selected groups

Group	Talkative-Good	Quiet-Good	Quiet-Bad
Number of turns	361	173	126
Score of group solution	7.67	8.33	3.00
Number of turn-usurping	122	56	33
Average prior mathematics grade of members	105.50	94.75	107.33

Through examining turn-usurping shifts in these three groups, the present study found that turn-usurping shifts seldom caused interruptions of the last speaker. The percentages of interruption were smaller than 10% across three groups.

Major intentions of these turn-usurping shifts were explored through an open coding process. It was found that students usurped a turn mainly to *add on* previous speaker, initiate a turn to *express new ideas* or *propose* some action plans, jump in to *regulate* problem solving procedure and group functions, *disagree* or *agree* with someone, and initiate a *question* (see Figure 1). In addition, students in the Talkative-Good group usurped a lot of turns to *repeat* the last speaker which was not the case in the two quiet groups. A further investigation showed that *repeat* happened frequently when one student wrote down the solution while the other three kept informing him/her on what to write down. Meanwhile, students in the Quiet-Bad group usurped turns mostly to propose action plans, regulate collaborations, initiate *off-task* utterances, and *express emotions*; while there was no agree- or disagreement compared to the other two groups with good solutions.

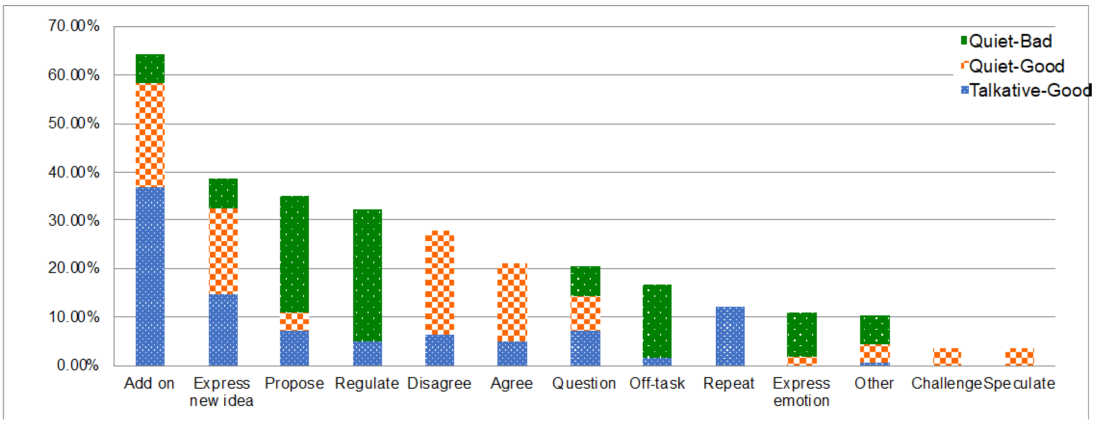


Figure 1. Distribution of major intentions of turn-usurping shifts in three representative groups.

The present study further examined the Quiet-Good group in solving the second problem to illustrate the facilitative and constructive functions of turn-usurping in D-CPS process. The second problem featuring *snake* requires students to propose three solutions to calculate the number of stones a sinuous snake will occupy when it spreads its body (see Figure 2). This problem (item ID: M051006) was adapted from the Trends in International Mathematics and Science Study (TIMSS) that was conducted in 2015 (TIMSS & PIRLS International Study Center, 2015). It mainly requires students' reasoning ability rather than their specific content knowledge.

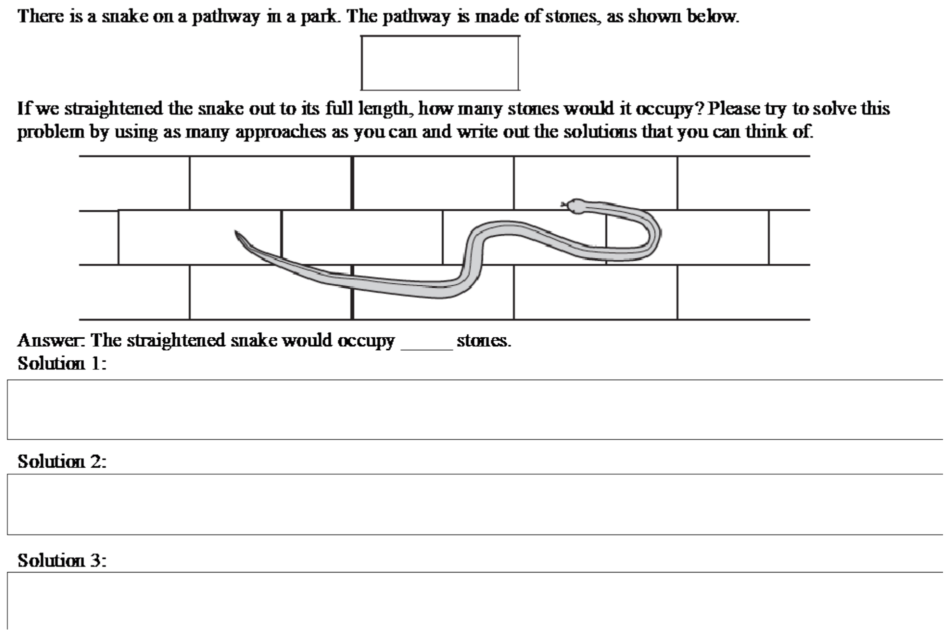


Figure 2. A translated English version of the snake problem.

The Quiet-Good group totally generated 51 turns in solving this problem. Four members' characteristics and participations were shown in Table 4. Sun was nominated as the group leader throughout discussions possibly due to his academic advantage. Qiu is academically as advantageous as Sun. While Yan and Chen position in a relatively low academic status. In the process of solving the *snake* problem, Chen and Sun accessed to the conversational floor mainly through receiving turns from others. Qiu had a balance in involving three types of participation shifts; while Yan participated in the discussion mostly through usurping turns. Yan produced the least amount of turns as well.

Table 4. Characteristics of four students in the Quiet-Good group

Pseudonym of the speaker	Yan	Chen	Sun	Qiu
Age	11	11	10	11
Gender	Female	Female	Male	Male
Recent mathematics grade[a]	88.0	81.0	106.0	104.0
Recent Chinese grade[a]	93.5	89.5	114.5	113.0
Mathematics self-concept[b]	2.78	3.00	3.63	3.78
Mathematics enjoyment[b]	3.44	4.00	3.89	4.00
Social anxiety[c]	1.900	1.500	1.200	1.300
Number of occupied turns	6.00	16.00	17.00	12.00
Percentage of turn-usurping	67%	38%	18%	33%
Percentage of turn-receiving	17%	50%	53%	42%
Percentage of turn-claiming	17%	13%	29%	25%

a. The maximum score is 120.
b. Four-point Likert scale. The maximum score is 4.
c. Three-point Likert scale. The maximum score is 3.

The selected excerpt happened when students tried to think about one solution for the *snake* problem (see Table 5). The qualitative analysis found that this discussion segment revealed various functions of turn-usurping shifts in moving forward and complexifying the group discussion. First, turn-usurping could help open a new dialogic space through initiating new questions (turn 32) or expressing new ideas (turn 37). At turn 32, Yan jumped in and initiated one question to the whole group on whether the small tongue of the snake in the picture should be counted in. This question got an instant response at the following turn which made all group members clear with target length of the snake. At turn 37, Qiu interrupted the arguments on whether the snake occupies three or five stones and proposed one new answer: four stones. This new idea stimulated reflections on previous answers and initiated a new discussion thread on the appropriateness of the answer four.

Second, turn-usurping could also help jump back to previous arguments (turn 34). Sun suggested the whole group to think over again at turn 29 and held back Chen's utterance at turn 31. At turn 34, Chen justified her previous idea of three stones and challenged Sun's answer of five stones. She usurped the turn to continue her utterance at turn 31 and strengthened her arguments at turn 34 which helped shift discussion back to previous unsettled divergence of views between Sun and her.

Third, turn-usurping could diverge the discussion flow through expressing disagreement (turn 42). At turn 42, Chen jumped in to disagree with Qiu's solution which contrasted with Sun's hesitate *yes* towards Qiu at the previous turn. This stimulated Sun to express clear attitude towards Qiu's answer and add on Chen's disagreement at turn 43. Such two continuous turn-usurping shifts involved disagreement and add-on which helped refine existing solutions and stimulate new ideas.

Table 5: How many stones would the snake occupy? Discussion segment in the Quiet-Good group.

Turn	Speaker	Target	Content	P-shift	Intention of usurping
29	Sun	Group	Then think it over again. We think about how to calculate it on earth.	Receive	
30	Chen	Chen	If, if you are right…	Claim	
31	Sun	Chen	Think it over first ((Sun interrupted Chen)) (2.0)	Receive	
➡ 32	Yan	Group	Does the tongue of the snake count or not? ((in low voice))	Usurp	Question
33	Qiu	Yan	It does not count.	Claim	
➡ 34	Chen	Group	I think it should be three stones because the body of a real snake is not that big at all. If it was five stones and each stone is long, how could it be possible?	Usurp	Justify Challenge
35	Sun	Chen	If it was not five stones, it could not be three stones neither because it is crooked here.	Claim	
36	Chen	Sun	But I moved it here like this just now. I did like this after moving it here. Therefore, the crooked part has been counted in.	Receive	
➡ 37	Qiu	Group	I think it is four stones.	Usurp	New idea
38	Sun	Qiu	Why?	Claim	
39	Chen	Qiu	Four stones are somewhat::	Usurp	Other
40	Qiu	Group	Move the head of the snake here, and then move here, then it reaches here after being straightened.	Receive	
41	Sun	Qiu	Yes::	Claim	
➡ 42	Chen	Qiu	If it was straightened, the tail could reach here at most.	Usurp	Disagree
➡ 43	Sun	Chen	Correct if being straightened. Straighten it, and it means it will reach here, right?	Usurp	Add on
44	Chen	Sun	Group leader ((Sun)), I have another idea that is we hypothesize it was several meters long, hypothesize::, hypothesize::	Receive	

Discussion and conclusion

Turn-usurping is one approach of turn-taking where a speaker usurps the conversational floor which has been assigned to someone else by the last speaker. This study presents a concise and very first examination on turn-usurping in D-CPS in terms of its impact on social structure, features of its actor, underlying intentions, and its impact on the interaction process. The findings suggest the positive impact of turn-usurping on maintaining participation equality and its constructive functions in moving forward and complexifying group discussions.

Turn-usurping and participation equality

The present study revealed a positive correlation between the percentage of turn-usurping in one group and the equality of individual participations. This is possibly due to the disruptive nature of turn-usurping. Human interaction is reciprocal (Blau, 1964; Gergen, Greenberg & Willis, 1980). If people talk specifically to someone, there is always an expectation of feedback from the same person. This is also demonstrated in the present study that turn-receiving is a robust turn-taking approach. Continuous turn-receiving shifts tend to cause a locally closed interaction chain unless speakers could consciously involve other members which, however, is a high-level competence that students need to be explicitly taught or guided (King, 2008; Michaels & O'Connor, 2009). In addition, the possible status problem in a group might worsen this situation because students tend to address frequently to the high-status students which can easily cause social dominance or isolation (Cohen & Lotan, 1995, 2014). Turn-usurping as a disruptive turn-taking approach does not follow the usual organization rules of turn-taking (Sacks, Schegloff & Jefferson, 1974). It reflects speaker's strong agency and tends to break current reciprocal turn-taking sequence and initiate a new chain of reciprocal conversation.

This study also found that students who participated mostly through usurping turns were likely to be those with low intellectual status, low-level confidence in mathematics and high-level social anxiety, which indicates the existence of status problem in the present study. Low-status students were seldom addressed by other members and fought for most of their turns in the discussion. This is against the essential premise of dialogic interactions. Genuine dialogue requires the equal rights of various voices (Bakhtin, 1929/1984). Such emphasis on equitable interactions reflects the intrinsic ethical considerations of the dialogism theory (Matusov et al., 2019). Instead of aiming at reducing achievement difference, equity in learning interactions emphasizes the construction of equitable relations among people (Boaler, 2008). Since turn-usurping currently is the major participation approach of low-status students, it seems reasonable that high rate of turn-usurping was associated with higher participation equality.

Constructive functions of turn-usurping

Benefits of turn-usurping also reflect in its constructive rather than disruptive impact on group discussion. The study found students mostly did not interrupt the last speaker when usurping a turn although they overlooked last speaker's allocation of the conversational floor. Therefore, turn-usurpers also show respect for the last speaker by allowing her finishing the turn and smoothly taking up the next turn to contribute.

Furthermore, students tend to produce high-quality utterances in a usurped turn although some turn-usurping shifts might involve off-task behavior. This is possibly because of the strong agency of students when they usurp a turn. A turn usurper possibly thinks long and hard before jumping in the discussion or blurt out disagreements or queries stimulated by the speaker. Therefore, utterances produced through turn-usurping are more likely to involve productive talk moves (King, 2008; Lazonder et al., 2003; Teo & Daniel, 2007). These productive talk moves in a usurped conversational floor further help manage and shift dialogic space in group discussion (Wegerif, 2007) including initiating a new dialogic space, jumping back to the previous one, or diverging the current one. Therefore, turn-usurping indicates a potential transition point in D-CPS and deserves further investigations in the future.

Practical implications

Previous studies have established that to best enable the success of a collaboration, there should be no significant difference among individual participations in collaborative problem solving (Asterhan & Schwarz, 2009; Dillenbourg et al., 2016). Its absence may lead to information loss, dominance by a majority of the team members or limitations on a team's potential to perform various tasks (Borge & Carroll, 2014; Woolley, Chabris, Pentland, Hashmi & Malone, 2010). The present study briefly demonstrates the positive effects of turn-usurping shifts in mitigating participation inequality and facilitating group discussion. It is thus practically meaningful to encourage students to freely jump right in group discussion through actively usurping turns in D-CPS activities.

In addition, turn-usurping turn out to be a major approach for low-status students to participate in the present context. It is thus also practically necessary to encourage students to monitor whether a turn-usurper has been isolated in discussion. Based on insights of the complex instruction approach (Cohen & Lotan, 1995), teachers could also assign competence to turn-usurpers through publicly praising the intellectual contributions in a usurped turn and arousing peers' attention to this contribution. The equity of learning interaction emphasizes the fairness of accessing to the conversational floor (Shah & Lewis, 2019). In addition to encouraging the behavior of turn-usurping whereby low-status students create participation opportunities for themselves. Teachers can also guide students to talk specifically to low-status students so that low-status students could get more participation opportunities.

The present study is inevitably limited in some ways. There were only three representative groups selected for the qualitative analysis part which aimed to address the last two research questions. Furthermore, the author was the only coder for the qualitative analysis. Therefore, more data and stricter coding process should be involved to further validate the current explorative findings. In addition, the current study was contextualized in Chinese culture background. Further research is also needed to examine whether turn-usurping features might differ across different cultures.

References

Asterhan, C. S. C., & Schwarz, B. B. (2009). Argumentation and explanation in conceptual change: Indications from protocol analyses of peer-to-peer dialog. *Cognitive Science*, *33*(3), 374–400.

Bakhtin, M. M. (1929/1984). *Problems of Dostoevsky's Poetics, Edited and Translated by Caryl Emerson, with an Introduction by Wayne C. Booth* (C. Emerson, Trans.). Manchester: Manchester University Press.

Boaler, J. (2008). Promoting 'relational equity' and high mathematics achievement through an innovative mixed-ability approach. *British Educational Research Journal*, 34(2), 167-194.

Borge, M., & Carroll, J. M. (2014). Verbal equity, cognitive specialization, and performance. *Proceedings of the 18th International Conference on Supporting Group Work*, 215–225.

Cohen, E. G., & Lotan, R. A. (1995). Producing Equal-Status Interaction in the Heterogeneous Classroom. *American Educational Research Journal*, *32*(1), 99–120. https://doi.org/10.3102/00028312032001099

Cohen, E. G., & Lotan, R. A. (2014). *Designing groupwork: Strategies for the heterogeneous classroom Third Edition*. Teachers College Press.

Dillenbourg, P., Lemaignan, S., Sangin, M., Nova, N., & Molinari, G. (2016). The symmetry of partner modelling. *International Journal of Computer-Supported Collaborative Learning*, *11*(2), 227–253. https://doi.org/10.1007/s11412-016-9235-5

Engle, R. A., Langer-Osuna, J. M., & McKinney de Royston, M. (2014). Toward a model of influence in persuasive discussions: Negotiating quality, authority, privilege, and access within a student-led argument. *Journal of the Learning Sciences*, *23*(2), 245–268.

Gibson, D. R. (2005). Taking Turns and Talking Ties: Networks and Conversational Interaction. *American Journal of Sociology*, *110*(6), 1561–1597.

King, A. (2008). Structuring peer interaction to promote higher-order thinking and complex learning in cooperating groups. In *Computer-Supported Collaborative Learning Series 8*.

La Greca, A. M., & Stone, W. L. (1993). Social anxiety scale for children-revised: Factor structure and concurrent validity. *Journal of Clinical Child Psychology*, *22*(1), 17–27.

Lazonder, A. W., Wilhelm, P., & Ootes, S. A. W. (2003). Using sentence openers to foster student interaction in computer-mediated learning environments. *Computers and Education*, *41*(3), 291–308. https://doi.org/10.1016/S0360-1315(03)00050-2

Matusov, E., Marjanovic-Shane, A., & Gradovski, M. (2019). Dialogic Pedagogy and Polyphonic Research Art. In *Dialogic Pedagogy and Polyphonic Research Art*. https://doi.org/10.1057/978-1-137-58057-3

Michaels, S., & O'Connor, C. (2009). Conceptualizing Talk Moves as Tools. *Language*, 1–32. https://doi.org/10.3102/978-0-935302-43-1

Mullis, I. V. S., & Martin, M. O. (Eds.). (2013). *TIMSS 2015 Assessment Frameworks*. Chestnut Hill, MA: TIMSS & PIRLS International Study Center, Boston College.

Sacks, H., Schegloff, E. A., Jefferson, G., & Harvey Sacks, E. A. S. and G. J. (1974). A Simplest Systematics for the Organization of Turn-Taking for Conversation. *Language*, *50*(4), 696. https://doi.org/10.2307/412243

Shah, N., & Lewis, C. M. (2019). Amplifying and Attenuating Inequity in Collaborative Learning: Toward an Analytical Framework. *Cognition and Instruction*, *37*(4), 423–452. https://doi.org/10.1080/07370008.2019.1631825

Tavakol, M., & Dennick, R. (2011). Making sense of Cronbach's alpha. *International Journal of Medical Education*, *2*, 53-55.

Teo, Y.-H., & Daniel, C. (2007). Using Sentence Openers to Support Students' Argumentation in an Online Learning Environment. *Educational Media International*, *44*(3), 207–218. https://doi.org/10.1080/09523980701491658

Tsvetkova, M., Garciá-Gavilanes, R. & Yasseri, T. (2016). Dynamics of disagreement: Large-scale temporal network analysis reveals negative interactions in online collaboration. *Scientific Reports*, *6*(November), 1–10. https://doi.org/10.1038/srep36333

Wegerif, R. (2007). *Dialogic education and technology*. Springer.

Woolley, A. W., Chabris, C. F., Pentland, A., Hashmi, N., & Malone, T. W. (2010). Evidence for a collective intelligence factor in the performance of human groups. *Science*, *330*, 686–688.

Intersections of the Political and the Scientific: Examining Ideological Practice in Science Class

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Abstract: In current polarized times, political ideologies shape how we act and speak, yet are given little attention in both the learning sciences and in science education, where they hold particularly damaging ramifications for disciplinary learning. This study argues for attention to political ideologies, or shared systems of representation that guide how we interact within governmental, electoral, and political spheres. Integrating neo-Marxist philosophy of ideology with notions of cultural practices, this study uses discourse analysis to explore the role of political ideologies in discourse as grade 9 US science students learn about climate change. This work identifies political ideologies prevalent in a science classroom. It examines ideologies' intersection with and divergence from scientific disciplinary engagement. This research demonstrates the role of political ideologies in youth sensemaking.

Introduction

Today, political ideology shapes how we act, speak, and experience the world, particularly around contentious science issues, such as climate change and COVID-19. The influence of political ideology on adults is clear, yet science classrooms tend to treat youth as ideology-free. Further, learning occurs at an intersection of heterogenous meaning-making practices (Rosebery, Ogonowski, DiSchino, & Warren, 2010); leaners engage in diverse ways of making sense of the world, many not scientific. As humans, such practices always involve ideologies, or systems of taken-for-granted assumptions that shape how we speak and act. In the polarized times of 2020, political ideologies are especially prevalent in sensemaking. Although discussed rarely, practices that enact ideologies, particularly political ideologies, have ramifications for science learning. This study investigates political ideologies embedded within students' discourse. Analyzing classroom discourse, this study takes a step towards understanding ideological practices that arise interactionally and influences on science learning.

Conceptual framework

As humans, we make meaning of our worlds through cultural participation (Rogoff, 2003). Cultural practices are related to context; as context shifts, so do the practices that constitute that culture. As a person tends to participate in multiple cultures, one typically makes meaning of the world through a diversity of practices, relevant to the many cultures to which they belong. This heterogeneity of human cultural practices is fundamental to learning, as learning happens when diverse meaning-making practices intersect (Roseberry et al., 2010).

Ideology

Drawing on Philip, Gupta, Elby, and Turpen (2018), I argue that the heterogenous cultural practices students bring to classroom learning involve ideology and that such practices hold implications for learning. Grounded in Althusser (1971) and Hall (1985), I view ideology as the shared systems of representation through which we live our lives. Furthermore, I build on Althusser's assertion that it is through human action and speech that ideology comes to have "material" existence. In this sense, Althusser viewed ideology as practice, living out in the rituals of communities and institutions. Cultural practices thus reflect and reproduce ideology. Drawing on Althusser, this study views schools as places where ideology gets reproduced but also takes on Hall's dialogic lens, which offers a vision of school as a place not just of ideological reproduction but also one of ideological re-articulation—where current connections of an ideology are broken and new ones created, as multiple discourses intersect and ideologies are continually reformed. I apply this lens, asking about what ideologies emerge in a science classroom and how those ideologies get reproduced, contested, and rearticulated.

Defining political ideologies

This study uses the concept of political ideologies, defined as the shared systems of representation through which we understand political institutions and our relationships to them. These shared systems are ones that allow us to hold assumptions about governmental, policy, and electoral systems and our actions related to those systems, as well as the distribution of social goods made possible through those systems. Political ideologies and related cultural practices are quite salient within US culture today, as seen in vitriolic public political debate and trends of deepening political divisions. Because of this salience of political ideologies, I argue for the necessity of its investigation in classroom-based learning. Science classrooms in particular are critical places in which to understand political ideologies, as cultural practices enacting political ideologies can pose peril to science, given that US conservative political ideology is increasingly associated with distrust of science (Gauchat, 2012). Yet, research in science learning tends to give little attention to ideology, an inattention at odds with the reality of the current social landscape. The few studies that have considered ideology reveal evidence for its salience in youth scientific reasoning (e.g. Walsh & Tsurusaki, 2018; Zummo, Donovan, & Busch, 2021).

Ideology & learning

Research has conceptualized learning as trajectories of increasing proficiency in cultural practices (Rogoff, 2003). To new situations learners bring a set of heterogenous practices with which to make meaning, and learning occurs as these practices intersect. The practices learners bring are inextricably tied to the ideology that shapes their lives. Cultural practices, which occur in social contexts, mediate the materialization of ideology (Hall, 1985); what people do and say facilitates the existence of ideologies in the material world. These words and actions, tied to ideology, influence the heterogenous practices that individuals use to make meaning. Learning and ideology are thus inextricably linked, as they are both tied deeply to how we engage with ideas and each other and how we navigate and make meaning of the world (e.g. Philip et al., 2018).

It is crucial to investigate practices linked to ideology and their influence on science learning for two key reasons. First, the emergence of ideology in classrooms can influence what students learn (e.g. Philip et al., 2018). What concepts get surfaced, reproduced, and rearticulated in the classroom social space is linked to what gets learned. Second, a key goal of science education is for students to use scientific meaning making resources to participate in the broader world (Osborne & Dillon, 2008). Yet, for many adults in the US, practices shaped by ideology, specifically political ideology, preclude scientific ways of making meaning around polarized issues, such as climate change and COVID-19. It is the responsibility of science education to shift this pattern so that scientific meaning making resources are not as readily relegated.

Language & discourse

Language and discourse mediate both science (a cultural practice of knowledge production) and the enactment of ideology. Language shapes the knowledge produced through cultural practices of science (Norris & Phillips, 2003; Vygotsky, 1978). Similarly, modern standards for science education are built around language-mediated practices that produce knowledge, such as arguing from evidence and building explanations (e.g. Achieve, 2013). This concept is mirrored in research on discourse-centered classrooms (e.g. Berland & McNeill, 2010) and recognition of the social construction of science knowledge (e.g. Kelly, 2007). In this view, knowledge production is mediated by not just an individual's language but by the discourse of the social classroom. The result is discourse-rich science classrooms in which knowledge is produced and mediated by what students say and do.

Language and discourse also mediate enactment of ideology (Bakhtin, 2010; Hall, 1985), as they allow for its material registration. Practices that make material ideology are mediated by language—the same language used to mediate meaning making in science classrooms. It is thus important to analyze classroom discourse to understand both how youth engage in disciplinary practice and how ideology, materialized through practice, influences disciplinary practice. Analysis can elucidate how scientific and ideological practices intersect, challenge each other, and diverge. To understand the role of ideology in meaning making, I look to classroom discourse, asking: 1) What political ideologies are prevalent in a 9th grade science class studying climate change? 2) In what ways do political ideologies and scientific disciplinary engagement intersect and/or diverge?

Methods

Context, participants, & data collection

This study took place in two grade 9 science classrooms in a US city, both taught by Mr. Thompson, an experienced teacher. Students came from a diversity of backgrounds, including socio-economic, racial and ethnic, and language backgrounds at a public school serving a socioeconomically diverse neighborhood. This study examined student discourse within several whole class and small group discussions. All discussions occurred within a curriculum unit on climate change in which students engaged in scientific practices, such as analyzing and interpreting data, to construct disciplinary content knowledge about global climate change. However, this study examined only discourse that took place outside of scaffolded activities. Data sources were audio recordings of: 1) unplanned, open-ended whole class discussions, and 2) small group activities in which students were not explicitly asked to use scientific practices. These data were selected because students were *not* specifically asked to use scientific concepts or practices; students were perhaps more likely to draw on heterogenous ways of making meaning used in their lives beyond school. Approximately 500 minutes of discussion was analyzed.

Data analysis

I transcribed data at the level of spoken discourse and used transcripts for discourse analysis (e.g. Gee, 2014). This process involved developing two coding schemes (Miles, Huberman, & Saldaña, 2014): one to characterize political ideologies and one to characterize disciplinary engagement.

Analytic framework 1: Ideology in pieces

To characterize political ideologies, I developed an emergent coding scheme using the analytic lens of Philip's (2011) ideology in pieces. Merging diSessa's (1993) theory of conceptual change with Hall's (1985) notion of ideology, Philip employed this lens for analysis of ideological sensemaking. This lens conceives of "pieces" of ideology that individuals use to make sense of the social world. These *naturalized axioms*, or taken-for-granted assumptions about how we live together, form ideologies. Through these axioms ideology is made material. Through axioms' articulation and re-articulation, individuals sustain, investigate, and challenge various ideologies. Philip theorized this framework to explain sensemaking about racialized contexts, arguing that individuals tend to rely on naturalized axioms when making meaning of race and racialization. I argue that a similar framework can explain sensemaking about politicized contexts, particularly when those politicized contexts are situated within a science learning experience, such as when studying climate change. While the words "political" and "politicized" can hold many meanings, in this study I use them to describe the ideologies that guide our governmental, policy, and electoral systems and our actions and interactions related to those systems. This definition includes ideologies guiding the two dominant political parties (Democratic and Republican), their stated positions, and their underlying tenets, as well as common discourses used by party leaders. To understand what political ideologies were prevalent, I coded for "pieces" of ideology, inferring naturalized axioms from students' discourse when they made assumptions about reality or about what is desirable. From naturalized axioms, I interpreted the broader ideology guiding axioms. Through an iterative process, I developed a codebook to characterize axioms and ideologies. Additionally, I coded for whether the speaker, in using the axiom, sustained, interrogated, or challenged the axiom and/or broader ideology. A selection of the finalized coding scheme can be seen in Table 1. Codes were applied at the level of talk turn whenever naturalized axioms were salient.

Table 1: Selection of ideology codebook.

	Definition	Naturalized axiom (code)
Individualism	A prioritization of individuals' rights over those of the collective; prioritization of oneself or one's immediate community	An issue is not a problem until it affects me or us
		An issue is not a problem until everyone notices
		Laws should not limit individuals' rights
		Individuals have rights to resources
		Negative consequences are excusable if they affect only a minority of people
Denialism	An ideological space in which denial of certain phenomena or observable events is normalized	People either believe or deny phenomena
		Belief and denial are related to politics
		Some phenomena are either real or a hoax
		Belief and denial are intractable
Economism	A prioritization of the economy; centering the economy, money, and market forces as of primary importance; an ideological space in which capitalism is normalized	The marketplace works
		Money is compelling
		Job creation is key
		Inequality is normal

Analytic framework 2: Productive Disciplinary Engagement

To understand scientific disciplinary engagement as it co-occurred with emergence of political ideology, I used an analytic lens built on Engle and Conant's (2002) productive disciplinary engagement (PDE), through which, Engle and Conant argued, the social construction of scientific knowledge occurs. Disciplinary engagement reflects "contact between what students are doing and the issues and practices of a discipline's discourse" (Engle & Conant, 2002, p. 402). Thus, I define disciplinary engagement as participation in the social construction of scientific knowledge—a process that involves a range of practices, including arguing from evidence, constructing explanations, analyzing trends, using quantitative reasoning, and critiquing others' ideas. To characterize disciplinary engagement, I developed coding scheme informed by prior work on the practices that constitute scientific knowledge construction (e.g. Achieve, 2013; Ford & Forman, 2006). I began with this *a priori* set of disciplinary practices as codes and then refined codes through engagement with the data. Codes were applied at the level of talk turn only when there was substantial evidence for engagement (e.g. Engle & Conant, 2002).

Results

RQ1: What political ideologies are prevalent?

Table 1 shows ideologies that emerged in all analyzed discussions: individualism, denialism, and economism. Ideologies that emerged less frequently were: imperialism, communitarianism, scientism, and technocentrism.

Individualism

A core tenet of US Republicanism (e.g. Hoover & Nash, 2016), individualism prioritizes the rights of individuals. Adherents tend to be more concerned with individuals' freedoms than the common good (Kahan et al., 2011); individualism anchors one end of a spectrum on the other end of which is communitarianism, which prioritizes the collective. Although associated with US Republicanism, individualism underlies neoliberalism, which shapes our modern political and economic system. In this classroom, individualism emerged through naturalized axioms used for sensemaking about the effects of climate change, who experiences those effects, and to what degree. An example can be seen in a whole class discussion that occurred the first day of the climate change unit.

Starting the discussion, Tony asked "When will it EVER affect us?" Emphasizing "EVER", Tony expressed dismissiveness, suggesting that climate change was not a problem for him or the people surrounding him. This move evidenced a naturalized axiom that an issue is not truly a problem until it affects oneself or one's community (Table 1). Reflective of individualism, this comment shows Tony prioritizing his own experience, in which he does not see effects of climate change. This comment makes material individualism, for if one makes sense of the world through individualism, and one is not personally affected by a shifting climate, then the effects of climate change are likely unproblematic. Tony's comment was met with a variety of animated responses. Several students challenged the individualist ideology made material by Tony. For instance, Arianna immediately responded by shouting "When we don't have a planet to live on!" Others acted to sustain it. For example, in response to Arianna, Nigel resurfaced Tony's individualism by saying "It's not affecting ME," again making material a system of representation in which the individual in central.

Denialism

Denialism emerged through several naturalized axioms (Table 1). In this classroom, denialism was a way of making sense of the social world that involved constructing some phenomena—specifically climate change—as something to be believed or denied. It is not that in making material this ideology students denied climate change, but, rather, that climate change was represented as something that can be denied. Denialism reflects a deep history of climate change in the US as a source of political divide, with skepticism amplified by prominent Republican politicians (Dunlap et al., 2016). An example can be seen in one small group's collaborative work on the first day, as they were engaging in a discussion-based activity designed to elicit prior knowledge. The students shared their responses to an earlier prompt of "What do you know about climate change?" (Transcript 1)

1.1	Arianna	Okay, tell me what you--
1.2		It's real, and it's not fake
1.3	Mason	It's real because--
1.4	Arianna	Zach, what else did you have?
1.5	Zach	I have Donald Trump doesn't believe it.
1.6		I don't know, I didn't write down a whole lot.
1.7	Arianna	Okay, we can--
1.8		Let's change that to political
1.9		Political parties claim that it's fake
1.10	Zach	Yeah
1.11	Arianna	That it's fake and that it's propaganda for Democrats
1.12	Zach	Yeah, that's basically it.

In asserting that climate change is "real" and "not fake" (Line 1.2), Arianna aired the implicit assumption that some people do not "believe" in climate change, thereby communicating that climate change is something to be believed in. While well-intentioned, her comment conveyed the idea that viewing climate change as fake remains an option for some, perhaps just not for these students in this moment. It framed climate change as something whose reality is contested, making material an ideology in which some phenomena are seen as real and others as fake. Zach's response and Arianna's following reaction together surfaced another naturalized axiom often articulated with statements of "belief". This axiom assumes that politicians are central figures in "belief"; and, the belief/denial spectrum correlates with political affiliation. By asserting that Donald Trump "doesn't believe it" (Line 1.5), Zach aired this axiom, sustaining ideology of denialism.

Economism

Economism was evidenced through students' prioritization of the economy, capitalism, and profit-generation (Table 1). An example can be seen in Transcript 2, when students in a small group discussed potential solutions.

2.1	Willa	I guess
2.2		Make electric cars more affordable so that more people are able to buy them
2.3		And umm…
2.4		I put--
2.5		If possible make large buildings and factories switch over to solar panels
2.6		If it would not pose a huge threat to their business
2.7	Ty	Okay
2.8		So for mine I did
2.9		Geothermal plants
2.10		Cause that's very efficient
2.11		Creates jobs

Willa put forward her idea for a solution, an idea grounded in the broader ideological context of capitalism—that if goods, such as electric cars, are more affordable, more people will buy them. This solution for climate change is one that sustains current economic ideology by leveraging naturalized axioms about the marketplace (Table 1). Willa continued to make material economism as she brought up industry regulations, saying that factories should be made to switch to solar panels "if it would not pose a huge threat to their business" (Line 2.6). With this caveat, Willa prioritized profit, acknowledging that generating income remains a priority, thereby sustaining economism. Then, by positioning job creation as a benefit of geothermal plants, Ty also surfaced an axiom of economism (Table 1), while also tying potential solutions to climate change into economic ideology and sustaining economism. Similar examples can be seen across the dataset. Not typically used for extended interrogation of this ideology or for challenging it, such naturalized axioms were often used by students in ways that sustained it, such as the ways in which Willa and Ty used them—to make sense of how dealing with climate change could be incorporated into pre-existing economic structures and ideals

RQ2: In what ways do political ideologies and scientific disciplinary engagement intersect and/or diverge?

Emergence of ideologies preceding (productive) disciplinary engagement

One phenomenon observed was the emergence of an ideology preceding disciplinary engagement. The disciplinary engagement that ensued in these cases often involved an intertwining with naturalized axioms; thus, I consider these moments examples of ideology made material within scientific disciplinary engagement. One example can be seen in the whole class discussion described earlier that began with Tony's question of "When will it EVER affect us", a making material of individualism. This laid the groundwork for ensuing episodes. Following Tony's comment, several students made evidence-based arguments about climate change already being a problem, thereby challenging Tony's expression of individualism. Eventually, while pointing to evidence of ice melt, one student said that "a lot of people still think climate change is a hoax", a comment that sustained denialism. The episodes that followed moved from sustaining denialism to interrogating it, at times, through disciplinary engagement. For example, Arianna engaged in perspective taking to consider why one might call climate change a "hoax." Cameron reasoned quantitatively, saying that correlation "is not the same as causation", and used that reasoning to critique a classmate's piece of evidence about increasing forest fire intensity, thereby sustaining denialism by giving skepticism plausibility. In response, Arianna cited evidence showing that a recent large fire was not necessarily caused by climate change but then went on to draw on scientific models of climate change making conditions conducive to intense fires. Martina built on this interrogation with disciplinary engagement, saying that the fires alone one could "call it off as coincidence", yet with a higher-level analysis of other global trends, one could see significant climatic changes. Within this discussion, ideologies and disciplinary engagement were often intertwined, with naturalized axioms emerging in disciplinary engagement and used for the social construction of knowledge, as they were sustained, challenged, and interrogated by students' disciplinary engagement. Across the dataset, there was evidence for this sort of co-occurrence.

Making ideologies explicit in critique

Another trend that emerged was the making explicit of ideologies within the disciplinary practice of critique. For example, in a small group discussion that turned to the relative role of city buses in climate change, Arianna and Mason disagreed. Although naturalized axioms constituting relevant ideologies were at first implicit, as the disagreement unfolded, Arianna made assumptions explicit in critique of Mason's argument. At first, Mason and Arianna engaged disciplinarily in obvious ways via quantitative reasoning in comparing the emissions of buses to cars, yet implicitly underlying the conversation were assumptions of who should have access to the resource of public transportation. However, this assumption did not become explicit until the debate stalled and Arianna declared that "people need [buses] though, you're just not one of them". Here, she challenged the ideology of individualism that had been shaping Mason's engagement. Within this discussion, engagement early on was disciplinary, with both students drawing on quantitative reasoning and specific evidence to advance claims. It was only when this disciplinary engagement stopped progressing that Arianna pivoted to ideological engagement to challenge the individualist ideology appearing to shape Mason's engagement and to further her critique.

Ideological engagement in the absence of science

There were several cases where political ideologies emerged and led only to non-disciplinary engagement, as were there cases in which ideologies emerged and appeared to preclude further engagement. An example of the latter can be seen in a small group discussion. After Nathan asked how climate change could be fixed, John said "we can stop giving gas to f-ing China, and they can stop running their cars". Prior to this episode, the three students had been discussing the greenhouse effect and how CO_2 was altering it—an example of disciplinary engagement. Yet, with Nathan's posed question, John surfaced assumptions reflective of both individualism and imperialism, invoking assumptions about the respective roles of China and the US in causing climate change and alluding to rights to resources. John's comment about China went unresponded to; it was not part of any evident disciplinary engagement and it did not appear to spur any further engagement in general; following this episode, there were several moments of silence and then talk turned to topics unrelated to the task.

Discussion

Interpretations of this analysis rely on the theoretical concepts that ideology is made material through language and discourse (Bakhtin, 2010; Hall, 1985), and that knowledge is produced through cultural practices mediated by that same language and discourse, (Vygotsky, 1978) and, further, that this process unfolds in the social space (Philip et al., 2018; Roseberry et al., 2010). Additionally, it is within these cultural practices that ideology is reproduced, contested, or re-articulated (Hall, 1985); consequently, the reproduction and/or transformation of ideology has implications for knowledge produced through interactions in which ideology is made material. With this theoretical framework, I argue that the meaning making in which students engaged involved heterogenous practices, some of which involved political ideologies, as made material through naturalized axioms (Philip, 2011). Therefore, the knowledge produced socially through collective meaning making was shaped and informed by the ideologies sustained, contested, and interrogated. Ideology mediated students' knowledge production.

Affordances of political ideologies' emergence

Although science education has historically aimed to keep politics out of the classroom, I see potential in explicitly considering political ideologies into learning. In one class, students' interrogation of denialism led to disciplinary engagement that was, to a degree, productive. As students interrogated assumptions of denialism, many engaged in scientific practices. Political ideologies shaped knowledge production, but they did so in ways that pushed student thinking beyond the bounds of an existing ideology to question it and did so in ways that incorporated scientific practices. Furthermore, this interrogation questioned an ideology that, I argue, has limited societal response to climate change and damaged the value of science as an institution. The prevalence of denialism has built space for skepticism over climate science, allowing such skepticism to thrive and be deployed by opponents to mitigation measures (Oreskes & Conway, 2011). Although this interrogation did not quite transform or extinguish denialism, it facilitated an examination and re-articulation of it. Through the discussion, there was a movement from the need to convince others of climate change to the need to understand their perspective, thereby rearticulating skepticism as not something to be suppressed but something to be investigated and understood.

Separately, this study gives evidence for ideologies as tools in argumentation, as seen in the bus debate. Arianna and Mason first drew on quantitative reasoning to argue, but the debate eventually stalled. Arianna then made explicit ideology about the distribution of social goods. In doing so, she uncovered a new lens through which to compare her argument to Mason's. Making explicit the ideology that guided each perspective clarified points of disagreement, helping the argument progress. Notably, Arianna pivoted to drawing on ideology when attempting to critique. One potential explanation for this pivot could lie with critique, a challenging practice that could lead to the leveraging of multiple resources. Alternatively, there may be something about critique itself that surfaces ideology. Since critique involves positioning by taking a stance against an idea, it could surface facets of identity, which is linked to ideology (Althusser, 1971).

The potential for ideologies in learning builds on research in socio-scientific issues (SSI), where scholars have shown that supporting students in drawing on their own moral frameworks—cultural practices not traditionally viewed as scientific—can support science literacy (Sadler, 2009). This study expands the SSI field by going beyond moral practices to define the political-ideological, which I argue are essential to consider in a time of political extremism. When drawn on in conjunction with scientific meaning making resources, political ideology could support disciplinary engagement and learning. Yet, I recognize the potential danger of this statement and concurrently argue that it is the responsibility of science education to help youth use these practices—ideological and scientific—in tandem in ways that align with (and do not damage) science.

Problematic sides to emergence of political ideologies

The emergence of political ideology can also be problematic, as evidenced here. First, potentially damaging ideologies can be sustained and reproduced, and student discourse often sustained ideologies. One could argue that sustaining individualism succeeds in inhibiting actions that could mitigate climate change. Likewise, one could argue that the reproduction of economism is problematic, as embrace of neoliberal economics has contributed to deepening inequality (Azevedo et al., 2019). Reproduction of ideologies can limit the possibilities for real transformation in a society that is far from perfect. Second, this study suggests that political ideologies can also preclude disciplinary engagement. In many moments, drawing on political ideologies appeared to supersede engagement with scientific meaning making. With the greater sociocultural context of ideological extremism and distrust of science, this observation is problematic. This sort of practice can contribute to the uncivil, anti-science discourse that permeates current society. If we want to reduce societal schisms over science, we need to actively work against the tendency to prioritize political ideologies over scientific resources. While I acknowledge that drawing on political-ideological resources for making sense of socio-scientific issues is unavoidable (and at times beneficial, as described above), I argue that science educators have a responsibility to help students do so in ways that do not denigrate science. These findings thus move me to advocate for science education that supports youth in engaging in civic discourse. Similar to other recent calls (Allchin & Zemplén, 2020; Feinstein & Waddington, 2020), I argue that science education must help youth not only use science responsibly but also be explicit about the sources and epistemologies of their ideas, recognizing that some emerge from political-ideological realms and some from scientific. It is our responsibility to help young people understand the heterogeneity of epistemic resources used and cultural practices engaged in as people navigate the world.

Implications

As an exploratory analysis, this piece lays the groundwork for future investigations of the influence of political ideologies on disciplinary learning. It speaks to Philip et al.'s (2018) argument that ideology influences learning. To their call to the learning sciences community, I add one specifically targeted at the field of science education for attention to ideology, particularly with the heightened emphasis on learning through discourse. While dialogic classrooms are essential to meaningful, disciplinary learning, it is critical to remember that discourse is also the medium through which ideology emerges, is made material, and is reproduced, challenged, and/or rearticulated. In this way, ideology holds influence over the knowledge produced through a science learning experience. Additionally, I suggest future work to examine the relationship between ideology and identity, with attention to how this relationship operates with in scientific disciplinary engagement, such as critique. Althusser (1971) and Hall (1985) argued that ideology is inherently related to identity, as the individual gets "interpellated" by ideology. With this study illuminating the relevance of ideology to disciplinary engagement it becomes time to investigate the identity of students who with their discourse make material ideology. As for educational practice, this study suggests that making ideology explicit, particularly when it shapes scientific practice, could be valuable to classroom learning. People, including youth, will always be living out ideologies through what they say and do. Rather than ignore this reality, we, as educators, should help young people learn to be explicit about the ideological aspects of their thinking and how that might influence their disciplinary work. I advocate for civic discourse in science classrooms, so that youth learn to engage in the civil discourse with which adults appear to struggle today.

Conclusion

This study offers a step into understanding the relationship between ideology and disciplinary engagement, laying the groundwork for future research in largely uncharted territory. A key takeaway is that political ideology did emerge through student discourse and appeared to shape the knowledge being produced through social interaction. Importantly, this emergence occurred within free-form discussions when students were not explicitly asked to use science. It is well known that adults tend to rely on a constellation of cultural practices, including political-ideological practices, to make sense of their worlds as politics become an aspect of identity increasingly salient in US culture. This study suggests that youth, too, draw on political ideology in navigating science-related issues.

References

Achieve, Inc. (2013). The next generation science standards, for states, by states. Retrieved September 22, 2020, from https://www.nextgenscience.org/

Althusser, L. (1971). Ideology and ideological state apparatuses (notes toward an investigation). Lenin and philosophy and other essays (pp. 127–186). Monthly Review Press.

Bakhtin, M. M. (2010). The dialogic imagination: Four essays (Vol. 1). University of Texas Press.

Azevedo, F., Jost, J. T., Rothmund, T., & Sterling, J. (2019). Neoliberal ideology and the justification of inequality in capitalist societies: Why social and economic dimensions of ideology are intertwined. Journal of Social Issues, 75(1), 49–88.

diSessa, A. (1993). Toward an epistemology of physics. Cognition and Instruction, 10(2&3), 105–225.

Dunlap, R.E., McCright, A., & Yarosh, J.H. (2016). The political divide on climate change: partisan polarization widens in the U.S. Environment: Science and Policy for Sustainable Development, 58(5), 4–23.

Engle, R.A. & Conant, F.R. (2002) Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. Cognition and Instruction, 20(4), 399-483.

Ford, M. J., & Forman, E. A. (2006). Chapter 1: Redefining disciplinary learning in classroom contexts. Review of Research in Education, 30(1), 1-32.

Gauchat, G. (2012). Politicization of science in the public sphere: A study of public trust in the United States, 1974 to 2010. American Sociological Review, 77(2), 167–187.

Gee, J. P. (2014). An introduction to discourse analysis: Theory and method. Routledge.

Hall, S. (1985). Signification, representation, ideology: Althusser and the post-structuralist debates. Critical Studies in Mass Communication, 2(2), 91–114.

Hoover, H., & Nash, G. H. (2016). American individualism. Hoover Press.

Kelly, G. J. (2007). Discourse in science classrooms. In S.K. Abell, K. Appleton, & D.L. Hanuscin (Eds.), Handbook of research on science education (Vol. 1, pp. 443-469). New York: Routledge.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2014). Qualitative data analysis: A methods sourcebook. 3rd. ed: Thousand Oaks, CA: Sage.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. Science Education, 87(2), 224–240.

Oreskes, N., & Conway, E. M. (2011). Merchants of doubt: How a handful of scientists obscured the truth on issues from tobacco smoke to global warming. Bloomsbury Publishing USA.

Osborne, J., & Dillon, J. (2008). Science education in Europe: Critical reflections (Vol. 13). London: The Nuffield Foundation.

Philip, T. M. (2011). An "Ideology in pieces" approach to studying change in teachers' sensemaking about race, racism, and racial justice. Cognition and Instruction, 29(3), 297–329.

Philip, T. M., Gupta, A., Elby, A., & Turpen, C. (2018). Why ideology matters for learning: A case of ideological convergence in an engineering ethics classroom discussion on drone warfare. Journal of the Learning Sciences, 27(2), 183–223.

Rogoff, B. (2003). The cultural nature of human development. New York, NY: Oxford University Press.

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. Journal of the Learning Sciences, 19(3), 322–357.

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. Studies in Science Education, 45(1), 1–42.

Vygotsky, L. (1978). Mind in society. Cambridge, MA: Harvard University Press.

Walsh, E. M., & Tsurusaki, B. K. (2018). "Thank you for being Republican": Negotiating science and political identities in climate change learning. Journal of the Learning Sciences, 27(1), 8–48.

Zummo, L., Donovan, B., & Busch, K. C. (2021). Complex influences of mechanistic knowledge, worldview, and quantitative reasoning on climate change discourse: Evidence for ideologically motivated reasoning among youth. Journal of Research in Science Teaching, 58(1), 95-127.

Exploring the Solution Generation Process in the Problem-Solving Phase followed by Instruction: How Do Learners Perceive their Knowledge Gaps?

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Abstract: This study investigates how the awareness of knowledge gaps (AKG) manifests by observing the problem-solving phase in PS-I(problem-solving followed by instruction). Comprehensively exploring the discourses of learners in this phase while seeking to categorize knowledge states around AKG will strengthen the underlying mechanism of PS-I. Understanding how AKG manifests will help pave the way for further research on how various knowledge states influence the effectiveness of PS-I, facilitating the design of appropriate instructional interventions to promote desirable knowledge states. With twelve graduate students as participants, this study qualitatively analyzes conversational discourses of the problem-solving phase and finds that students spend most of their time solving problems and seldom evaluate their thoughts, while only a few express their experience of a knowledge gap. The authors suggest categories of knowledge states around AKG and the distinctive characteristics of each category.

Keywords: awareness of knowledge gaps, problem-solving followed by instruction, qualitative content analysis

Introduction

The learning approach known as problem-solving followed by instruction (PS-I) has emerged as an attractive research area over the last decade because it may offer students productive learning experiences regardless of their initial unsatisfactory performances (Kapur, 2016). Under the PS-I approach, instructional interventions promote the learner's self-made tryouts (in the initial problem-solving phase) and use this experience to construct a strong schema that will be subsequently useful in the instruction phase (Likourezos & Kalyuga, 2017; Loibl et al., 2017). Research groups in productive failure and invention activity, which are strategies representative of the PS-I approach, have reported positive effects (Darabi et al., 2018; Loibl et al., 2017), with even more favorable effects emerging when compared to the instruction followed by problem-solving (I-PS) approach (Schalk et al., 2018).

What makes the problem-solving process in the PS-I approach unique compared to the conventional problem-solving after instruction approach? The review of Loibl and her colleagues (2017) described three mechanisms for how the external instructional event of PS-I triggers an internal state in the learner: a) prior knowledge activation, b) awareness of knowledge gaps, and c) recognition of the deep features of the target concept. The second mechanism, which is the focus of this study, is key to the efficacy of PS-I. The failure to solve a problem is ineffective if students are unaware of their failure because learners need to *know what they don't know* to be better prepared for the upcoming instruction, both cognitively and affectively (Hmelo-Silver et al., 2018). Awareness of knowledge gaps (AKG), which is a main cognitive event during the problem-solving phase, is an important aspect of the PS-I approach as it relates to the use and elevation of meta-cognition, which plays a crucial role in complex problem-solving and knowledge construction (Likourezos & Kalyuga, 2017). The knowledge gap highlights what a learner lacks and thus needs to know, thereby making the failure experience productive. However, little is known about how to support AKG.

This study starts with curiosity, asking whether a student can reach the 'knowing what they do not know' state, and if so, how this AKG manifests and whether the learner's state of AKG affects the effectiveness of PS-I. As a preliminary phase for the abovementioned research question, this study focused on how students become aware of their knowledge gap by exploring the process of problem-solving in PS-I in both deductive and inductive ways. Specifically, the current study first qualitatively examined learners' conversational discourse in problem-solving during PS-I using a deductive content analysis. Then, the authors conducted an inductive content analysis with the same talk-aloud data to classify the knowledge states around AKG. Identifying the characteristics of each state facilitates the understanding of how learners experience their knowledge gaps and how AKG manifests during problem-solving through comparisons with other knowledge states. This understanding offers practical implications for research on scaffolding strategies for positive experiences around AKG in PS-I.

Awareness of knowledge gaps in the PS-I approach research

Among PS-I advocates, researchers interested in invention activity (see Schwartz & Martin, 2004) are those who conceptualized the idea of the knowledge gap and measured it with questionnaires. Glogger et al. (2013) focused on the experience of the knowledge gap as a cognitive outcome of invention activity and assessed it using nine items on six-point self-rated scales (e.g., "My knowledge was insufficient to complete the task"). Their results indicated that invention activity increased the knowledge gap. They used a five-item version in their follow-up study and reported the same result (Glogger et al., 2015).

Subsequently, Loibl and Rummel (2014) introduced the term 'awareness of knowledge gaps'. The idea is rooted in the impasse-repair-reflect process (vanLehn, 1999) and the imperfect mental model view (Chi, 2000), which highlights the mental repair process of students when they become aware of their incapability in processing the incoming information within their current knowledge. Loibl and Rummel compartmentalized this awareness of incapability into a global awareness of knowledge gaps (i.e., "an awareness that they have knowledge gaps without being able to specify which component they are lacking", p.75) and an awareness of specific knowledge gaps (i.e., an awareness elicited during instruction by "helping them to detect differences in a more specific manner", p.75). They argued that identifying knowledge gaps may induce modifications to learners' current partial, naïve, or erroneous schemas, and suggested that instruction that compares a student's solution to the canonical solution can specify the gaps that occurred globally in the problem-solving phase. Using five items (e.g., "I lack knowledge required to solve this problem" and "I think I did not find a canonical solution for this problem", p. 81), they demonstrated that a PS-I session can trigger global AKG, with students in the PS-I group reporting more knowledge gaps than those in the I-PS group. In their follow-up studies, they emphasized comparing and contrasting activities as a remedy in specifying the knowledge gap and a connector to the next mechanism (i.e., deep feature recognition) (Loibl et al., 2017; Loibl et al., 2020).

The idea of AKG is also supported by other advocates of the PS-I approach. In his comprehensive work on productive failure, Kapur (2016) stressed the importance of differentiating relevant prior knowledge and identifying knowledge gaps as mechanisms of learning through problem-solving (see also Hmelo-Silver, Kapur, & Hamstra, 2018). Using Glogger and colleagues' (2015) questionnaire items, Lee et al. (2018) reported that supporting the problem-solving phase with meta-cognitive prompts increased AKG. Newman and DeCaro (2019) emphasized AKG as a metacognitive benefit of exploratory learning, providing guidance for students to perceive knowledge gaps. They examined whether students perceive knowledge gaps differently according to the order of instruction (i.e., instruction-first versus explore-first) and activity implemented (i.e., invention versus worked example). Finding evidence of a significant main effect and an interaction effect, they suggested providing pretests with worked examples as a supporting strategy for AKG.

However, the previous studies only dealt with global AKG using self-reported scales. Hence, how such awareness does, or does not, emerge during problem-solving is still not fully understood. As to the important role of AKG in the PS-I approach, instructional interventions for AKG arise as a remarkable research topic. In other words, the learner's experience around AKG needs to be scrutinized: Is it enough to understand learners' AKG as global AKG, or are there any other knowledge state categories around AKG? Why do some learners develop AKG, while others do not? This study investigates how AKG manifests by observing the problem-solving phase in PS-I. Comprehensively exploring the discourses of learners in this phase while striving to categorize knowledge states around AKG will strengthen the underlying mechanism of PS-I. Further, understanding how AKG manifests will open an avenue for future research to examine how various knowledge states impact the effectiveness of PS-I and subsequently design appropriate instructional interventions that promote desired knowledge states.

Research questions

1. What cognitive processes do learners experience when they assess the given problem and develop their own solution?
2. How do learners evaluate their knowledge during the problem-solving phase in PS-I?
3. How can the states of the awareness of knowledge gaps be defined?

Methodology

The main analysis method used in this study was qualitative content analysis. The advantage of content analysis lies in its ability to draw replicable and valid inferences from observed conversational discourses to their context (Krippendorff, 1980). Qualitative content analysis is an effective method for understanding and describing phenomena by creating or applying categories and concepts (Elo & Kyngäs, 2008; Mayring, 2000). Regarding the first research question, the authors first qualitatively examined learners' conversational discourse in problem-solving in PS-I using deductive content analysis. With a coding scheme adapted and revised from previous research (Poole & Holmes, 1995; Große & Renkl, 2007), students' conversation texts were categorized into one of the codes.

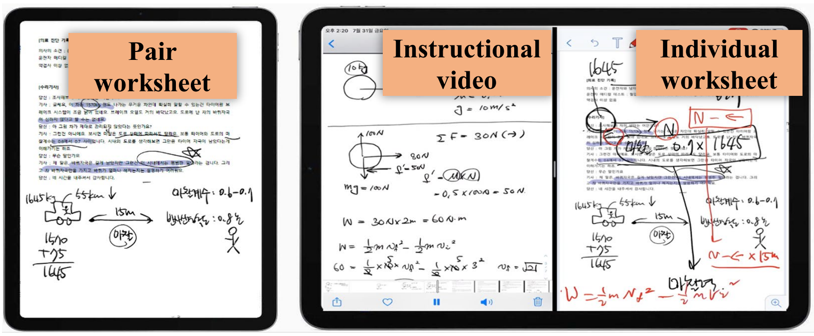
Based on the implications from the first content analysis result, an inductive content analysis was conducted with the same talk-aloud data after defining different analysis units to answer the second and third research questions. The knowledge states around AKG were classified, and the authors categorized several variations of how the students self-evaluated their knowledge during problem-solving. In the process, the authors open-coded the discourse data and identified the characteristics of each state through comparisons between categories.

Material and participants

With the publisher's permission, this study used the problem scenario from Kapur's (2008, pp.419-421) work, which is ill-structured and carefully designed. The problem scenario encompassed investigating a speeding case, targeting the concept of frictional force and work-kinetic energy. The first author translated the problem scenario into Korean with an American English professor who is bilingual in Korean and English. After translating the problem, the validity of the material was confirmed by a high-school physics teacher. Twelve graduate students majoring in Educational Techology were recruited from a graduate school in South Korea (nine females and three males; average age = 25), who received $5 value gift cards as a reward for their participation. The participants were randomly assigned to one of six pairs.

Procedures and data collection

The experiment followed procedures in the conventional PS-I approach, i.e., peer problem-solving followed by instruction. The participants worked with iPad Pro 2s and Apple Pencils during the experiment session to record the dialogue and notes taken during the session. The default 'screen recording mode' was used to collect spoken and written data. For the problem-solving phase, the pairs of students were each given 25 minutes to collaboratively solve the problem scenario with a peer, sharing one iPad and one Apple Pencil (see Figure 1 (a)). After the problem-solving phase, the participants individually watched an instructional video that included a lecture on the target concepts and a solution explanation for the problem scenario. As they worked individually in the instruction phase, one iPad and one Apple Pencil were provided per student. The participants were asked to watch the instructional video on the left-hand side of the screen along with the scribbled version of the problem scenario file on the right-hand side of the screen; they were able to take notes over their previous notes if necessary (see Figure 1 (b)). The spoken data in the collected recordings were subsequently transcribed into script format and used for the dialogue analysis. The written data were used in a supplementary role in the analysis of the spoken data. This study mainly focused on the discourse data generated during the problem-solving phase. Investigating the effects of the PS-I approach (e.g., post-test results…etc.) was beyond our research scope.



(a) (b)

Figure 1. Sara and Josh's pair worksheet (a) and Sara's individual worksheet for the instruction phase (b).

Data Analysis

This study used two qualitative content analyses with the same conversational discourse data: Deductive content analysis to examine the cognitive processes or aspects that the learners experienced during problem-solving, followed by inductive content analysis to categorize the different states of knowledge and define each state through comparisons between categories. As the selection of the analysis units depends on what the analysis aims to discover (i.e., in relation to the research question; Mayring, 2000), the authors selected different analysis units for each content analysis.

Deductive content analysis for problem-solving discourse

The authors adapted two coding schemes used in previous studies on student interactions (Kapur & Kinzer, 2009; Poole & Holmes, 1995) and self-explanation in learning from erroneous examples (Große & Renkl, 2007), integrating them to ensure the integrated coding scheme was sufficient to achieve the current research aim. While the coding scheme from Kapur and Kinzer (2009) reflected the multifaceted nature of student interaction, it lacked separate room for impasse-related and error-related utterances. The coding scheme from Große and Renkl (2007) provided logical and clear distinctions between those utterances. As the current study aims to explore the cognitive processes that learners experience when they solve a given problem, the authors needed to differentiate from other categories such utterances that may show a cognitive trajectory towards a different knowledge state. As a preparation phase for the content analysis, the authors divided the discourse transcript into idea units, which were selected as including words or sentences containing a context for a meaning unit in terms of each category.

The authors then conducted a preliminary coding based on the adapted coding scheme, which included the categories of *Problem Assessment, Orientation, Impasse, Solution Development, Recognition of Error, Identification of Reasons for the Error*, and *Solution Evaluation without Error Detection*. During the preliminary coding process, new categories were found, namely *Guess and Assumption, Prior Knowledge*, and *Motivation*. After closely reading the discourse transcripts, it turned out that the learners often tried to make assumptions based on contextual information about the problem, such as "I think the coefficient of friction has something to do with the weight of the car". This study created a new category for this sort of utterance, *Guess and Assumption*, because the authors believed that making assumptions could be a starting point for an awareness of a knowledge gap. Moreover, *Prior Knowledge* was added to the codes because the learners often retrieved relevant concepts when assessing the problem and generating and evaluating the solution. Aligning new information obtained from assessing the given problem with their prior knowledge can be a sign of learners revisiting their memory (Park et al. 2020) and preparing to generate a solution, which, in many cases, leads to global AKG (Loibl & Rummel, 2014). After learners realized that they needed more knowledge to solve the problem, some of them stated that they wanted to learn the need-to-know knowledge from the following instruction. The authors coded these utterances as *Motivation*. The first and second author then coded every idea unit based on the final coding scheme (see Table1). The inter-rater reliability was good (Cohen's κ = 0.74), and the final code was determined by resolving any discrepancies through discussion.

Table 1: Coding scheme for problem-solving discourse

Codes	Description	Example
Problem assessment	Mentions details of a problem, prioritizes details, makes connections between details, or provides new perspectives in interpreting aspects of a problem.	"Um... For now, I think what counts is... the total weight and time, not the total weight and the speed limit. like we thought."
Orientation	Tries to orient or guide the group's process	"Let's write down and then think about it"
Impasse	Expresses confusion, pauses for a long period, and/or states unexpected difficulty and negative monitoring	"Coefficient of friction... apply the coefficient of friction. Then the way is... (long pause)"
Solution development	Mentions a (sub-)goal, an operator, or a relevant formula, tries anticipative reasoning, and/or suggests ideas, proposals, alternatives, or rebuttals	"Distance 15, velocity 55. Shall we calculate the speed using distance velocity and time (DVT)?"
Guess and assumption	Guesses next solution steps, and/or makes assumptions on concepts and processes to assess a problem and generate and evaluate a solution	"But since high coefficient of friction means a stronger friction, doesn't it mean the brake should work faster? That's how I see it."
Prior knowledge	Activates prior knowledge and/or aligns it with new information	"Suppose the distance is 15 meters, then, um, this is X and it would be best to know the acceleration inclination, mmm F= ma..."
Recognition of error	Mentions that there is an error and/or finds an error in the generated solution	"This is 4.5 again? Maybe not, I don't think this is it, obviously, 559."
Identification of reasons for the error	Gives reasons for the errors	"I think the coefficient of friction we set here should not be 1."
Solution evaluation without error detection	Gives an evaluation of the generated solution (but does not find any potential errors)	"When we say this is 25, what's the reason for dividing it with the weight? ... I mean we divided the total distance... right? I think what we did is right!"

Motivation	States motivation to learn need-to-know knowledge from the following instruction	"I think there was something like square of the weight. 70... no 1675. I hope the video shows this part."

An inductive content analysis for knowledge state categorization during problem-solving

During the course of applying the deductive approach, new categories of the problem-solving discourse emerged in regard to learners' attempts to guess the next solution steps, prior knowledge alignment, and motivational aspects. The authors were able to identify that the utterances of these categories were presented by *some* participants but *not all* participants. Based on this finding, the authors conducted the second content analysis in an inductive manner to explore how the learners' knowledge states varied in the problem-solving phase of PS-I.

A new selection of idea units for the analysis with the same discourse data was made because the aim of the second content analysis was different from that of the first analysis, namely to analyze how learners evaluate their current knowledge and to define the states of AKG. Knowledge states in an individual learner may vary depending on different related concepts. Thus, an idea unit was selected if it included phrases representing a knowledge state around each related concept (e.g., kinetic energy variation, work-energy relation, friction)

After identifying all idea units, the first and second author conducted open coding. During the process, the coders suggested a total of eight categories, namely, a) *Knowledge not Accessed,* b) *Knowledge not Evaluated,* Knowledge Evaluated as c) *Sufficient,* d) *Intuitive,* e) *Naïve,* or f) *Uncertain*, g) *Insufficient and Unspecified Knowledge Gaps*, and h) *Insufficient and Specified Knowledge Gaps*. The coders then assigned idea units to these categories. In the discourse, explicit signs of self-evaluation (e.g., "I think we were wrong here") were rarely presented, although some remarks (e.g., "If I know the formula to use this...") could be indirectly inferred as self-evaluation. The coders used these signs as criteria to determine whether parts of the discourse belonged to self-evaluation. During the course of the preliminary coding, the *Intuitive* category was removed because self-evaluating their own knowledge as intuitive was always involved in parts of either *Sufficient*, *Naïve* or *Uncertain* (e.g., "This reminds me of energy because everything has energy, but I don't know whether we are on the right track. Do you?"), but not vice versa, in the data collected. In a similar vein, the coders agreed to integrate *Naïve* and *Uncertain* into a single code, *Naïve and Uncertain,* because both codes could be used to describe the same knowledge states in the current study. Table 2 shows the final categories identified through the analysis.

Table 2: Categories of different knowledge states around AKG

Categories		**Definitions**
a) Knowledge not accessed		Students do not mention a certain knowledge element.
b) Knowledge not evaluated		Students mention a certain knowledge element (or activate prior knowledge), but no verbal evidence of their self-evaluation of the element is found.
c) Self-evaluated knowledge	c-1) Sufficient	Students mention a certain knowledge element (or activate prior knowledge) and regard the retrieved element as sufficient to solve the problem.
	c-2) Naïve and uncertain	Students mention a certain knowledge element (or activate prior knowledge) and regard the retrieved element as naïve or uncertain to solve the problem.
	c-3) Insufficient and unspecified knowledge gaps	Students mention a certain knowledge element (or activate prior knowledge) and regard the element as insufficient to solve the problem with an expression of impasse. They do not know the exact point that they are missing.
	c-4) Insufficient and specified knowledge gaps	Students mention a certain knowledge element (or activate prior knowledge) and regard the element as insufficient to solve the problem with an expression of impasse. They know the exact point that they are missing.

Findings

The analyses resulted in two main findings. The first finding comprises a quantitative description of the analysis result using the newly developed coding scheme for the participants' talk-aloud data. The second finding presents examples of the different knowledge states around AKG.

Finding 1: Students spend most of their time solving the problem and seldom evaluate their thoughts.

According to the descriptive analysis of the conversational discourse in the problem-solving phase, over 42% of utterances out of 559 idea units in total belonged to problem assessment. All six peer groups devoted at least more than 30% of talk to assessing the problem. Students seldom engaged in meta-cognitive processes such as recognition of error (utterance count=18), identification of reasons for the error (utterance count=7), or other types of solution evaluation (utterance count=9), although they relatively often faced moments of impasse (utterance count=64), made assumptions on concepts or processes (utterance count=71), and retrieved prior knowledge (utterance count=41) when solving the given problem. The utterance frequency rate is illustrated in figure 2.

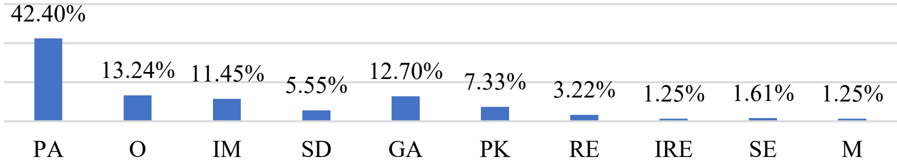


Figure 2. Utterance frequency rate.

Abbreviations: PA. problem assessment; O. orientation; IM. impasse; SD. solution development; GA. guess and assumption; PK. prior knowledge; RE. recognition of error; IRE. identification of reasons for the error; SE. solution evaluation without error detection; M. motivation.

Finding 2: Only a few expressed their experience of knowledge gaps.

The examples for each knowledge state around AKG are presented in table 3. Six categories were found in total, although only two of these were related to AKG, namely c-3 and c-4. Moreover, there were only two cases of c-3 and c-4, while several cases were found for the other categories (the current paper introduces only one example dialogue for each category due to the word limit).

Table 3: Example dialogues of different knowledge states around AKG

Categories	**Example dialogues**
a) Knowledge not accessed	N/A
b) Knowledge not evaluated	Eugine: But since high coefficient of friction means a stronger friction, doesn't it mean the brake should work faster? That's how I see it. Grey: Or in my opinion, because it's heavier, I thought the inertia would be stronger and it might have caused longer time to stop.
c-1) Sufficient	Grey: When we say this is 25, what's the reason for dividing it with the weight? Dividing it with the weight suggests, inversely, we used multiples, by multiplying the time the weight can travel, I mean we divided the total distance... right? I think what we did is right.
c-2) Naïve and uncertain	Jin: Same here. I'm just going by instinct. While going for 2.2 seconds, he braked 15 meters behind, he stopped, so he didn't cra(sh)… he went 15 meters in 2.2 seconds. John: And the force of the 1645kg is 15 meters, then? (Jin: Really?) Yeah, the car went 15m. Because the heavier the weight, the harder the friction. When it's stronger, right? So I… give up? A different method? … (long pause) Jin: This is 4.5 again? Maybe not, I don't think this is it, obviously, 559. John: But if we know the speed, ummm Jin: Shouldn't we look at the car, not the speed?
c-3) Insufficient and unspecified knowledge gaps	Lucy: Does this 3 second have any significance in the problem? Along with this, so many numbers appear in the latter part of the problem, like the km, 0.6 to 0.7, etc.? Do we have to go all mathematical with these numbers? Jane: Mathematically, but since we don't know how they're connected... (long pause) But thinking about it, 3 seconds is a very short time, then can this be an evidence that the driver foresaw this and stopped
c-4) Insufficient and specified knowledge gaps	Kim: Then, like this. This is a huge difference. Kim: But what bothers me is what we missed... Kim: There may be a way to solve the problem using the coefficient of friction on this road. Right? I feel like this was mentioned for a reason. Seo: Ah... it mentions the weather too... Kim: There's no reason to slide since it's a dry road... But because he has history of accident, it's hard to prove his innocence so we have to present a clear evidence. Seo: Coefficient of friction... apply the coefficient of friction. Then the way is... (long pause) Kim: If I know the formula to use this...

Discussion

General discussion

The current study comprehensively investigated the conversational discourse during the problem-solving phase in PS-I to identify the cognitive processes that learners undergo when solving a problem and how they reach, or do not reach, the state of AKG. To achieve this goal, this study conducted two separate qualitative analyses. Through deductive content analysis, the authors discovered that during the long period of problem assessment and solution generation, the learners sometimes faced moments of impasse and rarely found errors or reasons for the errors. It seemed that when challenged by impasse moments, learners often made assumptions about information that did not clearly align with their current knowledge. These phenomena required the addition of new categories to the coding scheme used in the previous study on PS-I (Kapur & Kinzer, 2009). The authors assumed that learners are rarely urged to revisit their memory to repair current naïve knowledge (vanLehn, 1999; Chi, 2000) in such challenging explorative problem-solving activities in PS-I. As modifications of the current partial or erroneous schema follow the identification of knowledge gaps, how learners' knowledge states vary and what makes the AKG state different from others should first be understood to support the PS-I mechanism.

Building on this emergent implication from the first content analysis, this study conducted the second content analysis in an inductive way. Based on the analysis results, this study classified the self-evaluated knowledge states around AKG as shown in Figure 3.

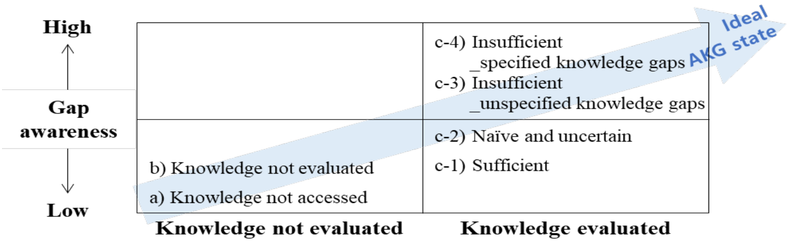


Figure 3. Classification of self-evaluated knowledge states in terms of gap awareness.

Apparently and naturally, students could not activate any relevant prior knowledge when they had no idea about a concept (i.e., a) knowledge not accessed). When a targeted concept was beyond the students' level, they kept generating irrelevant remarks. Also, in many cases, even when they activated related concepts, the students still did not perceive the existence of gaps in their ideas because they did not evaluate their knowledge structure of the concept (i.e., b) knowledge not evaluated). Regardless of the possibility that they might have perceived a gap but this was not expressed in the conversation, the context indicated that the students did not reach the state of AKG. It is hard to tell whether the out-of-focus utterances were meaningless for learning, but considering the preparatory effect of the PS-I approach, there needs to be a fence that guides students and prevents them from straying far beyond the track. Even when the students evaluated their thoughts, there were various categories of a perceived knowledge state. Some felt confident about their knowledge and consequently did not experience a gap. Some felt uncertain about their ideas or regarded their ideas as naïve, but they did not notice potential knowledge gaps or show a willingness to dwell on the uncertainties. When the students noticed that their knowledge was insufficient to solve the problem, some specifically located the lacking point, while others just felt that something was missing.

From a comprehensive view, the authors would like to aggregate their findings into the concept of AKG, which has been suggested as a key mechanism for PS-I. While it remains arguable which state in the category can be considered AKG, this study carefully suggests that the ideal AKG state, which previous PS-I research indicated as 'knowing what you don't know', is the last state of knowledge evaluation, namely insufficient and specified knowledge gaps. This is when a student clearly notices the limit of their knowledge and is aware of a learning concept that is needed to solve the problem.

Again, the authors do not conclude that the other states in the category positively (or negatively) affect the efficacy of PS-I. The hypothesis on whether these other states are cases for unproductive failure is contentious and should be closely investigated. In truth, the findings of this study indicate that the students barely reached the insufficient and specified knowledge gaps state, while most of their thoughts remained in other pre-AKG-regarded categories, such as sufficient, naïve and uncertain, and insufficient-unspecified knowledge gaps. This finding is not surprising, given that the learners spent most of their problem-solving time assessing the given problem. Even though some learners agonized over the impasse and tried guessing what they needed to know – which the authors considered as starting points of becoming aware of knowledge gaps – most of them did not go beyond this to evaluate their knowledge in those moments or identify errors and reasons for the errors.

This issue can inform the next research question, namely whether each state in the categories leads to productive PS-I. Would students need to be precisely aware of their gaps in order to integrate knowledge and be prepared for the instruction? The authors assume that specific AKG, which learners can experience after agonizing over moments of impasse or explicit or implicit errors (Loibl & Rummel, 2014), would have a better preparatory effect on instruction and bring more beneficial outcomes. The abovementioned study addressed the use of comparing and contrasting activities to specify AKG, however, there still remains room in finding supporting strategies for reaching the AKG state during the problem-solving phase. In this regard, this study suggests classifications, descriptions, and examples of different knowledge states around AKG. This categorization can be utilized as guidance in establishing the directions and boundaries of scaffolding strategies for AKG in future research. Thus, the authors propose follow-up studies that firstly, expand the research scope from the problem-solving phase to the instruction phase to see how different knowledge states around AKG (which is perceived during the problem-solving phase) affect learners' behaviors during the instruction and learning outcomes, and secondly, explore the effects of instructional interventions promoting AKG.

References

Chi, M. T. H. (2000). Self-explaining expository texts: the dual processes of generating inferences and repairing mental models. In R. Glaser (Ed.), *Advances in Instructional Psychology* (pp. 161-238). Hillsdale, NJ: Lawrence Erlbaum Associates.

Darabi, A., Arrington, T. L., & Sayilir, E. (2018). Learning from failure: A meta-analysis of the empirical studies. *Educational Technology Research and Development, 66*, 173-189.

Elo, S., & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of advanced nursing, 62*(1), 107-115.

Glogger, I., Fleischer, C., Grüny, L., Kappich, J., & Renkl, A. (2015). Inventing a solution and studying a worked solution prepare differently for learning from direct instruction. *Learning and Instruction, 39*, 72-87.

Glogger, I., Kappich, J., Schwonke, R., Holzäpfel, L., Nückles, M., & Renkl, A. (2013). Inventing prepares learning motivationally, but a worked-out solution enhances learning outcomes. In M. Knauff, M. Pauen, N. Sebanz, & I. Wachsmuth (Eds.), *Proceedings of the 35th annual Conference of the Cognitive Science Society* (pp. 2416-2421). Austin, TX: Cognitive Science Society.

Große, C. S., & Renkl, A. (2007). Finding and fixing errors in worked examples: Can this foster learning outcomes?. *Learning and instruction, 17*(6), 612-634.

Hmelo-Silver, C. E., Kapur, M., & Hamstra, M. (2018). Learning through problem solving. International handbook of the learning sciences, 210-220.

Kapur, M. (2008). Productive failure. *Cognition and instruction, 26*(3), 379-424.

Kapur, M. (2016). Examining productive failure, productive success, unproductive failure, and unproductive success in learning. *Educational Psychologist, 51*(2), 289-299V

Kapur, M., & Kinzer, C. K. (2009). Productive failure in CSCL groups. *International Journal of Computer-Supported Collaborative Learning, 4*(1), 21-46.

Lee, J., Joo, H., & Kim, D. (2018). The effects of experiences of productive failure with different types of metacognitive prompts on learners' representation and solution method, cognitive load, and knowledge gap, *Journal of Learner-Centered Curriculum and Instruction, 18*(8), 845-865.

Likourezos, V., & Kalyuga, S. (2017). Instruction-first and problem-solving-first approaches: alternative pathways to learning complex tasks. *Instructional Science, 45*(2), 195-219.

Loibl, K., Roll, I., & Rummel, N. (2017). Towards a theory of when and how problem solving followed by instruction supports learning. *Educational Psychology Review, 29*(4), 693-715.

Loibl, K., & Rummel, N. (2014). Knowing what you don't know makes failure productive. *Learning and Instruction, 34*, 74-85.

Loibl, K., Tillema, M., Rummel, N., & van Gog, T. (2020). The effect of contrasting cases during problem solving prior to and after instruction. *Instructional Science*, 1-22.

Mayring, P. (2004). Qualitative content analysis. *A companion to qualitative research, 1*(2), 159-176.

Newman, P. M., & DeCaro, M. S. (2019). Learning by exploring: How much guidance is optimal?. *Learning and Instruction, 62*, 49-63.

Park, J., Park, C., Jung, H., & Kim, D. (2020). Promoting case indexing in case library learning: Effects of indexing prompts on self-explanation and problem solving. *Journal of Computer Assisted Learning, 36*(5), 656-671.

Schalk, L., Schumacher, R., Barth, A., & Stern, E. (2018). When problem-solving followed by instruction is superior to the traditional tell-and-practice sequence. *Journal of educational psychology*, *110*(4), 596.

VanLehn, K. (1999). Rule learning events in the acquisition of a complex skill: an evaluation of cascade. *Journal of the Learning Sciences, 8*(1), 71-125.

Design Knowledge and Learning Pathway of a Grassroots Innovator

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Abstract: Many poverty alleviation efforts employ a charity-based approach that re-entrenches inequitable power relations and results in solutions that are inappropriate for the local context. Recently there have been calls to leverage the design knowledge of "grassroots innovators" for sustainable development. I draw upon a five-week ethnographic study to describe the design knowledge and learning pathway of an exemplary grassroots innovator and examine how social norms and power dynamics have shaped their learning opportunities. The findings counter deficit narratives about design and engineering expertise in marginalized groups and contribute to a better understanding of how to support the development of grassroots innovators.

Keywords: indigenous knowledge, learning pathway, engineering, design, social justice

Introduction

In the summer of 2015, I travelled to a rural village in the Philippines as part of an engineering service-learning project. The interdisciplinary project team included two faculty advisors and about half a dozen students from a large public university in the U.S. We had been approached by a Philippines-based non-governmental organization (NGO) that operates across the country to build homes for the homeless and incubate social enterprises to provide jobs for the jobless. The village—built by the NGO—lacked reliable and affordable electricity, forcing many residents to use candles and kerosene as light sources, which is damaging to both human health and the environment and can result in accidental fires. To address this issue, our team had designed a solar street lamp to light up outdoor areas. The NGO hired the village handyman and electrician, Rogelio, to help us construct and install the lamp. He cut and welded the metallic structure, laid the concrete foundation, and soldered the electrical components. At one point in the process, our team spent hours trying to pass electrical wires through the inside of the street lamp pole. Rogelio noticed our struggle and came over with an improvised tool—a piece of stiff wire with a hook on one end—and proceeded to thread the wires through the pole in a matter of minutes.

We left the Philippines hoping that the villagers would replicate our design and install street lamps throughout their village. However, several months later we discovered that the locals were not replicating the street lamp as we had intended because it was too large, complex, and expensive. The community members did not even find the street lamp very useful because it only lit a small portion of their village. Eventually, after eleven months of operation, the lamp malfunctioned due to water damage from the harsh weather conditions, which include frequent typhoons, but the community members did not possess the proper resources to repair it.

Unfortunately, this kind of story is all too common. Many socioeconomic development and poverty alleviation efforts employ a similar type of charity-based approach involving a top-down transfer of resources from donors to beneficiaries without meaningful community involvement, yet this re-entrenches inequitable power relations and results in solutions that are inappropriate for the local context (Nieusma & Riley, 2010). A quote by Paulo Freire, Brazilian social justice educator, frames the issue: "To alienate humans from their own decision-making is to change them into objects," (Freire, 1968). Friere argued that people cannot be liberated from oppression; they must liberate themselves. A more bottom-up approach, known as participatory design, involves expert designers and members of impacted communities working together to create technology-based solutions (Schuler & Namioka, 1993). Participatory design approaches recognize the knowledge held by community members about their local context. However, models of collaboration in participatory design often take a deficit view of community members in relation to design-related knowledge, assuming that there is a need to build their design capacity at the start of the process (e.g., Drain & Sanders, 2019).

Recently, there have been calls to recognize the structural causes of inequities and leverage existing community-based design knowledge, practices, and traditions in addressing them (Costanza-Chock, 2020; Reynante et al., 2017). Individuals from marginalized groups who generate novel, improvised, technology-based solutions to local problems have been referred to as "grassroots innovators" (Campbell, 2017). The practices of grassroots innovators are useful not only for solving local problems, but they might also serve as a way to promote sustainable development on a larger scale if they were supported more broadly (Seyfang & Smith, 2007) and used as a source of inspiration for more sustainable Western engineering and design practices (Hess & Strobel, 2013).

After the street lamp episode, our project team transformed our approach to build our project around Rogelio, who we recognized as a grassroots innovator. Rogelio collaborated with the university students to design and prototype handheld solar lanterns, which are substantially more desirable, affordable, and replicable than the street lamp (see Figure 1). The design of the lanterns leveraged Rogelio's knowledge of mechanical and electrical fabrication and his experience working with locally available and repurposed materials. Rogelio has since taught several of his fellow villagers how to manufacture and repair the lanterns, and they are in use throughout the community.

Figure 1. Handheld solar lantern prototype.

What experiences contributed to Rogelio becoming such an exceptional grassroots innovator? Other members of his village possess similar skills, but not to the same extent, and notably none of them are women. Answering this question may contribute to a better understanding of how to recognize and support the development of grassroots innovators more broadly. I trace Rogelio's long-term learning pathway, describe how his experiences supported the development of particular kinds of knowledge and practices relevant for grassroots innovation, and examine how cultural factors and power dynamics have shaped his learning opportunities.

Conceptual framework and methodology

To explore Rogelio's learning across space and time, I draw upon the Learning Pathways framework (Nasir et al., 2020), which conceptualizes learning as occurring along culturally organized "learning pathways". These pathways are longer-term trajectories of participation in activities that take place across formal and informal learning spaces, are facilitated or constrained by social systems and institutions that differentially position individuals' access to resources and experiences, and are shaped by issues of identity. This framework provides a way to illuminate the structural causes of some of the inequities experienced by grassroots innovators as well as the community-based design knowledge that can be leveraged to address these inequities.

I constructed Rogelio's learning pathway by describing and visualizing key learning activities over time, settings where they take place, the people and resources involved, and salient social identities. This method centers a "wide-angle view" of learning, highlighting the dynamics of learning over weeks, months, and years (Barron et al., 2013). Learning pathways can help map and describe the origins, evolution, and development of engagement in activities over time and how these patterns of sustained activity result in more stable interests and areas of expertise (Barron, 2010).

I collected data during five weeks of ethnographic fieldwork at the rural village in the Philippines in June and July of 2019. Ethnography provides rich, contextual information about the shared cultural patterns of members in a group and is thus appropriate for exploratory research into the design practices and learning pathways of individuals (Creswell, 2013). Rogelio (37 years old at time of observation) is our focal community member since he is an exemplary grassroots innovator. Over the five week period I generated 23 days of field notes, 190 photos, and 159 minutes of video. I also conducted a 45-minute semi-structured interview with Rogelio at the end of the ethnography. During data collection, I focused attention on Rogelio's design skills related to grassroots innovation and his explanations of how he developed those skills. I wrote analytic memos to support interpretation and sensemaking of the data (Emerson et al., 2011). In these memos, I attempted to construct a narrative chronology of Rogelio's relevant experiences, and I subsequently checked these interpretations with Rogelio.

To analyze the data, I used an inductive qualitative analysis approach (Boyatzis, 1998), which consisted of open coding the observation field notes, interview transcript, and analytic memos. I coded the texts for information related to Rogelio's design knowledge and learning pathway. The field notes, interview transcript, and memos were coded simultaneously as a way to triangulate the data and therefore enhance validity (Creswell, 2013). I then conducted thematic analysis by reviewing the coded excerpts to identify patterns (Saldaña, 2015).

A primary limitation of this work is that I am not a member of the community I studied. I have lived my entire life in the U.S., and although I do have Filipino heritage, I did not experience Filipino culture in a deep, meaningful way growing up. I also have an academic background in engineering and education. These identities and experiences position me as a privileged outsider in relation to the community members, and in turn shape my interpretations of results. I attempted to mitigate this issue by foregrounding Rogelio's own voice and consulting with him about the findings to incorporate his input and feedback.

Rogelio's learning pathway

Rogelio was born in 1983 in the Bicol region of the Philippines. He grew up in poverty, unsurprising since the Philippines is a developing country: ~44% of the population lived below the poverty line at the time of Rogelio's birth (Asian Development Bank, 2009). Due to his family's financial constraints, Rogelio often repurposed readily available materials into toys throughout his childhood. This practice of 'bricolage' (Levi-Strauss, 1966) is the "making use of bricoles—the odds and ends, the bits left over, the set of unrelated or oddly related objects... The bricoleur always has a view to what is available, what is at hand" (Harper, 1987, p. 74).

These early habits led Rogelio to become extremely resourceful in his later design work, resulting in highly affordable solutions. Even many of his tools are improvised, including a ladder made from pipes and rebar and a soldering iron holder made from a wood block and pipes (see Figure 2). Other materials I saw him co-opt during my fieldwork included plastic cups, compact discs (CDs), PVC plates and pipes, and a mobile phone USB charger. Upon being asked about this practice during the interview, Rogelio said that, "Some person they throw the garbage, but there's some things we can use. I try to keep it. I store a lot of reuse materials."

Figure 2. Some of Rogelio's improvised tools: (a) ladder; and (b) soldering iron holder.

Readily available materials and tools shape Rogelio's imaginable design space. During one prototyping session, Rogelio looked around at the eclectic assortment of materials lying beside him—including cannibalized components from other prototypes—and held them near his new prototype to visually imagine how they might be repurposed to help him achieve his intended design. Bricolage seems to be a widespread cultural practice throughout the Philippines, as I noticed many improvised structures and vehicles (our language translator referred to this as "Pilipino Ingenuity").

Around the age of 12, Rogelio started drawing cartoons. His father was an architect, and Rogelio thinks that perhaps watching his father draw blueprints imbued him with some innate talent for sketching. Sketching is a key form of communication in design activities (Sanders et al., 2010). After high school, at 18 years old, Rogelio got his first job working as a construction laborer building houses. His duties included mixing cement, laying bricks, bending steel, and installing plumbing. At the age of 20, he spent two years working in a factory assembling consumer products such as bicycles, ovens, and rice cookers.

At 22 years old, Rogelio started along the path to becoming an electrician. He studied electronics and building wiring for 4 months at a vocational school and took a government test administered by the Technical Education and Skills Development Authority (TESDA) to obtain a certification required for working abroad.

Simultaneously, he apprenticed with his brother, an electrician, for one year. Rogelio hated the work at first because it was physically demanding, but eventually he found that it came more easily: “It’s simple when you love your work,” he said. After completing the apprenticeship, Rogelio started working as an electrician. Unfortunately, a few years later there was a violent typhoon that flooded his house and destroyed his high school diploma and TESDA certificates, which have since prevented him from obtaining work abroad.

During his time studying and working as an electrician, Rogelio had been living in a slum. At the age of 28, he got the opportunity to move to a rural village built by a Philippine-based poverty-reduction NGO (the same organization that later partnered with my team on the solar lamps and lanterns). Rogelio’s father had served as the foreman overseeing construction of the village. Rogelio built a bamboo structure next to his house to serve as a garden. The NGO hired Rogelio to be the electrician and handyman for the village and other nearby facilities owned by the NGO, which ran a farm adjacent to the village and supported various social enterprises, many based on products from the farm. The NGO also hired Rogelio’s sister to work as a housekeeper for the residences where volunteers and visitors to the farm stayed. Over the next few years, Rogelio says he became “famous” in the region for his electrician and handyman skills and was often sought out by surrounding communities to fix their electrical and mechanical problems. Rogelio’s identity as an electrician is very salient for him.

Rogelio’s work as a construction laborer, electrician, and handyman furthered his bricolage skills and fostered the development of craft knowledge, including soldering, welding, and manipulating various materials (e.g., metal, plastic, bamboo). Craft knowledge is kinesthetic and intuitive, entailing a deep understanding of the ‘ways’ of many materials—how they respond to attempts to alter their shape and pliability—acquired through tactile, empirical perception (Crawford, 2009; Harper, 1987). One episode revealing Rogelio’s craft knowledge was when he created an improvised flange on a straight PVC pipe’s end, which he learned while apprenticing with his brother (see Figure 3).

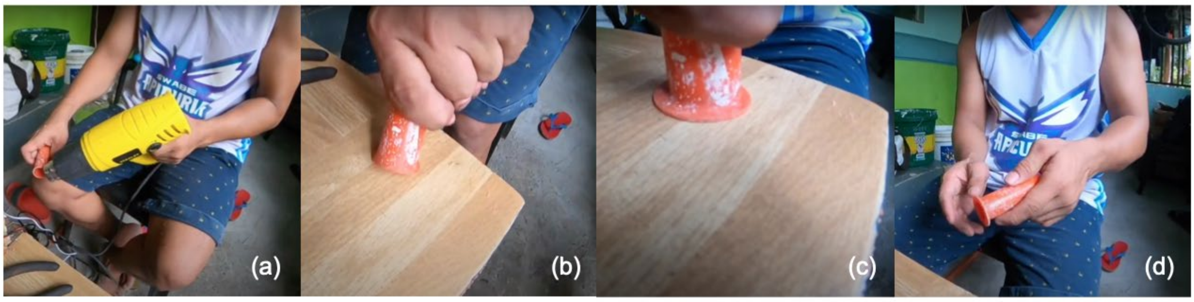

Figure 3. Rogelio’s process of creating an improvised PVC flange: (a) heat one end of a PVC pipe until it becomes malleable; (b) simultaneously press and twist the heated end of the pipe on a flat surface; (c) hold the deformed pipe in place until it cools and hardens; (d) finished product.

Rogelio’s craft knowledge expertise, with its basis in material reality, seems to have led him to develop a preference for creating physical artifacts to support his design thinking and communication. “It’s hard to work without materials at hand,” he said during the interview. At one prototyping session, Rogelio laid components and materials on the table in front of him and held them up next to each other in various combinations to visualize how they might fit together, but soon remarked, “Maybe we make a sample because it’s hard to think which is the best.” During one collaborative design session, a university student co-designer was attempting to verbally explain her design idea to Rogelio, but he was struggling to comprehend and instead stated, “Maybe we need a sample.” Making tangible things is one of the primary forms of communication in design activities (Sanders et al., 2010).

Rogelio also embraces trial-and-error experimentation, learning through iterative testing to progressively refine solutions. Despite his deep craft knowledge, Rogelio occasionally made mistakes, as when he cut off the bottom of a cup of noodles and attempted to drill a hole in it, but the plastic cracked severely. He immediately grabbed another plastic cup of noodles, this time drilling the hole before cutting off the bottom, succeeding. He also made multiple lantern prototypes to improve the design (see Figure 4), saying: “Let’s think about how to make it better. It’s experiment time.” The success of trial-and-error testing in many fields, particularly engineering and design, indicates its value as a general epistemic strategy (Pirtle, 2010).

Figure 4. Various solar lantern prototypes.

When I first visited Rogelio's village in the summer of 2015, he was 33 years old. The mission of the service-learning program is to partner with nonprofit organizations to improve the well-being of underserved communities and provide cross-cultural design experiences for students. It was through a partnership with the NGO that built Rogelio's village that he had the opportunity to join our project. We used Rogelio's existing craft knowledge and bricolage practices as bridges to new content—specifically, interpreting and drawing circuit diagrams for solar energy systems. These are forms of scientific knowledge—mental constructions that are more intellectually tractable than material reality, and in particular amenable to mathematical representation (Crawford, 2009). Rogelio said that it is "very good to know how to do solar," which he learned from the university team. He integrated this new scientific knowledge with his existing craft knowledge and bricolage skills to create a solar lantern made from a repurposed plastic jar, PVC pipe, a solar panel, LEDs, and a battery (see Figure 1).

A couple years after we began working with Rogelio, he tried to start a business making and selling "golden" duck eggs (i.e., eggs soaked in turmeric). The NGO that had built Rogelio's village had provided resources such as funding and physical space to other aspiring entrepreneurs, but they were primarily foreigners or formally educated, wealthy Filipinos. When Rogelio sought assistance from the NGO founder/director (who is also Filipino), his request was denied. Rogelio says he became angry and "got into arguments" with the NGO staff. Simultaneously, our university team decided it would be useful to try and help the local villagers start a business making and selling the handheld solar lanterns to spread light to other communities and provide an additional income source. We identified Rogelio as the most likely candidate for the business leader, but when we approached the NGO director, we discovered he lacked faith that a poor Filipino villager could be a successful entrepreneur. Thus, Rogelio was twice denied the opportunity to learn entrepreneurship skills, and possibly achieve greater financial security for his family. After revealing how his aspirations for entrepreneurship were crushed, Rogelio told me that he hopes to study engineering one day because he dreams about fulfilling a promise to his wife about being able to give her everything she desires.

Key learning activities, settings, resources, people, and social identities are mapped along Rogelio's learning pathway using a timeline representation in Figure 5. This visualization helps highlight patterns of learning activities. I recognize that all of Rogelio's various social identities are intersectional and embedded throughout, but I foreground certain identities that seem particularly germane for a given learning activity.

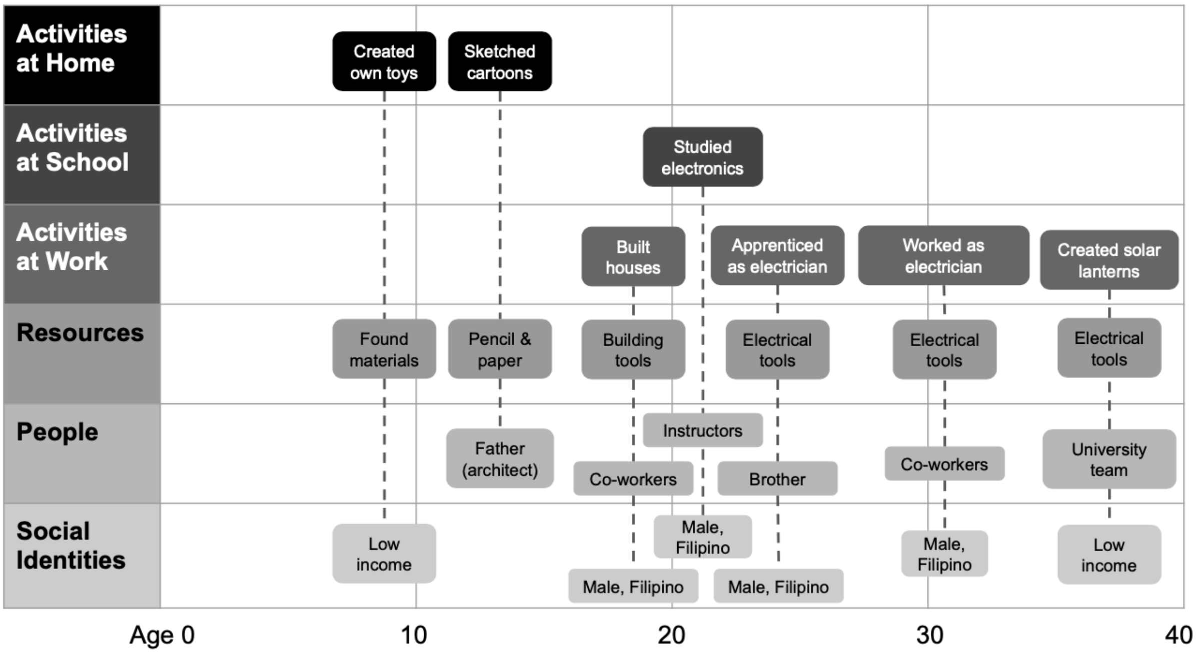

Figure 5. Visualization of Rogelio's learning pathway.

Discussion

This work contributes to growing evidence countering pervasive notions that individuals from low-resource and marginalized communities lack design knowledge (e.g., Blikstein, 2008; Campbell, 2017; Cavallo, 2000). Rogelio learned how to become a grassroots innovator in several ways. He developed much of his craft knowledge by constructing physical artifacts. According to the theory of Constructionism, learning happens particularly well through the process of actively making tangible objects in the real world (Papert, 1980). Apprenticeship also played an important role, as Rogelio said he learned many "tricks of the trade" (e.g., making the improvised PVC flange) by watching and imitating his brother and other co-workers. Learning is often facilitated in this way through legitimate peripheral participation in a community of practice (Lave & Wenger, 1991). Rogelio learned his scientific knowledge through collaboration with the university service-learning team, which supports claims that mutual learning occurs during participatory design activities (Schuler & Namioka, 1993). Formal education seems to have played a minor role, as Rogelio pursued electronics vocational training for only four months and never mentioned other formal educational experiences.

Various institutions and social systems structured access to opportunities and positioned Rogelio along his learning pathway. For example, socio-economic class played an important role. Rogelio has lived in poverty his entire life, and the associated financial and material constraints forced him to create his own toys as a child and his own tools as an adult, thus fostering his bricolage skills. As Plato taught us in the 'Republic', 'our need will be the real creator'. People in socio-economically developing contexts have always been driven to improvise and innovate due to inequality, poverty, and unmet needs (Campbell, 2017). Rogelio's nationality and gender also played a key role in his learning pathway. The development of his craft knowledge was supported by access to men who served as role models and sources of learning: his father, an architect and construction foreman; his brother, an electrician; and various other male co-workers. Access to these people and associated learning experiences positioned Rogelio as capable, and he began to develop an identity as a grassroots innovator. This positioning was enabled by social norms in the Philippines, since jobs like construction worker and electrician are considered acceptable for men, but not women (Asian Development Bank, 2013). If Rogelio were a woman, he may have instead become a housekeeper like his sister. Furthermore, the intersectionality of Rogelio's ethnicity and class enabled him to gain scientific knowledge through his partnership with the university team, since we were seeking to work with low-income communities, but it hindered his opportunities to gain entrepreneurship skills. The director of the partner NGO doubts that poor Filipinos can be successful entrepreneurs. Many NGOs ostensibly support poverty alleviation, but they can also obstruct by operating in a way counter to community self-determination (Del Gaudio et al., 2016). There is often a power differential between poverty-alleviation organizations and their beneficiaries, and this imbalance is exacerbated through charity-based approaches (Nieusma & Riley, 2010). As the results of this study demonstrate, other individuals or organizations have the potential to reduce such power asymmetries by leveraging their own privilege to serve as allies by positioning marginalized individuals as knowledgeable and capable designers.

For those seeking to identify grassroots innovators, it is important to recognize that all members of marginalized groups have useful knowledge based on cultural practices (Moll et al., 1992). For example, bricolage seems to be a widespread cultural practice throughout the Philippines. One way to support grassroots innovators is to create Constructionist learning environments that center their indigenous skills and resources to support learning about and through technology. Our team leveraged Rogelio's existing craft knowledge and bricolage practices to engage him in creating solar energy systems. Other researchers have successfully used this approach in other developing countries such as Thailand (Cavallo, 2000) and Brazil (Blikstein, 2008). However, to avoid re-entrenching power asymmetries between researchers and members of non-dominant communities, it is important to take a participatory approach by involving grassroots innovators as co-designers of learning experiences (Bang & Vossoughi, 2016) and of new technologies and infrastructures that support knowledge production (Gutierrez et al., 2020).

Another way to support grassroots innovators is to mirror their advances by legitimizing their knowledge as valuable. Historically, making and tinkering were core components of engineering, but in the second half of the 20th century there was a push towards mathematization and scientization (Blikstein, 2013). Nowadays, engineers are not expected to do manual labor, only to define the details for an artifact to be made by someone else (Pawley, 2012). The primacy of math and science within contemporary conceptions of engineering serves to exclude non-Western ways of knowing (Hess & Strobel, 2013) and can alienate learners who hold more embodied and experimental funds of knowledge (Smith & Lucena, 2016). Rogelio does not consider himself to be an engineer, yet even if he did, would the engineering field—or society at large—allow him to claim this identity? Some scholars have argued for valuing a plurality of epistemologies in science (Medin & Bang, 2014) and computer programming (Turkle & Papert, 1990), and the same is needed in engineering. In particular, bricolage is posed as an equal-status alternative to the abstract analytical methodology of Western science (Levi-Strauss, 1966; Turkle & Papert, 1990). Broadening the definition of *what* counts as engineering and *who* counts as an engineer would imbue grassroots innovators with much needed cultural capital and allow them to develop a sense of engineering agency while affirmatively foregrounding historically marginalized ways of knowing and doing that may be vital in solving the pressing problems of sustainable development.

References

Asian Development Bank. (2009). *Poverty in the Philippines: Causes, constraints, and opportunities.* Asian Development Bank.

Asian Development Bank. (2013). *Gender equality in the labor market in the Philippines*. Asian Development Bank.

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction, 34*(3), 173-193.

Barron, B. (2010). Conceptualizing and tracing learning pathways over time and setting. *National Society for the Study of Education, 109*(1), 113-127.

Barron, B., Wise, S., & Martin, C. (2013). Creating within and across life spaces: The role of a computer clubhouse in a child's learning ecology. In B. Bevan, P. Bell, R. Stevens, & A. Razfar (Eds.), *LOST opportunities: Explorations of educational purpose* (vol. 23). Springer.

Blikstein, P. (2008). Travels in Troy with Freire: Technology as an agent for emancipation. In P. Noguera & C. Torres (Eds.), *Social justice education for teachers: Paulo Freire and the possible dream* (pp. 205-244). Sense.

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. In J. Walter-Herrmann & C. Buching (Eds.), *FabLabs: Of machines, makers and inventors.* Transcript.

Boyatzis, R. (1998). *Transforming qualitative information: Thematic analysis and code development.* SAGE.

Campbell, A. (2017). Lay designers: Grassroots innovation for appropriate change. *Design Issues, 33*(1), 30-47.

Cavallo, D. (2000). Emergent design and learning environments: Building on indigenous knowledge. *IBM Systems Journal, 39*(3&4), 768-781.

Costanza-Chock, S. (2020). *Design justice: Community-led practices to build the worlds we need.* The MIT Press.

Crawford, M. (2009). *Shop class as soulcraft.* Penguin.

Creswell, J. (2013). *Qualitative inquiry and research design: Choosing among five approaches.* SAGE.

Del Gaudio, C., Franzato, C., & de Oliveira, A. (2016). Sharing design agency with local partners in participatory design. *International Journal of Design, 10*(1), 53-64.

Drain, A., & Sanders, E. (2019). A collaboration system model for planning and evaluating participatory design projects. *International Journal of Design, 13*(3), 39-52.

Emerson, R., Fretz, R., & Shaw, L. (2011). *Writing ethnographic fieldnotes.* University of Chicago Press.

Freire, P. (1968). *Pedagogy of the oppressed.* Seabury Press.

Gutierrez, K., Jurow, A., & Vakil, S. (2020). Social design-based experiments: A utopian methodology for understanding new possibilities for learning. In N. Nasir, C. Lee, & R. Pea (Eds.), *Handbook of the cultural foundations of learning* (pp. 330-347). Routledge.

Harper, D. (1987). *Working knowledge: Skill and community in a small shop*. The University of Chicago Press.

Hess, J., & Strobel, J. (2013). Indigenous ways of doing: Synthesizing scholarly literature on ethno-engineering. *International Journal of Engineering, Social Justice, and Peace, 2*(2), 55-80.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge University Press.

Levi-Strauss, C. (1966). *The savage mind.* The University of Chicago Press.

Medin, D., & Bang, M. (2014). *Who's asking? Native science, Western science, and science education*. The MIT Press.

Moll, L., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into Practice, 31*(2), 132-141.

Nasir, N., McKinney de Royston, M., Barron, B., Bell, P., Pea, R., Stevens, R., & Goldman, S. (2020). Learning pathways: How learning is culturally organized. In N. Nasir, C. Lee, & R. Pea (Eds.), *Handbook of the cultural foundations of learning* (pp. 195-211). Routledge.

Nieusma, D., & Riley, D. (2010). Designs on development: Engineering, globalization, and social justice. *Engineering Studies, 2*(1), 29-59.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* Basic Books.

Pawley, A. (2012). What counts as "engineering": Toward a redefinition. In C. Baillie, A. Pawley, & D. Riley (Eds.), *Engineering and social justice: In the university and beyond* (pp. 59-85). Purdue University Press.

Pirtle, Z. (2010). How the models of engineering tell the truth. In I. van de Poel & D. Goldberg (Eds.), *Philosophy and engineering*. Springer.

Reynante, B., Bratton, M., & Hein, L. (2017). From first- to third-order social change in development engineering: A case study. *Proceedings of the Global Humanitarian Technology Conference*. IEEE.

Saldaña, J. (2015). *The coding manual for qualitative researchers.* SAGE.

Sanders, E., Brandt, E., & Binder, T. (2010). A framework for organizing the tools and techniques of participatory design. *Proceedings of the 11th Biennial Participatory Design Conference*. ACM.

Schuler, D., & Namioka, A. (Eds.). (1993). *Participatory design: Principles and practices*. Erlbaum Associates Inc.

Seyfang, G., & Smith, A. (2007). Grassroots innovations for sustainable development: Towards a new research and policy agenda. *Environmental Politics, 16*(4), 584-603.

Smith, J., & Lucena, J. (2016). Invisible innovators: How low-income, first-generation students use their funds of knowledge to belong in engineering. *Engineering Studies, 8*(1), 1-26.

Turkle, S., & Papert, S. (1990). Epistemological pluralism: Styles and voices within the computer culture. *Signs, 16*(1), 128-157.

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Cross-Sectional Study of Students' Molecular Explanations of Inheritance Patterns

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Abstract: Genetics is an important topic in the biology curriculum of many countries. Learning genetics is difficult because it involves the need to reason about complex ideas and to link between mechanisms that occur at different levels of organization. Previous research in genetics education has studied either students' understanding of inheritance patterns or their understandings of molecular genetics; very few studies have examined students' understanding of the connection between these ideas. To address this gap, we conducted a cross-sectional interview study with students from middle school to high school, as well as undergraduate and graduate students, after they had experienced "status-quo" instruction in genetics. We analyzed student responses and described the molecular mechanistic explanations students used to explain inheritance patterns. Our findings allowed us to propose a progression describing the gradual use of genetics ideas. We discuss the implications of the tentative progression for instruction aimed at supporting reasoning in genetics.

Introduction

Discoveries originating from genetics research are increasingly becoming part of our daily lives. These include the discovery of gene editing, the availability of genetic testing (e.g., 23andMe), GMO-based products in grocery stores, increased prenatal testing, and the use of novel therapies for cancer treatment (Boerwinkel, Yarden & Waarlo, 2017; Gericke & Smith, 2014). For instance, the company 23andMe provides genetic testing to the public without consultation with a genetic counselor to help the consumer interpret the results of the tests (23andMe, 2020). This may be problematic for individuals who may not have a full grasp of genetics or have difficulties understanding the probability of developing a genetic disorder. These interpretations of genetic screens may cause anxiety in the consumer or possibly influence important medical decisions, like deciding whether to have breast cancer screenings or prenatal testing (Bellcross, Page, & Meaney-Delman, 2012; Hawkins & Ho, 2012). Additionally, the discovery of CRISPR by Emmanuelle Charpentier and Jennifer Doudna, and their recent winning of the Nobel Prize, has led to important ethical discussions about the role these discoveries have in society and the possibility of genetically modifying human embryos to prevent inherited diseases (Weisbverg, Badagio & Chatterjee, 2017).

Yet, high school graduates and college students often have difficulties comprehending these scientific advances, which can make it difficult to engage with the civic, personal and ethical issues they may encounter stemming from genetics advances (Stern & Kampurorakis, 2017). Stewart, Cartier and Passmore (2005) proposed that genetics literacy consists of understanding three models of genetics. These models include: (a) the inheritance model, which explains patterns of inheritance (e.g. recessive, dominant, sex-linked) and the understanding of how alleles (gene variants) are transmitted across generations; (b) the meiotic model, which involves the physical transfer of genes from one generation to the next through sex cells; and (c) the molecular model, which includes the cellular and molecular mechanisms by which genes bring about traits. This model involves the understanding that genes code for proteins and that changes (mutations) in the recipe (DNA) may lead to changes in the structure and function of proteins. Moreover, genetics literacy involves the linkages among these models along with understanding the role of the environment (Duncan, Rogat & Yarden, 2009; Stewart et al., 2005).

To help students become literate in genetics, it is important to facilitate student understanding of the connection between molecular and the inheritance models as making connections can help students understand the underlying molecular mechanisms involved in the expression of traits (Haskel-Ittah & Yarden, 2019; Marbach-Ad & Stavy 2000). For example, in muscular dystrophy there are two main types of mutations in the dystrophin protein a complete loss-of- function of the dystrophin protein or the production of a misshapen protein that is still partially functional. Duchenne muscular dystrophy (DMD) is the most common type of this disorder and consists of a loss-of-function mutation in the dystrophin gene (Falzarano et al., 2015). The second most common type for this disorder is Becker muscular dystrophy. This type of muscular dystrophy has a milder effect than Duchenne because in Becker's muscular dystrophy the dystrophin protein has structural problems that cause it to have an altered form (Falzarano et al., 2015). However, the protein can partially function to allow for the formation of muscle cells. These disorders may originate through mutations in early development or be inherited.

Regardless of the type of inheritance the problem with the muscle cells are caused by mutations in the genes that code for proteins involved in making muscle cells. Understanding how it is possible that a disorder like muscular dystrophy can have different forms, and origins involves understanding the link between classical and molecular genetics. However, the linking of these models is one of the areas of most difficulty for students because it involves understanding the mechanisms that occur at different levels of organization consisting of understanding what happens at the molecular, cellular and organismal level (Duncan, 2007; Todd & Romine, 2017). Few studies have examined how students form these connections and none have taken a cross-sectional approach (Todd & Romine, 2017; Wolyak, 2013).Therefore, we know little about how such understandings develop over the secondary and undergraduate levels. To address this gap, we conducted a cross-sectional interview study with students from middle school and high school, as well as undergraduate and graduate students, after they had experienced "status-quo" instruction in genetics. Our aims for this work were to (a) characterize the kinds of explanations students use to provide the link between inheritance patterns (recessive or dominant) with the underlying molecular mechanisms, and (b) characterize how these explanations change over the course of schooling.

We developed qualitative analyses of cross-sectional data with the purpose of identifying and characterizing the ways the students in each grade developed molecular explanations of inheritance patterns. The following research questions guided our analyses: 1) What kinds of molecular explanations can students provide for inheritance patterns? , and 2) How does the use of these explanations change over the course of schooling? We next describe the theoretical frameworks that informed our research questions.

Theoretical framework: Framework of genetics literacy and a normative model of genetics

To characterize the explanations that students used, we drew on the framework of genetics literacy by Stewart, Cartier and Passmore (2005) to identify core genetics ideas, and on a normative model of genetics that consisted of Muller's 1932 definition of mutation as the *loss or gain* of function of a protein (Wilkie, 1994). This definition is still widely used by scientists and textbooks to describe the effects of mutation in protein function (Griffiths et al., 2005; Zhou et al, 2020). Together these two frameworks allowed us to identify and characterize the ideas students were using to reason about molecular mechanisms involved in the expression of phenotypes, such as how a gene for albinism brings about observed physical differences in skin and hair color.

The framework of genetics literacy allowed us to classify and identify the ideas that belonged to the inheritance and the molecular model (Stewart et al., 2005). For example, ideas around inheritance patterns and the connection genes and proteins and we then analyzed the ways the students developed molecular explanations for inheritance patterns.

The normative model of genetics allowed is to identify and classify the mechanisms that the students developed to reason about inheritance patterns. Muller's 1932 model describes how scientists reason about mutations and their effects in protein function. Mutations can be classified as *loss of function* or *gain of function* (Muller, 1932). In *loss of function* mutations there may be either a complete loss of the protein or a reduction of the protein function, which can result in disease. For instance, in sickle-cell anemia the hemoglobin protein is affected by a mutation that causes a change in structure (Pauling, Itano, Singer & Wells, 1949). Normally, hemoglobin is a protein that transports oxygen that is located on the cytoplasm of red-blood cells. In the mutated form, the hemoglobin has a different shape and is less efficient at transporting oxygen. As a consequence, the lack of oxygen causes the red blood cell to become "sickled". This causes the cells to stick together and have difficulties moving through the blood vessels (Hopkins, 2020; Pauling et al., 1949). Loss of function mutation is usually the mechanism involved in recessive disorders and in some dominant disorders depending on how the mutation is affecting the individual. In contrast, gain of function mutations can lead to an increase in protein expression (more protein is being produced than what is needed), a protein that interferes with the function of another or the gain of a new function. For example, in Hungtinton's disease there is a mutation in the sequence of DNA that produces a protein that is much longer than normal (Bates, 2005). This protein is then cut into fragments ("toxic proteins") that bind to each other and accumulate in neurons, affecting the normal functions of the cells. Gain of function mutations are more often related to dominant disorders (Jones & Hughes, 2011). Therefore, the normative model allowed us to identify if students were able to develop loss and gain of function explanations of inheritance patterns. Our analysis characterizes the different ways students reasoned about classical genetics and molecular genetics and about problems that involved integrating knowledge from both models. We describe a progression of mechanism exhibited across several grades (middle school to graduate students). Findings from this study provide evidence about how students make links among the genetics models and contributes to the limited research base on genetics literacy.

Methods

Study context and participants

The aim of this study was to understand the kinds of explanations that students provided to connect the classical and molecular models of inheritance. We gathered cross-sectional interview data from students at different levels and expertise in genetics. We interviewed students from the following groups: 15 students in middle school (MS), 81 11th-grade biology students, 15 high school biology advance placement students (AP), 31 undergraduates and 12 graduate students that had completed coursework in genetics. Prior to the interview we made sure that the students in each group completed status-quo instruction in genetics and participated in the genetics units or courses that were appropriate to their grade level. For instance, the high school students completed lessons on the structure and function of proteins and their relationship to genes, and they also learned about inheritance patterns. The high school (AP and 11th grade students) and middle school students that participated were from two districts. District 1 consisted of a diverse suburban school with the following demographics: 40% African American, 30% Hispanic, 17% Asian and 13% Caucasian with 50% of the students eligible for free or reduced-fee lunch. District 2 consisted of a suburban school with the following demographics: 55% Caucasian, 35% Asian, 4% African American and 6% Hispanic with 15% of the students eligible for free or reduced-fee lunch. The university students (graduate and undergraduate students) were from a large diverse north-eastern university with the following demographic: 39.8% White, 23.3% Asian, 12.2% Hispanic or Latino, 7.82% Black or African American, 2.79% Two or More Races, 0.212% Native Hawaiian or Other Pacific Islanders, and 0.0605% American Indian or Alaska Native.

Data collection

We collected individual interview data from each student. The interviews lasted 45-60 minutes and consisted of open-ended tasks modified from a previous studies (Castro-Faix, Duncan & Choi, 2020; Duncan, Choi, Castro-Faix & Cavera, 2017). In the first task, the students were asked to reason about the molecular mechanisms for the inheritance of a hypothetical recessive disorder that we called blood-clotting disorder (BCD). The students were given a pedigree that showed the recessive trait “skipping” a generation and they were asked about the genes and traits of th0e individuals shown in the pedigree. The goal of this first task was to evaluate student understanding of inheritance patterns, the role of sex cells in inheritance, and the molecular basis of genetic traits. In the second task, the students were asked to reason about two hypothetical disorders, one dominant and one recessive. In the case of the dominant disorder, the patient is heterozygous for the disorder (Bb). The individual inherited a ‘b’ copy that codes for the “normal” protein and a ‘B’ mutated allele that codes for a mutated protein that does not work properly. In the case of the heterozygous recessive disorder (Aa), the individual inherited an ‘A’ copy that codes for the “normal” protein and an ‘a’ allele that codes for a mutated protein that does not work properly. We then asked students to explain how a heterozygous genotype can result in a healthy individual (Aa – recessive disorder) and a sick individual (Bb – dominant disorder). The purpose of this task was to elicit molecular explanations for the disease and to figure out how they would explain each disorder. In the third task, students were given 16 cards listing genetics terms like: cell, alleles, chromosomes, DNA, proteins, recessive, *etc*. The students were then asked to arrange the cards in a concept web and draw arrows that linked the terms (as many as they could). The concept web was used to encourage the participants to organize their ideas and explain the terms and the relationships they noted among the terms (Butler-Kisber & Poldma, 2010). In this task, our goal was to emphasize the relationship between alleles and proteins, and to observe how the students elaborated on this relationship.

Data Analysis

Each task was then analyzed qualitatively to determine what kinds of molecular explanations students provided for the inheritance patterns of trait; that is, all three tasks were analyzed using a directed content analysis approach with the purpose of identifying and examining how students integrated ideas from the molecular and inheritance model of genetics ideas (Chi, 1997; Hsieh & Shannon, 2005; Mayring, 2000) and used these ideas to develop molecular mechanistic explanations of inheritance patterns. According to Hsieh and Shannon (2005), the goal of this approach is to inform an existing conceptual framework or theory. The existing theory focuses the research questions that are going to be studied and provides direction about the variables to be studied (Hseih & Shannon, 2005). We used Stewart et al.’s (2005) model of genetics literacy to focus our research questions. The framework provided the initial coding scheme and the relationships between the codes that were used to identify the molecular mechanisms that students used. Moreover, we aimed to characterize their ideas using a normative model of genetics that we previously described (Muller, 1934). This model allowed us to classify students responses into gain and loss of function mutations and to figure out if the students were using the molecular mechanisms previously discussed.

Results

Our results consist of two main findings: (a) we identified several mechanisms students used to connect the molecular and inheritance models, and (b) we characterized a progression (based on cross-sectional data) that describes the kinds of mechanisms students provided to connect the inheritance and molecular models.

What kinds of explanations do students provide to connect these two models?

We first analyzed the molecular mechanisms students were using to explain inheritance patterns. Table 1 shows the mechanisms students used to explain dominant and recessive disorders. The first column illustrates the molecular mechanisms we identified and how they map onto the normative model of genetics. The second column provides an example of students' statements for each context (e.g. dominant or recessive). Our findings indicate that students across all grades (see Table 1, Table 2) developed *loss and gain* of function explanations to explain why the heterozygote (Aa) is sick in a dominant disorder and healthy in a recessive disorder. We will discuss these in greater detail below. In the next section we will discuss each molecular mechanism and how it relates to the respective inheritance pattern.

Recessive disorder

In the context of the recessive disorder, the students were given a pedigree of a recessive disorder and were asked to explain how this disorder was inherited and to explain the molecular mechanisms that caused the heterozygote individual to be healthy. We found that the students invoked the mechanisms of c*ompensation* and *silencing* to explain why a heterozygote (Aa) individual is healthy in a recessive disorder. The following, quote from a middle-school student illustrates the use of the *compensation* mechanism. "The recessive genes have mutations, but the dominant genes make up for it because they make enough protein and that's why the carrier (Aa) is healthy". Students from all the groups, middle school (50%) to graduate school (100%), explained how the dominant allele was *"compensating*" or was producing enough protein to ensure that the heterozygote individual was healthy. That is, they seemed to understand that the dominant allele as being able to complete the function without the recessive allele. Similarly, 10% of the high schoolers, 15% of the AP students and 30% of the undergraduate students operationalized this explanation of compensation with a mechanism of *silencing* that involved the assumption that the recessive allele is non-functional. In this case, the recessive allele is being turned off or being *silenced* by mutations, therefore they assumed that a mutation can cause cells to turn off the expression of the recessive allele. For example, in the following quote, a high school student describes the recessive allele being silenced. "It could be that the gene is somehow mutated, and that gene expression of that gene is turned off. The recessive allele cannot be transcribed. You can't make any proteins from that gene". This is interesting, while not entirely accurate, because it shows that students at the high school level can understand that the silencing of genes can occur. In the next section we discuss how the students reasoned about dominant disorder.

Table 1: Molecular mechanisms that students used to explain the dominant and recessive patterns of inheritance

Molecular Mechanism	Student Example
1.*Loss-of-function* ***Compensation*** -the proteins made by the dominant allele is sufficient to allow the cell to function normally therefore the allele can compensate for the recessive. Inheritance Pattern: Recesive	"The "normal" proteins compensate for the protein that isn't working the DNA that they inherited from the parent that has the big "A" is "enough" to complete the function of the protein. The protein will be enough to carry on the function even if half of the protein is missing"

2. *Loss-of-function* ***Silencing*** Mutations can turn genes off. Inheritance Pattern: Recessive and Dominant	*Recessive:* "In that case just the dominant one, the amino acid that codes for whatever this has, it's going to exhibit only the dominant ones whereas the ones with the (r) are going to be kind of quiet. They're not going to be as active. I wouldn't say the (r) is making anything. I would say the (R) is making everything. I think the (r) is just there to pass down to the offspring." *Dominant:* "Well, sometimes in dominant disorders you might have proteins not working properly. I think in this case, is because he doesn't have enough healthy protein, and this can be caused by low transcription like problems with a promoter or a receptor not being able to initiate the particular protein to be made."
3.*Loss-of-function* ***Haploinsufficiency*** The dominant allele doesn't make enough. Inheritance Pattern: Dominant	"The big R is directions to make that protein, but the little r doesn't make anything, hypothetically. Then somebody with two big Rs would make ... they would have that instruction from both of their big Rs but somebody with a big R and a little r they would ... they would make the protein because of their big R, but maybe not to the same amount because they don't have two big Rs. The little "r" is not making enough protein, but the dominant allele makes enough."
4. *Gain-of-function* ***Dominant-Negative Mutations*** The protein interferes with the function. Inheritance Pattern: Dominant	"The heterozygote is sick because the mutated protein has something wrong in the structure that allows it to it bind to the healthy protein forming dimers and interferes with the function possibly by blocking it's active site."

Dominant disorder

In this context the students were given two multiple-choice questions that asked students to explain why a heterozygote (Aa) individual is sick in a dominant disorder. We found that students used the mechanisms of *haploinsufficiency*, *dominant-negative mutations* and *silencing* to explain why the heterozygote (Aa) individual is affected by the disorder (Table 2, row 3). *Haploinsufficiency* occurs when one allele in the pair of alleles is mutated causing a decrease in the total production of a protein. The use of this explanation suggests that students understood that the "healthy" allele is not able to produce enough protein for the individual to have a "normal" phenotype. For example, in the following quote a high school student states that "Sam" is not healthy because having one healthy allele "a" is not enough for him to be healthy. "Sam is not making enough protein to be healthy. He has one dominant(A) and one recessive allele(a). The recessive is the correct one , this allows him to make the Tropin but he doesn't make it in the quantities that he needs. He is missing one healthy allele therefore he doesn't make enough of the protein because of the mutation in the A allele."

Dominant negative mutation explanations were used to explain dominant disorders by 10% of the high school students, 20% of the AP students, 35% of the undergraduates and of the 90% of the graduate students. In this explanation, the students suggest that the mutated protein is somehow inhibiting the function of the healthy allele, therefore the heterozygote individual (Aa) is sick in a dominant disorder (Table 2, row 4). In the following quote, an undergraduate student explains that there may be a mutated protein interfering with the function of the normal protein. "The heterozygote is sick because the mutated protein has something wrong in the structure that makes it bind to the healthy protein and interferes with the function". The use of this mechanism suggests that students understood that proteins can interact with one another, sometimes leading to inhibition of their function.

Silencing in the context of the dominant disorder was used mainly by undergraduate and graduate students and it consisted of mutations that affect the activation of genes, therefore there was a lack of protein expression. For example, in the following quote a graduate student suggests that a gene is being silenced due to mutations. "Sam may be sick for several reasons. However, it is possible that regions that are related to gene activation were affected by the mutation therefore Sam is unable to make the protein he needs to be healthy."

In the next section we discuss how these explanations were developed by students across several levels of expertise.

Development of molecular explanations over time

Table 2 shows the frequencies of types of mechanistic explanations used by each group of students to explain recessive and dominant disorders. The data seems to indicate several interesting patterns. First, some mechanisms are observed with an increase in their use corresponding to education level (e.g., Table 2, rows 1-2). For example, the *compensation* explanation was used correctly by students across several grades to explain the inheritance of recessive and dominant disorders. Similarly, constructing *dominant-negative* explanations was challenging, but within reach, for high school students. All of the students used these in the correct context and situation. Second, the mechanism of "*silencing*" in the context of the recessive disorder was not used by middle school students, but it was used by high school students, AP students and very few graduate students. This mechanism was used in a non-normative way by the younger students while the graduate students provided more detail about how a gene can be "silenced. Additionally, silencing was used in the context of the dominant disorder by undergraduate and graduate students, including more detail on how the gene may have been inactivated and how this inactivation can lead to disease. Third, the *haploinsufficiency* explanation, in terms of the dominant allele and the dominant-negative mutations, were used in an appropriate context for the dominant disorder - mostly by graduate students (Table 2, rows 4).

Table 2: Progression of molecular explanations over time

Molecular Mechanism	Inheritance Pattern	MS	HS	AP	College	Grad
1. Compensation--the proteins made by the dominant allele is sufficient to allow the cell to function normally therefore the allele can compensate for the recessive.	Recessive	50%	70%	80%	100%	100%
2. Silencing-Mutations can turn genes off.	Recessive	0%	10%	15%	30%	50%
	Dominant	0%	0%	0%	20%	60%
3. Haploinsufficiency-the proteins made by the dominant allele is not sufficient to allow the cell to function normally.	Dominant	20%	35%	40%	50%	100%
4. Dominant Negative- the protein produced by the mutated allele interferes with the function of the "normal" protein.	Dominant	0%	10%	20%	35%	90%

Discussion and instructional implications

Genetics is an important, but challenging, subject for students to learn and understand. According to Stewart et al. (2005), a literate individual understands the links among the classical, molecular and meiotic models of genetic inheritance. There is little research to show how students integrate these models. Our findings characterize the different mechanisms that students used to link classical and molecular patterns of inheritance post status-quo instruction. The molecular explanations that students developed were, for the most part, consistent with the normative model of *loss and gain of function*. For example, the mechanism of *haploinsufficiency* involves the loss of part of the protein function leading to a decrease in the protein's expression, and the mechanism of *compensation* involves the understanding that although there may be a decrease in the protein's expression the other allele is able to compensate. Our findings indicate that middle school students were able to reason about these ideas of *compensation* and *haploinsufficiency*. These ideas involve an understanding that alleles can code for *enough* protein to complete a function and may suggest a molecular understanding of *dosage* (Duncan, 2017). Understanding *dosage* may allow allows students to traverse several levels of organization because it allows them to understand the relationships among alleles, protein and their physical effects. Helping students understand the relationships between genes and how they bring about their effects is conductive to understanding the mechanistic linkages between molecular and classical genetics (Haskel-Ittah & Yarden, 2019).

Our findings also show that students at the high school level can understand that genes can be turned *on or off.* This idea of *silencing* is critical in the understanding that genes are dynamic entities that are influenced by the environment. Authors, 2020 studied how undergraduates understood phenotypic plasticity, that is how organisms respond to changes in the environment. They found two types of mechanistic accounts: (a) the organism is passively responding to environmental changes, and (b) the organism senses and responds to the environment. Our findings seem to support the idea that understanding how organisms respond is difficult and we propose that understanding that genes can be turned on and off is an important part of conceptualizing how the environment influences gene expression. This is an important idea because understanding that genes are dynamic entities can decrease genetic determinism (Donovan, 2016). Moreover, Duncan, 2007 studied how students understood how plants responded (by ripening) to an environmental change (exposure to ethylene). She found that students that were not able to operationalize a gene expression (or silencing) schema were not able to understand or explain how the organism reacted to the environment or further explain how genes are regulated. Therefore, the understanding that genes can be turned on and off is an important idea for the understanding of gene expression (Duncan, 2007; Haskel-Ittah et al., 2020).

To conclude, we wish to discuss the progression of mechanism use. From these findings we have begun to identify a progression that captures the mechanisms that students used when reasoning about classical and molecular genetics. Duncan, Rogat and Yarden (2009) proposed a learning progression for the integration of molecular and classical ideas. Our findings support the progression and provide details about how students' reasoning about the linkage between molecular and classical genetics may develop over time. Duncan et al.'s (2009) learning progression describes the development of students understanding of eight genetics ideas (constructs) over time (middle school to high school).

Our findings, can begin to specify where instruction can focus to help students develop the mechanistic explanations for the link between molecular and classical genetics, for instance we have shown that instruction should focus on emphasizing that alleles code for proteins and that recessive and dominant are simply categorical to indicate the phenotypic effect of the proteins they code for and that these proteins they are structurally different due to changes in the sequence (recipe). Moreover, instruction should emphasize that proteins have distinct functions that have a direct result in the organism's physical traits. Understanding the connections among genes, proteins, and traits entails reasoning across multiple levels of organization (e.g., sub-cellular, cellular, and organismal levels), a conceptually challenging task since students need to understand the role each level of organization plays in inheritance phenomena and how biological mechanisms at each level relate to each other (Marbach-Ad & Stavy, 2000). Duncan and Tseng, 2011 argue that understanding the link between genes and traits can help students develop a framework for reasoning about complex systems (such as the interaction between classical and molecular genetics) that can be further developed when students understand how physical and cellular phenomena emerge from protein function. Therefore, helping students understand the relationship between genes and proteins can help elucidate the link between the two models.
Similarly, we have shown that helping students understand that genes can be regulated is important but difficult idea, therefore instruction should aim to help students understand that genes are dynamic entities that respond to the environmental changes the organism is interacting with. More studies need to be done to further understand how students reason about these ideas. This article begins to provide evidence about the ways that students link classical and molecular genetics.

References

23andMe. (2020). Retrieved from: https://www.23andme.com/

Bates, G. P. (2005). The molecular genetics of Huntington disease—a history. *Nature Reviews Genetics*, 6(10), 766-773.

Bellcross, C.A., Page, P., & Meaney-Delman, D. (2012). Direct-to-consumer personal genome testing and cancer risk prediction. *The Cancer Journal, 18*(4), 293 - 302.

Boerwinkel, D. J., Yarden, A., & Waarlo, A. J. (2017). Reaching a consensus on the definition of genetic literacy that is required from a twenty-first-century citizen. *Science & Education*, 26(10), 1087-1114.

Butler-Kisber, L., & Poldma, T. (2010). The power of visual approaches in qualitative inquiry: The use of collage making and concept mapping in experiential research. *Journal of Research Practice*, 6(2), M18-M18.

Chi, M. T. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *The Journal of the Learning Sciences*, 6(3), 271-315.

Castro-Faix, M., Duncan, R. G., & Choi, J. (2020). Data-driven refinements of a genetics learning progression. *Journal of Research in Science Teaching*.

Donovan, B. M. (2017). Learned inequality: Racial labels in the biology curriculum can affect the development of racial prejudice. *Journal of Research in Science Teaching*, 54(3), 379-411.

Duncan, R. G. (2007). The role of domain-specific knowledge in generative reasoning about complicated multileveled phenomena. Cognition and Instruction, 25(4), 271-336.

Duncan, R. G., Castro-Faix, M., & Choi, J. (2017). Informing a learning progression in genetics: Which should be taught first, Mendelian inheritance or the central dogma of molecular biology?. *International Journal of Science and Mathematics Education*, *14*(3), 445-472.

Duncan, R. G., Rogat, A., & Yarden, A. (2009). A learning progression for deepening students'understanding of modern genetics across the 5th-12th grades. Special issue on Learning Progressions for *the Journal of Research in Science Teaching*, 46(6), 644-674.

Duncan, R. G., and Tseng, K. A. (2011). Designing project-based instruction to foster generative and mechanistic understandings in genetics. *Science Education,* 95(1), 21-56.

Falzarano, M. S., Scotton, C., Passarelli, C., & Ferlini, A. (2015). Duchenne muscular dystrophy: from diagnosis to therapy. *Molecules*, *20*(10), 18168-18184.

Gericke, N. M., & Smith, M. U. (2014). Twenty-first-century genetics and genomics: Contributions of HPS-informed research and pedagogy. In *International handbook of research in history, philosophy and science teaching* (pp. 423-467). Springer, Dordrecht.

Griffiths, A. J., Wessler, S. R., Lewontin, R. C., Gelbart, W. M., Suzuki, D. T., & Miller, J. H. (2005). *An introduction to genetic analysis*. Macmillan.

Haskel-Ittah, M., Duncan, R. G., & Yarden, A. (2020). Students' Understanding of the Dynamic Nature of Genetics: Characterizing Undergraduates' Explanations for Interaction between Genetics and Environment. *CBE—Life Sciences Educatio*n, 19(3), ar37.

Haskel-Ittah, M., & Yarden, A. (2019). Students' conception of genetic phenomena and its effect on their ability to understand the underlying mechanism. *CBE—Life Sciences Education*, 17(3), ar36.

Hawkins, A.K. & Ho, A. (2012). Genetic counseling and the ethical issues around direct to consumer genetic testing. *Journal of Genetic Counseling*, 21(3), 367 - 373.

Hopkins. (2020). Retrieved from: https://www.hopkinsmedicine.org/health/conditions-and-diseases/sickle-cell-disease

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. *Qualitative health research*, *15*(9), 1277-1288.

Jones, L., & Hughes, A. (2011). Pathogenic mechanisms in Huntington's disease. In *International review of neurobiology* (Vol. 98, pp. 373-418). Academic Press.

Marbach-Ad, G., & Stavy, R. (2000). Students' cellular and molecular explanations of genetic phenomena. *Journal of Biological Education*, 34(4), 200-205.

Mayring, P. (2000, June). Qualitative content analysis forum qualitative sozialforschung. In *Forum: qualitative social research* (Vol. 1, No. 2, pp. 2-00).

Muller, H. J. (1932). Further studies on the nature and causes of gene mutations. *Proc. Sixth Int. Cong. Genet., Ithaca, New York, USA*, *1*, 213-255.

Shea, N. A., Duncan, R. G., & Stephenson, C. (2015). A tri-part model for genetics literacy: Exploring undergraduate student reasoning about authentic genetics dilemmas. *Research in Science Education*, *45*(4), 485-507.

Stern, F., & Kampourakis, K. (2017). Teaching for genetics literacy in the post-genomic era. *Studies in Science Education*, 53(2), 193-225.

Stewart, J., Cartier, J. L., & Passmore, C. M. (2005). Developing understanding through model-based inquiry. *How Students Learn*, 515-565.

Todd, A.N., & Romine, W. (2017) Difficulties in integrating the genetic-meiotic and genetic molecular models of genetics. A paper presented at the 2017 Annual Meeting of the National Association for Research in Science Teaching, San Antonio, TX.

Weisberg, S. M., Badgio, D., & Chatterjee, A. (2017). A CRISPR new world: attitudes in the public toward innovations in human genetic modification. *Frontiers in public health*, 5, 117.

Wilkie, A. O. (1994). The molecular basis of genetic dominance. *Journal of medical genetics*, 31(2), 89-98.

Wolyniak, M. J. (2013). Improved student linkage of mendelian and molecular genetic concepts through a yeast-based laboratory module. *Biochemistry and Molecular Biology Education*, 41(3), 163-172

Zhou, Y., Borchelt, D., Bauson, J. C., Fazio, S., Miles, J. R., Tavori, H., & Notterpek, L. (2020). Subcellular diversion of cholesterol by gain-and loss-of-function mutations in PMP22. *Glia*.

"Their Evidence is No Good": How Middle School English Learners and Students With Low Language Scores Successfully Engaged in Scientific Argument Critique

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Abstract: Argument critique is an important part of scientific argumentation. This paper explores the affordances of a tool for critiquing classroom arguments in science, the Critical Questions Model of Argument Assessment, and how it benefited students with low English Language Arts (ELA) scores, including English Learners (ELs). Critical questions (CQs) evaluate the strength of scientific arguments. This paper presents a comparative case study of how middle-school science students used CQs in two classrooms with high numbers of students with low ELA scores. We found that asking CQs helped students elaborate their thinking and writing and appropriate argument-related terms. Student confidence for engaging in argument critique grew over the course of the school year. The practice of using peer critique with CQs may have the added benefit of differentiating instruction in schools with high EL populations. Overall, the CQs helped to scaffold more complex student discourse among students with low ELA scores.

Keywords: Argumentation, Science Education, English Learners, Critical Thinking

Student oral and written discourse is a key component of reform-oriented approaches to teaching science for understanding (Chen et al., 2016; Sampson & Grooms, 2010). Through discourse, students need to grapple and critique alternative models of phenomena, including their own prior conceptions (Hunt & Minstrell, 1994). Given the centrality of discourse, to what degree can English Learners (ELs) and students with low English Language Arts (ELA) test scores participate in and benefit from this sort of dialogic science instruction? Rosebery et al. (1992) found EL middle school students were quite capable of appropriating scientific discourse, specifically making and testing elaborated hypotheses, when allowed to investigate phenomena related to ecosystems over the course of a year. Likewise, Suárez and Otero (2014) found that third-grade students could engage in scientific argumentation when the instruction was based on explaining tangible, physical phenomena (i.e., guitar sounds) that leveraged their everyday knowledge and terminology.

Beyond these findings, this paper explores a relatively new tool for enabling middle school students to engage in scientific argumentation in general and argument critique in particular, the Critical Questions Model of Argument Assessment (CQMAA; Dove & Nussbaum, 2018). Somewhat unexpectedly, we found that this tool could be particularly beneficial for students with low ELA test scores, many of whom were ELs. This paper presents a qualitative, cross-case analysis exploring some of the affordances of the CQMAA for enabling students who may struggle with language skills to participate in argumentative discourse. The paper is grounded in two conceptual frameworks: (1) a philosophic framework supporting the centrality of critical questions to scientific inquiry, and (2) a pedagogical framework providing some guidance on how ELs and students with low ELA scores can learn to productively use critical questions.

The critical questions model of argument assessment

Critical questions are somewhat standard questions that should be asked to evaluate an argument. As Walton (1996), Verheij (2003), and other philosophers have shown, there are various types of arguments, known as argument schemes, and attached to each scheme is a set of critical questions (CQs) that should be asked to evaluate an argument of that type. For example, in evaluating an argument based on a logical or scientific analogy, one should ask whether there are important differences between the two things being compared. An affirmative answer would weaken the argument, whereas a negative answer would strengthen it. These assessments can be made dialogically, through discussion. However, we have found—based on personal experience—that it is difficult to teach students to recognize the presence of schemes in ordinary discourse, both because of the large number of possible schemes, and because informal arguments do not always exactly fit nicely into the idealized structures of these schemes. We noticed, however, that there are similarities among many of the critical questions for different schemes, and based on this, identified a number of CQs that could be asked about most arguments. These CQs constitute the CQMAA for scientific arguments; there is a slightly different set for practical and policy arguments.

Table 1: CQMAA critical questions for scientific argumentation4

Number	Critical Questions
1.Structure	Is there an argument here? Can I underline the claim? Can I add a star to the evidence? Can I bracket the reasoning?
2.Evidence	Is there evidence? How good is the evidence?
3.Reasons	Are any of the reasons untrue or incorrect?
4.Accurate	Does the argument use or connect with accepted scientific principles?
5.Coherence/ Reasoning	Do the parts of the argument make a path you can follow or are there missing steps?
6.Alternatives	Are there other claims or conclusions that also fit the evidence? Can you rule out other or competing claims or conclusions?
7.Completeness	What is missing or weak in the argument?

As shown by CQ1, the CQMAA is meant to supplement the widely used claim-evidence-reasoning (CER) model of scientific argumentation first proposed by McNeil and Krajcik (2007). The CER model specifies three argument components: the claim (or conclusion), the evidence, and reasoning that connects the evidence to the claim. The CQMAA can be used to improve a student's CER argument. (The CQMAA could also be used with other argumentation models, such as the six-part Toulmin model, 1958, but the wording of CQ1 would need to be slightly altered.) The CQMAA can also be supplemented with more scheme-specific questions. For example, the second set of CQs, relating to evidence, could be supplemented with more specific questions regarding the clarity and reliability of the evidence (see Pluta et al., 2011). A number of science educators, such as Erduran et al. (2004), have called for supplementing the CER model with counterarguments and rebuttals, as these are key components of scientific discourse about alternative models, and the CQMAA is one attempt to meet this call.

For example, consider the phenomenon of lunar phases. Many students believe that the Moon's phases are caused by shadows cast by the Earth (Brunsell & Marcks, 2007). As evidence, students might cite a video showing how celestial bodies block sunlight during an eclipse, reasoning that because the Moon orbits the Earth, at some point the Earth will block the light falling on the Moon. Using the CQMAA, this CER argument could be critiqued based on the quality of the evidence ("It's about eclipses, not lunar phases"), missing steps ("Why and how often does the Earth block the Sun's light and why doesn't this result in an eclipse?"), and the presence of alternative models (i.e., lunar phases caused by the position of the Moon relative to the Sun). Based on a discussion of these issues, students could improve their understanding of the cause of lunar phases.

It should be noted that the CQMAA is a flexible framework; questions can be reworded if necessary to make them more understandable to students or more appropriate to the subject matter. Also, except for CQ1, the questions can be asked in any order, and not all the questions need to be asked.

The pedagogical framework

The CQMAA is intended to be used to support a form of oral discourse known as *collaborative argumentation* (Andriessen et al., 2003), in which students work together to construct and critique arguments. Collaborative argumentation has been found to promote deeper engagement and understanding of scientific concepts (Alexopoulou & Driver, 1996; Asterhan & Schwarz, 2007). Nussbaum and Edwards (2011) examined the use of a graphic organizer known as the Argumentation Vee Diagram containing CQs related to policy issues. They found that during collaborative argumentation that was preceded and followed by completion of an AVD, some ELs appropriated specific CQs and used them spontaneously during oral and written discourse (see also Nussbaum, 2003). The majority of ELs, however, needed the structure provided by the graphic organizer to ask these questions. Likewise, Liu and Stapleton (2020) collected data suggesting that among sixth-grade students, use of graphic organizers and other structured forms of instruction, such as five-paragraph essays, were important to enable ELs to generate written counterarguments.

Our pedagogical framework is rooted in the work of Vygotsky (Wink & Putney, 2004), particularly the notion of scaffolding (Wood et al., 1974) and the internalization or appropriation of social speech (see also work by Anderson et al., 2001). We recognize, however, that the pedagogical framework is incomplete, given the paucity of prior research conducted on how ELs and other students with low ELA scores learn scientific argumentation at the primary (Liu & Stapleton, 2020) and secondary levels (Nussbaum & Edwards, 2011). One purpose of the qualitative research described below is to add to our knowledge of this issue, based on a one-year professional learning (PL) program for secondary teachers, known as Argumentation and Learning for Secondary Science.

Methods

The PL program consisted of a phenomenon-driven 10-day summer institute where teachers used collaborative argumentation while investigating alternative predictions and explanations about phenomena related to force and motion. Participants also completed various graphic organizers individually and in small groups, including an *Argument Analysis Mapping Tool*, where participants generated claim-evidence reasoning (CER) argument components in the left column and then answered CQs from Table 1 in the right column. They also used model-evidence link (MEL) diagrams that ask students to assess two competing scientific models by specifying whether certain pieces of evidence support or contradict each model (Chinn & Buckland, 2012). MEL diagrams relate to Question 6 in Table 1.

Second, during the school year, teachers attended eight after-school sessions to engage in lesson planning and mutual problem solving. Teachers were expected to design and implement three (week-long) lessons using argumentation, one per Quarters 2-4. A segment of each lesson was observed by a discourse coach, who were either teachers with more experience in argument pedagogy or employees of the district's professional learning office. After observing a portion of each learning sequence, the coaches used an observation form and a semi-structured feedback form that was utilized to set short-term goals for further teacher development.

Participants

Seventeen teachers attended the 10-day summer institute on pedagogy for scientific argumentation. Our research sample consisted of seven teachers who completed the entire PL, of which four taught in schools with large populations of ELs. Because one teacher did not emphasize CQs much and one taught at the same school as one of our target teachers (and therefore his data provided somewhat redundant information), we focus in this paper on analyzing the instructional and discourse practices of the two remaining teachers. Both participants taught eighth-grade science.

One teacher, Deborah, was an African American teacher who formerly taught high school but moved to middle school four years previously. Her school's student population was 27.9% EL, with a high rate of student transience (42.3%). Only 31.5% of the students were rated as proficient on the state's criterion-referenced test (CRT) for ELA. The other teacher, Elissa, was White, with a number of years of teaching experience. She was new to her school, having recently moved from another state, and had a reputation as a strong teacher. She and the other science teachers at her school were seeking National Board Certification. The student population at her school was 31.1% EL with 27.6% transiency. Only 32% of the students were classified as proficient on the state ELA test. Both teachers indicated that their schools placed a strong emphasis on student discourse, including argumentation. Both sought a better understanding of the science and engineering practice standard in the national science standards relating to arguing from evidence. Both also wanted knowledge of more tools to promote student discourse related to argumentation.

In terms of racial composition, the students at Deborah's school were 58.1% Hispanic, 23.4% African American, 5.9% Asian, 5.5% White, 5.3% two or more races, and 1.8% other. The students at Elissa's school were 83.7% Hispanic, 10.9% African American, 1% Asian, 2.3% White, 1.5% two or more races, and 0.7% other.

Research questions and data collection

The first goal of the research was to assess how the teachers used CQs and other tools to scaffold the discourse and learning of students. The second goal was to better understand the quantitative findings reported in Nussbaum et al. (2020), that among the students taught by the seven participants in our larger sample, students with lower prior-year ELA scores benefited the most from our program in terms of growth in student confidence to argue and on performance on an argument evaluation test (AET). Both of these measures were administered at the beginning and end of the school year. The AET measured students' ability to critique arguments, and whether they would spontaneously use the criteria reflected in the CQs. Given the large number of ELs in the school district (Spanish speakers plus a large range of other languages), and the low average ELA test scores in some of the participating schools, we hypothesized that student improvements were largely, though perhaps not exclusively, tied to language proficiency. While there were a number of features of the teachers' learning environment that could have contributed to growth, such as the extensive use of cooperative learning and language-oriented learning goals, we specifically sought to understand how the use of CQs and peer critique functioned in these teachers' classroom and how these might have contributed to student growth on our outcomes.

Data primarily included video transcripts of the three class sessions that each coach observed (including both whole-class and some small-group discourse), the coaches' written evaluation and feedback forms prepared after each observed lesson, student work samples from these lessons, and exit interviews conducted with each teacher jointly with their coach. We also examined lesson plans and transcripts of the PL. Using content analysis (Berg, 2001), we first examined and coded the data for categories related to the research questions. We then further identified themes within and across teachers and identified illustrative cases. Claims made by participants in the exit interviews were tested through triangulation with other sources of data.

Results

Use of graphic organizers and critical questions

Both teachers incorporated various graphic organizers into their lessons. Deborah consistently used the argumentation mapping tool. This involved students working in small groups to construct a CER and then using CQs to critique another group's CER, discussing the critiques in class. This was followed by individual students preparing their own individual CERs. Elissa used the mapping tool in a similar fashion during the last two quarters, and in Qtr. 4 also had students critique one of their old CER's. In addition, Deborah extensively used MEL diagram activities, which implicitly highlighted CQ6 regarding alternative explanations. Elissa tended to try out various graphic organizers, some of which contained CQs. Elissa also extensively used talk stem cards that reflected accountable talk moves (Michaels & O'Connor, 2012), often giving students one or two to work on in a lesson. During the exit interviews, both teachers thought that the organization provided by graphic organizers was very valuable for their students, especially ELs.

Regarding CQs, Deborah had students systematically answer all the CQs in Table 1, whereas Elissa only emphasized the first four, primarily because of time constraints. During the exit interviews, Deborah and Elissa indicated that they liked how the CQs helped to structure and focus students' thinking and discourse, and kept the discussions more on-topic.

Effects of critical questions

Elaborating student thinking and writing

Deborah and her coach reported that because many of the students were ELs, they needed help with completing their thoughts when writing. Many of the critiques prompted by the CQs involved the need to explain more, or to include a "because" or "why." Deborah indicated during the exit interview that many of her students had to be pushed to write something, and the CQs were useful, for example, in pushing students to make their evidence more specific (e.g., not just referring to "the lab" but to what was actually done and observed). Lesson transcripts showed that students' critiques often related to being clearer, writing more, giving details and specifics, explaining reasoning, and not just answering a CQ with a "yes or no." The CQ regarding whether an argument created a path that could be followed or whether there were missing steps was often used to criticize arguments for lacking details. The CQ regarding "good evidence" was also productively used. As noted above, evidence was criticized if it was not clear, specific, and relevant. We observed one group reporting that this critique was helpful and that they would "explain more next time." In facilitating oral discussion, we observed that Deborah would sometimes push students to elaborate their critiques, specifically by using CQs as probing questions, e.g., "What do you mean?" "How do you know that?" or "What type of evidence?" By Qtr.4, students were asking "why questions" of one another. Deborah's coach explained in the exit interview that Deborah's students, compared to students in general, became less likely to answer questions with "I don't know" or just a "yes or no" and that this was a big deal. In the beginning, some students didn't finish the mapping tool, but they kept at it and got better over time. They also improved in making claims, evidence, and reasoning to all relate to one another and make sense. In addition, they were having "little discussions about what constitutes evidence" (for example, does the use of Punnett Squares in genetics constitute evidence?). Table 2 shows the content of a completed mapping worksheet where one group completed a CER argument and another group used CQs to critique it on the topic of whether mutations are helpful, harmful, or both.

Table 2: Completed mapping worksheet on genetic mutations completed during Qtr. 4

<table>
<tr><td colspan="3">Left Column Work – Group Number: 3
Right Column Analysis – Group Number: 7

Argument Analysis Mapping Process: Critical Questions</td></tr>
<tr><td>Claim
(conclusion)</td><td>I claim that genetic mutations can almost always cause harmful change to an organism</td><td rowspan="3">1. Structure: Is there an argument here?
Can I underline to claim? (claim or conclusion)
Can I add a star* to the evidence (evidence)?
Can I [bracket] the reasoning (reasons)?
Yes there is an argument here.

Critical Questions:

2. Is there evidence?
How good is the evidence?
It's not very good at all. Says what we've done. Not really supporting the claim at all. And some of the evidence is in the reasoning. I suggest for evidence you shouldn't talk about what we've done in class but talk more about a mutation that was harmful, to support your claim.

3. Are any of the reasons untrue or incorrect? No

4. Does the argument use or connect with accepted scientific laws?
Yes, just not the evidence.

5. Do the parts of the argument make a path you can follow or are there missing steps?
Yes. Just not the evidence.

6. Are there other claims or conclusions that also fit the evidence?
Can you rule out other or competing claims or conclusions?
Well the evidence doesn't support any claim only their reasoning does. So you can't rule out any based on the evidence.

7. What is missing or weak in the argument?
It's missing evidence, it doesn't support the claim so it makes the argument weak.</td></tr>
<tr><td>Evidence
(observation, text, data, etc.)</td><td>• Our class made posters about how mutations affect your life.
• Our class watched a slide show on how different mutations occurred.
• The class researched about different mutations and diseases.</td></tr>
<tr><td>Reasoning
(describe the science concept of the evidence used to justify the conclusion)</td><td>1) For example, a mutation called SLOS causes mental retardation which leads to small heads, split upper lips, and extra fingers and toes.
2) Some mutations occur when having certain genes or genetics.
3) Some mutations temporarily damage your organs forever or it can kill you.</td></tr>
<tr><td colspan="3">Notes. Student writing is in italics. Grammatical and spelling mistakes have been corrected.</td></tr>
</table>

Elissa also reported that CQs helped students elaborate more in their writing. In the exit interview, she stated that "students were writing literally a couple sentences at the beginning of the year, now they are writing full page paragraphs, across the board, almost all of them….I think the CQs and the MELs contributed, what good evidence in science looks like." (Elissa's Qtr. 3 lesson discussed how good evidence needed to be concrete, relevant, thorough, and persuasive.) There was also evidence that CQs helped to stimulate more elaboration during oral discourse. Elissa noted that critical questions were easy for her to integrate into her lessons and the discourse, as her students already did a lot of peer review. She found that having students evaluate one of their old CERs was very effective. During the exit interview, Elissa indicated that students would state, "I don't follow this" or "that's kind of incorrect, because evidence right here says that…." We also observed a number of students asking "why questions" during Qtr. 4 (e.g., Why do you think that?). Like in Deborah's classroom, CQs were used to prompt elaboration. Elissa's coach indicated that from her three observations, she noticed that by the end of the year students were using the CQs and talk moves more and were having productive discussions. Both teachers indicated that CQs were especially valuable for "reluctant writers" who, according to the teachers, had to be pushed to complete their thoughts or make their evidence more specific.

Appropriation of technical terms

Deborah's coach indicated in the exit interview that her students "actually used some of the words in the questions to kind of help them state what they're thinking." Deborah also provided students with technical terms that could be used in their critiques. For example, one group wrote in their critique of another group's CER that they had "no clear support," incorporating the term *support* into their discourse. During Qtr. 4, another group incorporated the term *structure* into the oral discourse (and into their written critique), as follows.

Guillermo:	What is missing? Can we just say basically everything? Well, except for the claim.
Placida:	Structure.
Guillermo:	Oh, yeah, structure is an actual good word to use.
Placida:	They don't have a structure. There's missing parts.
Guillermo:	What is missing is they don't have a strong structure. What kind of structure?
	[Teacher makes an announcement]
Guillermo:	But be more specific. Like what kind of structure are you talking about?
Placida:	Specific.

The discussion relates to CQ7 from Table 1 regarding completeness. The technical term *structure* was contained in CQ1, but here the students appropriated the term and used it in the discussion of another CQ. The excerpt also reflects the classroom norm of being specific when providing reasons and evidence. Student appropriation of argument-related language was not mentioned by the teacher or coach in Elissa's classroom.

Growth in student confidence to critique

Deborah's coach observed that the students were often reluctant to disagree with one another or critique one another's arguments. Her coach wrote that at first Deborah's students were very "...reluctant to discuss or express their ideas in a class or group…." But with time and practice, Deborah's students became more comfortable and confident with argumentation, and "more open in their ideas, relied less on the thoughts of Deborah, and led small-group discussions to effectively understand new phenomena." Likewise, for Elissa, both she and her coach reported that over time, students used more CQs and engaged more in argument critique. Both teachers underscored that critique will help others strengthen their arguments and, according to her coach, Deborah fostered a warm classroom environment that supported peer critique.

Discussion

The themes that emerged from the qualitative analysis were that engaging in collaborative argumentation involving peer critique pushed the students to elaborate their thinking and discourse and appropriate in some cases argument-related language. This was accompanied by increases over time in these students' confidence to engage in critique. The results suggest that using critical questions can allow students to participate in argument discussions more fully and to think about the science content for longer periods of time. In combination with the quantitative evidence reported in Nussbaum et al., 2020, the evidence indicates that CQs are especially beneficial for students with low ELA scores. Some CQs also are fairly short, making it easier for these students, especially ELs, to appropriate the language and use the CQs to participate in discussions, for example by asking "why" or "how do you know?" questions (see Nussbaum, 2002).

Use of CQ may also have the added benefit of helping to differentiate instruction. Given the high student transience rates in these schools, we conjectured that peer critique allowed students who were new to a classroom to receive feedback and scaffolding to write more fully. Many of these students presumably generated relatively unelaborated arguments, which provided additional material for other students to critique. Students in a given classroom for close to an entire year benefited by becoming more proficient and confident in more advanced elements of argumentation critique. These conjectures do need additional empirical confirmation but point to how CQs might function to provide differential levels of support in classrooms with high transiency and high numbers of ELs.

Our qualitative findings help to explain our quantitative findings (reported in Nussbaum et al., 2020), based on survey and test data, that the confidence of students with low ELA scores for engaging in critical argumentation grew over the course of the year, and that they became increasingly more willing to challenge the premises of an argument on a written transfer test, for example counterarguing that "the Earth is not cooling" in response to arguments against human-induced climate change.

Intervention studies with ELs in U.S. science classrooms within the last two decades have noted the importance of engaging students in reform-oriented discourse practices (i.e., speaking and writing) for ELs' academic development (e.g. Lara-Alecio et al., 2012; Lee et al., 2005; Llosa et al., 2016). However, the majority of previous work has been situated in 3rd-5th grades, with little focus on argumentation. Studies on argumentative practices focused on second language learners such as Liu and Stapleton's (2020) tend to be situated in non-U.S. classroom contexts. This study adds to the much needed work examining reform-oriented practices for ELs and students with low ELA scores in secondary science in the U.S. contexts, in addition to focusing on effective argumentation practices and scaffolds related to argument construction and critique.

We recognize that all science students may benefit from the asking and answering of critical questions and the student discourse that CQs are intended to promote. They are, however, particularly beneficial for students with low ELA scores, including "reluctant writers" and ELs. This is notable because some teachers may believe that engaging in more than the most basic forms of argumentation is beyond the abilities of these students. We argue to the contrary.

References

Anderson, R. C., Nguyen-Jahiel, K., McNurlen, B., Archodidou, A., Kim, S., Reznitskaya, A., Tillmans, M., & Gilbert, L. (2001). The snowball phenomenon: Spread of ways of talking and ways of thinking across groups of children. *Cognition and Instruction, 19,* 1-46. https://doi.org/10.1207/S1532690XCI1901_1

Alexopoulo, E., & Driver, R. (1996). Small-group discussion in physics: Peer interaction modes in pairs and fours. *Journal of Research in Science Teaching, 33*(10), 1099-1114. https://doi.org/10.1002/(SICI)1098-2736(199612)33:10<1099::AID-TEA4>3.0.CO;2-N

Andriessen, J., Baker, M., & Suthers, D. (2003). Argumentation, computer support, and the educational context of confronting cognitions. In Andriessen, J., Baker, M., & Suthers, D. (Eds.), *Arguing to learn: Confronting cognitions in computer-supported collaborative learning environments* (pp. 1-25). doi.org/10.1007/978-94-017-0781-7_1

Asterhan, C. S. C., & Schwarz, B. (2007). The effects of monological and dialogical argumentation on concept learning in evolutionary theory. *Journal of Educational Psychology, 99*, 626-639. doi.org/bkn25r

Berg, B.L. (2001). *Qualitative research methods for the social sciences.* Allyn & Bacon.

Brunsell, E., & Marcks, J. (2007). Teaching for conceptual change in space science. *Science Scope, 30*(9), 20-23. Retrieved October 30, 2020, from ERIC database.

Chen, Y.-C., Park, S., & Hand, B. (2016) Examining the use of talk and writing for students' development of scientific conceptual knowledge through constructing and critiquing arguments*. Cognition and Instruction, 34*(2), 100-147. https//doi.org/10.1080/07370008.2016.1145120

Chinn, C. A. & Buckland, L. A. (2012). Model-based instruction: Fostering change in evolutionary conceptions and in epistemic practices. In K. S. Rosengren, E. M. Evans, S. Brem, & G. M. Sinatra (Eds.). *Evolution challenges: Integrating research and practice in teaching and learning about evolution* (pp. 211-232). Oxford University Press. doi:10.1093/acprof:oso/9780199730421.001.0001

Dove, I., & Nussbaum, E. M. (2018). The critical questions model of argument assessment. In S. Oswald & D. Maillat (Eds.), *Argumentation and Inference: Proceedings of the 2nd European Conference on Argumentation, Fribourg 2017* (Vol. 2, pp. 263-280). College Publications.

Erduran, S., Simon, S. and Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's Argument Pattern for studying science discourse. *Science Education, 88*, 915–933. doi.org/10.1002/sce.20012

Hunt, E., & Minstrell, J. (1994). A cognitive approach to the teaching of physics. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 51-74). Cambridge University Press.

Lara-Alecio, R., Tong, F., Irby, B. J., Guerrero, C., Huerta, M., & Fan, Y. (2012). The effect of an instructional intervention on middle school learners' science and English reading achievement. *Journal of Research in Science Teaching, 49*(8), 987-1011. doi:10.1002/tea.21031

Lee, O., Deaktor, R. A., Hart, J. E., Cuevas, P., & Enders, C. (2005). An instructional intervention's impact on the science and literacy achievement of culturally and linguistically diverse elementary students. *Journal of Research in Science Teaching, 42*(8), 857-887. doi:10.1002/tea.20071

Liu, F., & Stapleton, P. (2020). Counterargumentation at the primary level: An intervention study investigating the argumentative writing of second language learners. *System, 89*, 102-198. https://doi.org/fgkr

Llosa, L., Lee, O., Jian, F., Haas, A., O'Connor, C., Van Booven, C. D., Kieffer, M. J. (2016). Impact of a large-scale science intervention focused on English language learners. *American Educational Research Journal, 53*(2), 395 – 424. doi:10.3102/0002831216637348

McNeil, K. L., & Krajcik, J. (2007). Middle school students' use of appropriate and inappropriate evidence in writing scientific explanations. In M. C. Lovett & P. Shah (Eds.), *Thinking with data* (pp. 233-265). Taylor and Francis. doi.org/10.4324/9780203810057

Michaels, S., & O'Connor, C. (2012). Talk science primer. TERC. Retrieved from https://inquiryproject.terc.edu/shared/pd/TalkScience_Primer.pdf

Nussbaum, E. M. (2002). The process of becoming a participant in small-group critical discussions: A case study. *Journal of Adolescent and Adult Literacy, 45*, 488-497. http://www.jstor.org/stable/40014737

Nussbaum, E. M. (2003). Appropriate appropriation: Functionality of student arguments and support requests during small-group classroom discussions. *Journal of Literacy Research, 34,* 501-544. doi:10.1207/s15548430jlr3404_5

Nussbaum, E. M., & Edwards, O. V. (2011). Argumentation, critical questions, and integrative stratagems: Enhancing young adolescents' reasoning about current events. *Journal of the Learning Sciences, 20,* 433-488. doi:10.1080/10508406.2011.564567

Nussbaum, E. M., Tian L., Van Winkle, M. S., Perera, H. N., Putney, L. G., Dove, I. J., & Carroll, K. (2020). Using the critical questions model of argumentation for science teacher professional learning and student outcomes. In Gresalfi, M. & Horn, I. S. (Eds), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020*, Volume 4 (pp. 1895-1902). Nashville, Tennessee: International Society of the Learning Sciences. https://repository.isls.org//handle/1/6469

Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching, 48*(5), 486-511. https://doi.org/10.1002/tea.20415

Rosebery, A. S., Warren, B., & Conant, F. R. (1992). Appropriating scientific discourse: Findings from language minority classrooms. *The Journal of the Learning Sciences, 2*(1), 61-94. https://doi.org/bn7x5x

Sampson, V., & Grooms, J. (2010). GENERATE AN ARGUMENT: An instructional model. *The Science Teacher, 77*(5), 32-37. https://eric.ed.gov/?id=EJ888144

Suárez, E., & Otero, V. (2014). Leveraging the cultural practices of science for making classroom discourse accessible to emerging bilingual students. In J. Polman, E. Kyza, D. K. O'Neill, I. Tabak, W. R. Penuel, A. S. Jurow, K. O'Connor, T. Lee, L. D'Amico (Eds.), *Learning and Becoming in Practice*. *Proceedings of the 11th International Conference of the Learning Sciences,* 2, 800-807. https:repository.isls.org/bitstream/1/1197/1/800-807.pdf

Toulmin, S. (1958). *The uses of argument*. Cambridge University Press.

Verheij, B. (2003). Dialectical argumentation with argumentation schemes: An approach to legal logic. *Artificial Intelligence and Law, 11*, 167–195. https://doi.org/b7k756

Walton, D. N. (1996). *Argumentation schemes for presumptive reasoning.* Erlbaum.

Wink, J., & Putney, L. G, (2002). *A vision of Vygotsky*. Allyn and Bacon.

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem-solving. *Journal of Child Psychology and Psychiatry, 17*(2), 89–100. https://doi.org/10.1111/jcpp.1976.17.issue-2

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Undergraduate Students Reasoning about Genetic Mechanisms

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Abstract: In genetics, a domain with a vast impact on citizens' lives, mechanistic reasoning is challenging. In order to promote the ability to reason mechanistically in genetics, we should first understand what knowledge students need in order to be able to provide mechanistic explanations in this domain. In this study we interviewed undergraduate students studying toward a biological sciences degree and asked them to explain several complex genetic phenomena. We analyzed those interviews via two complementing perspectives – a mechanistic perspective and a cognitive perspective for domain-specific reasoning. We identified the type of domain specific knowledge used by students for reasoning and their use of domain general principles for mechanistic reasoning. We found that domain specific knowledge is used to operationalize domain general principals such as identifying and unpacking entities and linking between different parts of the suggested mechanism. We also found that domain-specific knowledge is used for re-visiting one's own explanation.

Introduction and theoretical framing

Since the days of the scientific revolution, the search after the mechanisms underlying natural phenomena have become central in science (Shapin, 2018). The centrality of mechanisms in science has not escaped the attention of science educators, and the importance of mechanistic reasoning for the development of scientific expertise is well acknowledged. One of the goals in science education is to provide students with the ability to reason with and about the mechanisms underlying natural phenomena they may encounter in their everyday lives. This is because reasoning about such mechanisms leads to a better understanding of phenomena and provides one with the ability to explain and critically think on other explanations (Ahn & Kalish, 2000; Koslowski, 1996). Mechanisms consist of entities with specific properties that enable them to conduct certain activities (Craver & Darden, 2013; Machamer et al., 2000). These activities cause changes which eventually lead to the observed phenomena (Craver, 2001; Darden, 2008). Hence, to understand a mechanism and to reason about similar mechanisms, one should be able to identify and characterize the entities involved in the mechanism, and recognize the activities and functions executed by those entities (Russ et al., 2008). Those entities and interactions should be at least one organizational level lower than the phenomenon itself, and they should be able to explain how interactions between entities at this level lead to the final outcome – the phenomenon (Krist et al., 2018).

Studies in science education suggest that mechanistic reasoning is challenging across all ages and domains (Abrams & Southerland, 2001; Kampourakis & Zogza, 2008; van Mil et al., 2013) (Abrams et al., 2001; Kampourakis & Zogza, 2008; van Mil et al., 2013). For example, Students tend to focus on "why" phenomena occur instead of "how" they occur – a teleological view (Kampourakis & Zogza, 2008; Tamir & Zohar, 1991). It was also shown that novices tend to focus on components (structures) instead of interactions and processes, and that they experience difficulties in connecting elements (components and processes) into a complete mechanism. (Assaraf & Orion, 2005; Hmelo-Silver & Pfeffer, 2004; Ruppert et al., 2017).

In our work we focus on the domain of genetics and the complicated mechanisms involved in genetic phenomena. The ability to reason mechanistically in genetics is important due to the prevalence and impact of genetics on citizens' everyday lives. Genetically modified food, Gene therapy and genetic testing are examples for how issues from the field of genetics may appear in the everyday lives and require citizens to take a stand or make decisions. In order to make informed decisions in such issues some basic knowledge about how genetic information affects the final trait, i.e. genetics mechanisms and their involvement in trait formation, is needed (Boerwinkel et al., 2017).

However, many difficulties were characterized in reasoning about the domain of genetics and specifically in understanding the entities involved, their functions and how they interact and affect the observable trait (e.g. Duncan & Reiser, 2007; Haskel-Ittah & Yarden, 2018; Lewis et al., 2000; Marbach-Ad & Stavy, 2000; van Mil et al., 2013). In addition, even when students understand genetic mechanism at some level, their conception about these mechanisms is often deterministic. Namely, they do not understand the dynamic nature of these mechanisms and how they interact with the environment (Haskel-Ittah, Duncan, & Yarden, 2020; Heine et al., 2017; Stern & Kampourakis, 2017). conceiving of genes as the direct, unmediated cause of traits may lead to views of socially constructed human differences as immutable and stable. Hence, such deterministic conception is not only incorrect but may also contribute to the development of stereotypic and racist views (Donovan, 2014, 2016; Keller, 2005).

If our aim is to promote students' ability to reason mechanistically in genetics and understand its dynamic nature, we have to understand what knowledge resources students need in order to be able to provide mechanistic explanations about dynamic genetic phenomena. By "dynamic genetic phenomena" we refer to various phenomena in which the environment is sensed by genetically based mechanisms and consequently activates respond mechanisms which affect traits. These phenomena are named "phenotypic plasticity" because the observed trait (phenotype) is plastic and can be changed as a respond to the environment. For example, skin color is a genetic trait that is affected by genes coding for proteins which are involved in the production of a pigment named "melanin". This trait is plastic in the sense that UV radiation sensed by the skin cells can enhance the production of melanin and its spatial organization in the cells and thus it makes the skin appear as darker (Miyamura et al., 2011).

Prior research in science education has argued that both domain-general and domain-specific knowledge is needed for mechanistic reasoning (Duncan, 2007; Krist et al., 2018). Domain-general knowledge provides strategies and heuristics for reasoning about mechanisms (Krist et al., 2018; Russ et al., 2008). For example, Krist (2018) suggested three general principles (heuristics) for supporting mechanistic reasoning in science: a) considering a lower scalar level – considering processes that occurs at the scalar level below the level of the observed phenomenon, b) identifying and unpacking entities – characterizing the entities involved in terms of their properties and functions, and c) identifying interactions between these entities and how they bring about the target phenomenon.

Domain-general heuristics, such as those noted above, are not sufficient to provide plausible and domain-appropriate mechanistic explanations. In order to "operationalize" the general heuristics one needs domain-specific knowledge about the type and nature of components and processes in the mechanism (i.e., what are the particular entities and interactions at the lower scaler level). Duncan (2007) identified two domain-specific knowledge resources that were relevant for explaining molecular genetics phenomena: one is principle-like knowledge elements that are applicable to a wide variety of phenomena in the domain of molecular genetics (termed domain-specific heuristics) and the other are schemas about key domain-specific mechanisms (termed domain-specific schema). Duncan's (2007) research focused on relatively simple molecular genetics phenomena which do not involve modulation by the environment. It is unknown whether the same domain-specific knowledge forms are used (and are useful) when reasoning about more complex genetic phenomena such as genetic plasticity ones.

Our previous work suggested that the two types of knowledge, general and domain-specific, interact and bootstrap each other during reasoning (Haskel-Ittah, Duncan, Vázquez-Ben, et al., 2020). This is because domain-specific knowledge is needed in order to instantiate the domain-general principles, and the latter can cue domain-specific knowledge. In the case of the process of identifying entities at a lower scalar level, domain-specific schemas may constrain the plausible entities and typical activities that can play a role in the mechanism at that scalar level. In fact, a mechanistic explanation, as defined by Russ et al. (2008) should include entities and activities embodied in such schemas, otherwise the mechanism cannot unfold and bring about its outcome. For example, the general principle of going down one level when discussing the symptoms of a disorder at the cell level (e.g. sickle cell anemia) suggests referring to the molecular level. However, there are many entities in the molecular level (proteins, membranes, genes), domain-specific heuristics and schema can specify which ones matter and how.

While these two types of knowledge (general and domain specific) were described in prior work, we lack a clear characterization of the interplay between them. Analyzing the interactions between domain-general and domain-specific knowledge occurring while students reason about complex genetic phenomena can shed light on the knowledge that is needed for mechanistic reasoning in this domain. Thus, our research questions were:

1. What are the domain-general knowledge and domain-specific knowledge resources used by students when explaining complex genetic phenomena?

2. How do these knowledge resources interact in the course of reasoning?

Methodology

Study context and participants

In this study we interviewed 25 undergraduate students at different levels of their studies toward a biological sciences degree. Seven students were 1st year students, 11 students were 2nd year students and seven students were 3rd students. All the students were studying toward a degree in a life sciences– related field (nutrition, animal sciences, biochemistry). While these majors do differ, they share some similar basic course requirements. Therefore, all of our students completed a basic cell biology course, and all of our second- and third-year students completed a basic genetics course.

Instruments and data collection

We asked students to explain three phenomena (tasks) that involved complex genetic mechanisms. We first presented the phenomenon and then asked students "how do you think this happens". We encouraged students to explain the underlying mechanisms and to elaborate on the mechanisms they suggested by asking them to explain how each part of their suggested mechanism happens. The three tasks were:

1. Tanning – students were asked to explain how tanning occurs as a result of sunlight.
2. Stunting – students were asked to explain how growth is inhibited in malnourished children, and how it may affect the offspring of these children (given the information that it indeed affect the children)).
3. Smell imprinting in worms – students were asked to explain how the offspring of worms conditioned to attract to a particular smell, were also attracted to the smell stimulus also despite not receiving a reward or conditioning.

All these tasks involve a genetically based trait (skin color, height, behavior of attracting to a smell) which is changed due to signals from the environment (UV light, lack of nutrients and odor molecules). These signals are sensed by the organisms and activates a respond mechanism which interacts with components in the genetic mechanism itself. For example, in the case of smell imprinting, the smell conditioning activated a respond mechanism which led to epigenetic changes (changes to DNA, but not to its sequence) that imprinted this type of behavior.

Analysis

We analyzed the interviews via two complementing perspectives – the domain-general mechanistic perspective developed by Russ et al. (2008) and Krist et al. (2018) and the domain-specific mechanistic perspective using the model developed by Duncan (2007).

We characterized the knowledge resources used by students while reasoning and sorted them as instantiations of principles (domain-general mechanistic perspective) or instantiations of domain-specific heuristics and schemas (domain-specific mechanistic perspective). Instantiations of domain-general knowledge were coded as follows: a) Students' consideration of a lower scalar level by identification entities at this level – this code includes two domain general heuristics (i.e considering the lower scalar level and identifying entities). we could not separate between the two because students' attributions to a lower scalar level was via entities at this level (Cells, tissue etc.). b) Unpacking of entities and interactions – namely referring to the functions conducted by the entities their properties and interactions.

Instantiations of domain-specific knowledge were coded as follows: a) domain-specific schemas – we coded for schemas which were previously identified such as Activate, Inhibit, Sensing Signaling, Regulation of gene expression, Catalyze and Transport (Duncan, 2007). We also searched for emerging new schemas. Schemas are mini-mechanisms which involve interacting entities, hence we searched for statements which describe interactions between entities (e.g. "The hormone activate growth" or "this substance binds to a receptor so that the receptor sends a signal"). b) domain-specific heuristics - we coded for schemas which were previously identified such as proteins-as-central, Genes-code-for-proteins and effects-through-interaction (Duncan, 2007). We also searched for emerging new heuristics. Exploring for heuristics was done by searching for "rule like" statements which repeated in several interviews (e.g. "processes in the body are regulated" or "epigenetics modifications may affect the offspring").

We then analyzed the interactions between the two perspectives and the knowledge involved. We searched for heuristics that were used for identifying entities at a lower level. For example, the heuristic "proteins are central" which was identified by Duncan (2007) may be used for focusing on proteins in a sub cellular level. Thus, we searched for instances in which students explicitly stated that X should be involved and then they refer to X in their proposed mechanism.

Results

Domain-general knowledge resources

1.Considering a lower scalar level

All students considered entities at a lower scalar level in their explanations. Almost all answers referred to cells and the more complex answers, namely the ones which involved multiple entities and interactions, involved sub-cellular entities such as genes, receptors or enzymes. Although answers varied in terms of their complexity, this consideration of a lower scalar level appeared in all answer. This suggests that at the university level students understand that the mechanism responsible for a particular phenomenon lies at a lower, hidden, scalar level than the level of phenomenon itself.

2. Unpacking entities and interactions at the lower scalar level

While all students identified at least one entity at a lower scalar level, not all of them could unpack or fully characterize these entities, namely they did not explain what are the biological functions of these entities and how they impact the mechanism. Instead they mentioned that these entities are needed or are changed in the mechanism, without explaining how exactly they are involved. For example, in the context of tanning:

Mor,1st year: The UV radiation gets in, it damages the cells so it changes the tissue so it looks darker

Interviewer: How does this happen?

Mor,1st year: The UV leads to a chain of reactions, electron jumps, and the cell is damaged.

This type of explanation does not unpack the cells, namely it does not specify the cell properties, function or interactions between the cell, UV and the color of the tissue. Instead it only suggests an unspecified causal relationship between these entities.

On the contrary some answers specifically explained what is the function of the identified lower-level entities. An example of this type is:

Lavi 3rd year: I guess there's a mechanism that reacts to radiation and leads to melanin production

Interviewer: How does this happen?

Lavi 3rd year: There is an enzyme that can produce melanin and this enzyme is genetic, there is a gene coding for it…. there are molecules which are light sensitive and when they absorb light… maybe they are transcription factors which activates this gene [coding for the enzyme].

In this case, Lavi specifies how the interactions between the "UV sensing molecules" and the gene for the melanin producing enzyme leads to an over production of melanin.

It is interesting to note that 12 out of 21 (57%) explanations of 1st year students did not unpack entities, 8 out of 33 (24%) explanations in 2nd year, and only 3 out of 21 in 3rd year (14%) did not unpack them either. Also, all students unpacked entities in at least one explanation out of the three tasks. These two findings imply that students understand the need of unpacking entities but the knowledge resources they have in the domain may not afford such unpacking.

Domain-specific knowledge resources

Domain-specific schema

We identified, across students' explanations, all the seven schemas which were originally identified by Duncan (2007): Activate, Inhibit, Sensing Signaling, Regulation of gene expression, Catalyze and Transport. We did not identify any new schemas. This finding suggests that these seven schemas are fruitful for reasoning in the contexts of simple and complex genetic phenomena.

Domain-specific heuristic

We identified in students' explanations the use of the following heuristics which were previously described by Duncan (2007): Gene-code-for-proteins, proteins-as-central and structure-function. We also identified new heuristics (see table 1).

Table 1 – Heuristics used by undergraduate students in order to reason about phenotypic plasticity mechanisms.

Heuristic	Description	Example
Biological-processes-are-regulated	There are regulatory pathways which can respond to different situations	"the body knows if there are enough nutrients"

Genes-are-inherited	Inheritance is the transfer of DNA/genes from parents to their offspring	"then these changed genes were transferred to the offspring"
Genetic-modifications-in reproductive-cells-are-inherited	Only changes in genes of reproductive cells are inherited	"[it affected the offspring], so it probably changed something in the gametes"
Epigenetics-modifications-are inherited/not-inherited	epigenetics modifications persist in offspring cells/ epigenetics modifications are deleted in the embryo	"the epigenetics modifications were transferred to the offspring"/ "it should have been deleted in the embryo, though…"
Genetic-information-is-stable	genetic information does not easily change	"it is unlikely that the genetic code was changed because of this"

Unlike Duncan (2007) which focused on heuristics related to molecular genetics, in this study we explored also for heuristics at other levels. Thus, some of the domain-specific heuristics we identified are more broad. For example, the heuristic genes-are-inherited is not specifically related to molecular level mechanisms and may be also used to describe more general, macro-level, genetic phenomena. The heuristic biological-processes-are-regulated is not only related to genetics but to biology in general thus may be used for reasoning in other biological domains. These examples imply that heuristics may be at several levels of domain-specificity. The fact that we identified several new heuristics and no new schemas in our exploration may suggest that some heuristics are more context dependent than others as opposed to schemas which seem to be less context specific (i.e., apply to many distinct phenomena in the domain). In addition, heuristics seem to and range at different level of domain specificity (e.g. biology – genetics – molecular genetic). It should be noted that domain-specific schema may also have different levels of specificity. For example, schemas such as "activate" or "inhibit" seems to be more general in scope than "sensing" or "catalyzing" which involve more specific activities.

Interactions between knowledge resources in the course of reasoning

In order to answer the 2nd research question we analyzed the interactions between the types of knowledge-domain-general and domain-specific and between heuristics and schemas.

As noted earlier, we found that not all students managed to unpack the entities they identified, meaning they did not explain how the identified entities are involved in the mechanism. For example, students described the involvement of cells without explaining what exactly was changed in the cells or how this change resulted in the given phenomenon or they suggested that an enzyme was affected without mentioning the enzyme's function and how it was changed. We suggested that this is due to missing domain specific knowledge. Such explanations did not include any schemas (i.e. the cells or enzyme did not have any function). Hence, we would like to suggest that the missing knowledge needed to operationalize entities in domain-specific terms are relevant schemas. By relevant schema, we mean a schema that is perceived by the student as relevant. In some cases, students invoked a particular schema in one context (where they perceived it as relevant) but not in another context (because they did not see it as relevant even though it was). This means that key to developing a robust ability to explain genetic phenomena is conditional knowledge of when different schemas (and presumably heuristics) apply and when they do not.

We also found that students made use of heuristics in order to identify plausible entities. For example, the heuristic proteins-as-central, which determines that proteins are central entities in genetics phenomena, was used when students identified proteins as entities in the mechanism once the phenomenon was framed by the students as a genetic phenomenon. The domain-specific heuristic genes are inherited was used when students identified genes as entities in the mechanism once the phenomenon was framed as involving inheritance. An example for such use is in the context of smell imprinting. Mor, 1st year student, tried to explain how the offspring of the worm were attracted by a certain smell while never being exposed to it (only their mother was):

> "They [offspring] get a similar genetic code so the smell triggers it [a pathway lead to moving toward the smell] ….it all makes me think that a change happened to the genetic code".

Mor used the genes-are-inherited heuristics to posit the genetic code as a central entity in the mechanism she later described.

In other cases, domain-specific heuristics served as a link between two parts of the mechanism, namely parts which were not clearly connected by interacting entities. For example, the genes are inherited heuristic sometimes served as a link between what happened in the parent to what happened in the offspring without a need to explain the entire process of inheritance in which egg or sperm cells are produced and then fuse during fertilization (meiosis, fertilization). Genes-code-for-protein heuristic served to link between the genetic information and the product of a protein without a need to explain how genes are information units that are "read" by the cell as instructions for making proteins though cellular processes called transcription and translation. For example, May 2nd year, explained that growth inhibition involved a genetic mechanism but at first she explained it at the level of gene and then linked it to the protein via the genes-code-for proteins heuristic: "Maybe something blocks the gene which encodes the proteins that signals the body to grow, so the gene is not translated into protein". May does not explain how genes code for protein or how gene translation occurs but uses this heuristic as an input (gene) – output (protein) link. These heuristics specify input and outputs of processes and thus serve as a bridge between different parts of the mechanism.

Interestingly we also identified another type of domain general strategy that students often used which was not previously identified by Krist et al., (2018) or Duncan (2007) as essential for reasoning but consistently appeared in students' explanations. This is the process of re-visiting the explanation and criticizing it. We found that students used domain-specific heuristics in order to scrutinize and criticize their suggested mechanism. For example, after suggesting that the DNA sequence was probably changed, Michal (1st year) acknowledged that "From what I know a gene is not easily changed" Michal is criticizing the plausibility of her explanation by using the genetic information is stable heuristic. Other examples are from students trying to explain how growth inhibition due to malnutrition may be inherited. Both students (Ohad, 3rd year and Yuval, 2nd year) criticized their explanation which involved inheritance of epigenetic modifications by using the heuristic epigenetics-modifications-are-not-inherited: "From what I remember the epigenetic control is removed" (Ohad, 3rd year); "I think these Methylations are supposed to open but maybe I'm wrong" (Yuval, 2nd year). In these cases, students questioned their suggestion that epigenetics modifications persist in the offspring. This heuristic, which is true for some, but not all, cases was used in order to suggest that if this "rule" is applied here than the suggested mechanism cannot exist.

Discussion

In this study we searched for the role of different types of knowledge resources, domain-general and domain-specific, and their interactions. While in the literature general practices and domain-specific resources previously described for mechanistic reasoning (Duncan, 2007; Krist et al., 2018) were used as two distinct perspectives in observing mechanistic reasoning, we found a deep almost inseparable connection between them. More specifically, our result imply that undergrad students appreciate the need to identify and unpack entities at a lower scalar level. However, their explanations sometime do not include this identification and unpacking because they do not have domain-specific schemas which can act as placeholders for the specific functions and interactions between these entities. Hence their explanations may seem as a list of causes without specifying the interactions between these causes, namely the mechanism.

A recent study of Chinese elementary school students suggested that children often focus on patterns or causal relationships instead of the mechanism (Tang et al., 2020). The study offered that this is the result of the Chinese national standards and curriculum which are more focused on the pattern seeking than on mechanistic reasoning. Our results imply that understanding the need of a mechanism is also not enough, if there are no knowledge resources in the domain which allow the unpacking of entities into a mechanistic explanation. Hence not only domain general strategies should be explicitly taught (as suggested by Krist et al., 2018) but also domain-specific schemas should be emphasized and their building should be scafolded as part or teaching students how to reason mechanistically in a certain domain.

Our study also dealt with non-mechanistic, but important, parts of mechanistic explanations – heuristics. By definition, the heuristics themselves are not mechanistic since they explain what happens and do not involve functions and interactions between entities and activities (Braaten & Windschitl, 2011; Craver & Darden, 2013). However, our results suggest that these non-mechanistic rules have several roles in the process of mechanistic explanations. First, they act in the process constructing the mechanism because they are used for evaluating the plausibility of the involvement of specific entities in the mechanism or the mechanism as a whole. In addition, it seems that these heuristics also act as links between parts of the mechanism thus are important for the ability to connect parts in the mechanism into a coherent explanation.

In summary, we found that domain general knowledge and domain-specific knowledge interplay while students' reason about genetic mechanism. Our study implies that domain-specific heuristics and schemas exist in several levels of domain-specificity and that heuristics are used for several purposes such as to instantiating the identification of entities and for bridging gaps in the mechanism and schemas are used for unpacking entities. We also found that heuristics may be used for the purpose of evaluating the plausibility of the suggested mechanism. This study also suggests that a dual perspective of both domain-general and domain-specific knowledge is fruitful for studying mechanistic reasoning and provide a wider picture on the reasoning process than each of the perspectives separately.

Instructional Implications

Our study reveals the importance of domain-specific and domain-general knowledge for the ability to reason mechanistically. This means that both types of knowledge should be targeted explicitly not only in undergraduate education but all along science teaching. Since heuristics are non-mechanistic but important parts of mechanistic reasoning, we offer that their distinction from mechanistic schemas will be also explicitly taught.

In our study we found domain-specific heuristic which lay at different specificity levels than others and we offer that some schemas are also more general than others. This point should be empirically tested, and if indeed such hierarchy exist it may suggest that more general biological heuristics and schema should be constructed at younger ages and become more specific at higher grades. In such manner, students may be able to construct mechanistic explanations in biology already at these younger ages and develop this ability along the school years.

References

Abrams, E., Southerland, S., & Cummins, C. (2001). The how's and why's of biological change: How learners neglect physical mechanisms in their search for meaning. *International Journal of Science Education*, *23*(12), 1271–1281. https://doi.org/10.1080/09500690110038558

Ahn, W., & Kalish, C. W. (2000). The role of mechanism beliefs in causal reasoning. *Explanation and Cognition*, 199–225.

Assaraf, O. B., & Orion, N. (2005). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *42*(5), 518–560.

Boerwinkel, D. J., Yarden, A., & Waarlo, A. J. (2017). Reaching a consensus on the definition of genetic literacy that is required from a twenty-first-century citizen. *Science & Education*, *26*(10), 1087–1114.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science Education*. https://doi.org/10.1002/sce.20449

Craver, C. F. (2001). Role functions, mechanisms, and hierarchy. *Philosophy of Science*, *68*(1), 53–74.

Craver, C. F., & Darden, L. (2013). *In search of mechanisms: Discoveries across the life sciences*. University of Chicago Press.

Darden, L. (2008). Thinking again about biological mechanisms. *Philosophy of Science*, *75*(5), 958–969.

Donovan, B. M. (2014). Playing with fire? The impact of the hidden curriculum in school genetics on essentialist conceptions of race. *Journal of Research in Science Teaching*, *51*(4), 462–496.

Donovan, B. M. (2016). Framing the genetics curriculum for social justice: an experimental exploration of how the biology curriculum influences beliefs about racial difference. *Science Education*, *100*(3), 586–616.

Duncan, R. G. (2007). The role of domain-specific knowledge in generative reasoning about complicated multileveled phenomena. *Cognition and Instruction*, *25*(4), 271–336.

Duncan, R. G., & Reiser, B. J. (2007). Reasoning across ontologically distinct levels: Students' understandings of molecular genetics. *Journal of Research in Science Teaching*, *44*(7), 938–959.

Haskel-Ittah, M., Duncan, R. G., Vázquez-Ben, L., & Yarden, A. (2020). Reasoning about genetic mechanisms: Affordances and constraints for learning. *Journal of Research in Science Teaching*. https://doi.org/10.1002/tea.21595

Haskel-Ittah, M., Duncan, R. G., & Yarden, A. (2020). Students' Understanding of the Dynamic Nature of Genetics: Characterizing Undergraduates' Explanations for Interaction between Genetics and Environment. *CBE—Life Sciences Education*. https://doi.org/10.1187/cbe.19-11-0221

Haskel-Ittah, M., & Yarden, A. (2018). Students' Conception of Genetic Phenomena and Its Effect on Their Ability to Understand the Underlying Mechanism. *CBE—Life Sciences Education*, *17*(3), ar36.

Heine, S. J., Dar-Nimrod, I., Cheung, B. Y., & Proulx, T. (2017). Essentially Biased: Why People Are Fatalistic About Genes. In *Advances in Experimental Social Psychology*. https://doi.org/10.1016/bs.aesp.2016.10.003

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science*, *28*(1), 127–138.

Kampourakis, K., & Zogza, V. (2008). Students' intuitive explanations of the causes of homologies and adaptations. *Science & Education*, *17*(1), 27–47.

Keller, J. (2005). In genes we trust: the biological component of psychological essentialism and its relationship to mechanisms of motivated social cognition. *Journal of Personality and Social Psychology*, *88*(4), 686.

Koslowski, B. (1996). *Theory and evidence: The development of scientific reasoning*. Mit Press.

Krist, C., Schwarz, C. V, & Reiser, B. J. (2018). Identifying Essential Epistemic Heuristics for Guiding Mechanistic Reasoning in Science Learning. *Journal of the Learning Sciences*, 1–46.

Lewis, J., Leach, J., & Wood-Robinson, C. (2000). All in the genes?—young people's understanding of the nature of genes. *Journal of Biological Education*, *34*(2), 74–79.

Marbach-Ad, G., & Stavy, R. (2000). Students' cellular and molecular explanations of genetic phenomena. *Journal of Biological Education*, *34*(4), 200–205.

Miyamura, Y., Coelho, S. G., Schlenz, K., Batzer, J., Smuda, C., Choi, W., Brenner, M., Passeron, T., Zhang, G., & Kolbe, L. (2011). The deceptive nature of UVA tanning versus the modest protective effects of UVB tanning on human skin. *Pigment Cell & Melanoma Research*, *24*(1), 136–147.

Ruppert, J., Duncan, R. G., & Chinn, C. A. (2017). Disentangling the Role of Domain-Specific Knowledge in Student Modeling. *Research in Science Education*, 1–28.

Russ, R. S., Scherr, R. E., Hammer, D., & Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education*, *92*(3), 499–525.

Shapin, S. (2018). *The scientific revolution*. University of Chicago Press.

Stern, F., & Kampourakis, K. (2017). Teaching for genetics literacy in the post-genomic era. In *Studies in Science Education*. https://doi.org/10.1080/03057267.2017.1392731

Tamir, P., & Zohar, A. (1991). Anthropomorphism and teleology in reasoning about biological phenomena. *Science Education*, *75*(1), 57–67.

Tang, X., Elby, A., & Hammer, D. (2020). The tension between pattern-seeking and mechanistic reasoning in explanation construction: A case from Chinese elementary science classroom. *Science Education*, *November 2019*, 1–29. https://doi.org/10.1002/sce.21594

van Mil, M. H. W., Boerwinkel, D. J., & Waarlo, A. J. (2013). Modelling molecular mechanisms: a framework of scientific reasoning to construct molecular-level explanations for cellular behaviour. *Science & Education*, *22*(1), 93–118.

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Observing or Generating Solution Attempts in Problem Solving Prior to Instruction: Are the Preparatory Processes Comparable?

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Abstract: Problem solving prior to instruction (PS-I) approaches have been found to facilitate students' conceptual learning. It has been argued that the problem-solving processes prepare students for subsequent instruction. During problem solving, students are asked to generate multiple solutions to a novel problem. Yet, it is still unclear whether students actually need to generate solutions themselves to be prepared for learning from instruction or whether they could also receive solution examples and study those. Recent findings are mixed, requiring further analyses that investigate the preparatory processes during both types of activities. In this paper, we investigate students' cognitive processes during generation and observation of solution attempts in order to better understand and design for the preparatory mechanisms in PS-I. We hypothesized that both activities would involve similar cognitive processes for the preparation of subsequent learning. Our results confirm this comparability, suggesting that similar preparatory processes are at work.

Introduction

Recent research has demonstrated the success of instructional approaches that emphasize the role of problem solving prior to instruction (PS-I) for learning (for a review, see Loibl et al., 2017). Students, who participated in problem solving followed by direct instruction, were shown to perform higher in a conceptual knowledge test than students who received instruction first and practice problems after (I-PS) (e.g., Kapur, 2014b). Despite the success of PS-I, we still lack a full understanding of the cognitive mechanisms that prepare students for subsequent learning. Loibl et al. (2017) proposed three preparatory mechanisms: prior knowledge activation, awareness of knowledge gaps, and deep feature recognition. The present paper focuses on the preparatory mechanism *prior knowledge activation*. In our PS-I setting, which is also referred to as Productive Failure (PF) task, students in the problem-solving phase are instructed to generate multiple solution approaches to a novel and challenging mathematical problem (Kapur & Bielaczyc, 2012). The generation of different solution attempts is presumed to encourage students to activate and differentiate relevant prior knowledge, which facilitates processing the subsequent instruction (Kapur & Bielaczyc, 2012). While prior knowledge activation is assumed to be a core mechanism of PS-I (Kapur & Bielaczyc, 2012; Loibl et al., 2017), it is unclear whether the preparatory effect of prior knowledge activation is only afforded by generating solution oneself. In order to further examine this preparatory mechanism, studies have investigated whether observing examples of students' failed solution attempts has similar preparatory effects as generating solutions oneself (e.g., Hartmann et al., 2020, 2021; Kapur, 2014a). Kapur (2014a, 2014b) asked students in a so-called Vicarious Failure (VF) condition to evaluate examples of other students' solution attempts. Results showed that the VF students outperformed I-PS students in a knowledge test, indicating that VF students were prepared for subsequent learning. However, VF students were outperformed by PF students, suggesting a higher preparation effect in the PF condition. In contrast, Hartmann et al. (2021) found that students who generated solutions themselves (PF) did not perform better than those who observed examples of PF students' complete problem-solving process (VF). The mixed findings suggest that further research is needed to examine the comparability of the preparatory mechanisms at work in PF and VF. More specifically, empirical evidence is needed on the preparatory processes of knowledge activation. This paper aims to shed further light onto students' cognitive processes during both types of preparatory activities (i.e., problem solving in PF and observation of examples in VF) by comparing the think-aloud recordings (i.e., their verbalized thoughts) of matched PF and VF model-observer-pairs. In the following, we give an overview of relevant prior research and describe potential PF and VF cognitive processes.

Problem solving and observing examples as preparatory activities

When students in PS-I generate solutions to a novel problem which they are not yet able to solve, they are assumed to activate relevant prior knowledge and become aware of the limits of this knowledge. For instance, in a typical PF task about the concept of standard deviation, students need to find the most consistent soccer player based on the goal scores of three players within ten years. During subsequent instruction, students then receive an explanation about common mistakes in student solutions, which aims to relate to their knowledge gaps and facilitate the integration of new knowledge about the deep features of the canonical solution (e.g., standard deviation) (Loibl et al., 2017; Loibl & Rummel, 2014b).

Kapur and Bielaczyc (2012) highlighted the importance of generating own solution attempts during the problem-solving phase to afford prior knowledge activation. However, the specific processes underlying prior knowledge activation in PS-I still remain unclear and might not be exclusively related to the generation of own solution attempts. For instance, research on worked examples suggest that the observation of examples could serve as a similar or even better preparation for subsequent learning than problem solving (cf. Likourezos & Kalyuga, 2017; Newman & DeCaro, 2019). In an attempt to examine boundary conditions of PS-I, several studies investigated whether the observation of examples in form of students' solution attempts could also prepare for learning from instruction. In two experimental studies, Kapur (2014a, 2014b) designed VF conditions, in which he asked students to evaluate the validity of examples of erroneous and incomplete student solutions. Results revealed that evaluating examples prepared them for learning from subsequent instruction and lead to higher learning gains than those shown by students who received instruction first and practice problems after (I-PS). Yet, they were outperformed by students who generated solutions in a PF condition. In contrast, Hartmann et al. (2021) found that students of a VF condition who observed the problem-solving process of PF students, achieved equal learning gains as students of a PF condition and even outperformed them when they showed higher prior knowledge scores.

The recent findings by Hartmann et al. (2021) suggest that students in PS-I do not necessarily need to generate solutions themselves, but might achieve equal preparation for learning, by observing and making sense of another student's problem-solving process. Comparability regarding the preparation for learning would suggest that both, generating and observing solutions afford similar preparatory processes. However, overall, the comparison of learning gains in PF and VF has led to mixed findings. In order to find explanations for these findings and identify boundary conditions for the effectivity of PF and VF, it is necessary to achieve a better understanding of the cognitive processes afforded in both conditions. With this understanding, we can define relevant aspects for instructional designs that enable preparation for subsequent learning in PS-I. So far, the cognitive processes in VF have not been investigated and only few studies have attempted to describe the problem-solving processes within PS-I settings such as PF. Roll et al. (2012), Brand et al. (2018), and Brand et al. (2019) offered categorizations that divide problem solving in PS-I into different phases based on models of mathematical problem-solving or the inquiry cycle (cf. de Jong, 2006; Schoenfeld, 1985). We build upon these approaches and describe the cognitive processes of PF *and* VF students with the help of four categories: task orientation, engagement with solution attempts, elaboration of solution attempts, and evaluation of solution attempts (cf. Table 1). While the first three categories primarily feature prior knowledge activation processes, the fourth category deals with the metacognitive processes of evaluation and monitoring. All described processes can appear more than once and not necessarily consecutively during the preparatory activities (i.e., generation or observation of solution attempts) of both PF and VF conditions.

The first category is *task orientation*. In order to be able to engage in the preparatory activities, students have to understand the task's components and goal (cf. Roll et al., 2012; Schoenfeld, 1985). The students of both conditions receive the same problem about the formula of standard deviation (e.g., Kapur, 2012; Loibl & Rummel, 2014b). While the students of the PF condition are instructed to generate different solution attempts that display the consistency of three soccer players, the students of the VF group receive the problem as a basis for observation, but are not asked to generate solution attempts (cf. Hartmann et al., 2020, 2021). As both groups of students have not yet learned about standard deviation, it is plausible that both PF and VF students similarly need to form an understanding of what consistency means in the context of the given problem. For this task orientation, students might activate and reflect on their formal and informal prior knowledge about consistency in order to generate ideas or criteria that link their knowledge to the goal of the task. This can include both cognitive and metacognitive processes, however, we focus on the cognitive process of activating relevant prior knowledge for understanding the task.

The category e*ngagement with solution attempts* represents the main part of the preparatory activities in both conditions, the students deal with various solution attempts to the given problem. Roll et al. (2012) describe these processes as plan, design, and implementation stages. Both, generating solutions oneself (PF) and observing solutions (VF) require students to activate relevant prior knowledge. Even though both conditions implement different triggers for prior knowledge activation (i.e., generation versus observation of solution attempts), the VF observer has the opportunity to engage in the similar prior knowledge activation processes as the PF model through a step by step observation of the PF student's problem-solving process. Therefore, when the PF model comes up with a solution idea and starts to execute it (e.g., central tendencies such as mean, range or graphical solutions), the VF student observes the idea, which triggers the activation of relevant prior knowledge associated with the solution idea. Similar to the PF condition, students of the VF condition might think about own solution ideas. Additionally, they have the opportunity to compare their ideas with those of the PF model. Kapur (2012) showed that students generate a limited range of solutions that spans four categories. Therefore, we can expect students of both conditions to largely come up with the same types of ideas, and thus, to activate prior knowledge to a similar extent. Consequently, the observation and generation of solutions could trigger similar engagement with solution attempts in both conditions.

Elaboration of solution attempts defines another stage in the process: the analysis and interpretation of the solution attempts with regard to what they imply about the problem's solution (cf. Hartmann et al., 2021). In order to fully comprehend the implication, students need to interpret the results of their calculations in the context of the given problem (i.e., what do values such as the mean or range tell me about the consistency of the soccer players?). The students of both conditions are likely to engage in this process of sense-making in the same way in order to form an understanding of the present solution attempts. Through the analysis of solution attempts, students might be able to build an elaborated understanding of the generated solutions, that is, advancing and differentiating the knowledge that they activated when dealing with the different solution attempts (Kapur & Bielaczyc, 2012).

The last category is *evaluation of solution attempts.* In problem-solving, students rely on metacognitive skills such as monitoring and evaluation of the problem-solving process in order to ensure its success (Schoenfeld, 1985). Said metacognitive skills majorly come into play during the evaluation phase in PS-I, in which students evaluate the outcome of their solution attempts (cf. Roll et al., 2012). While students of the VF condition do not engage in the monitoring of their own problem-solving processes, they evaluate and monitor the problem-solving process of the PF model when trying to make sense of the PF model's solution attempts. As the students of both conditions deal with a novel problem, evaluation and monitoring processes could likewise encourage them to question the validity of solution attempts and become aware of their knowledge gaps (cf. Loibl et al., 2017). Additionally, monitoring processes of the PF model's problem-solving process could enable the VF student to identify errors or knowledge gaps in the PF model.

Based on the outlined cognitive processes in VF and PF, we hypothesize that a process analysis of the verbal reports of matched PF and VF model-observer-pairs (i.e., one VF student who observes the problem-solving process of one PF student) will show similar quantities of the outlined types of cognitive processes throughout both preparatory activities. That is, the model-observer-pairs will not significantly differ in the number of utterances related to the processes in each of the four categories discussed above.

Methods

Participants and design

The experimental study that provided the process data used in this paper was conducted in a German secondary school during regular mathematics classes (cf. Hartmann, 2020). The original sample of the study consisted of 110 students, who were randomly assigned to two conditions (i.e., PF and VF). Each student of the VF condition was randomly matched to students of the PF condition to form model-observer-pairs (PF: n = 55, VF: n = 55). During the preparatory activity, the students of the VF condition watched a live transmission (live screen recordings) of their matched PF students' handwritten notes during problem solving.

For the process analysis, we selected a subsample of 15 matched PF and VF model-observer-pairs (N = 30, PF: n = 15, VF: n = 15). In order to control for prior mathematical abilities (i.e., students' average of their last two grades in mathematics), which significantly predicted students' knowledge scores in the main sample, $r(108) = .71$, $p < .001$, the pairs were selected based on the similarity of their mathematical abilities. That is, only students with the same or minor differences (i.e., 0.5) in average grade were included in the subsample. A Bayesian paired t-test confirmed the comparability of the subsample and the main sample as the selected pairs showed equal conceptual learning scores, that is, the assumption that PF and VF pairs had similar learning scores (BF_{01}; H_0) is 2.11 times higher than the assumption of a difference in conceptual knowledge (BF_{10}; H_1).

Process data

For the process analysis, we used think-aloud audio recordings as an indicator of students' cognitive processes during problem solving in both conditions (cf. Ericsson & Simon, 1980). Based on the PF coding scheme by Brand et al. (2018), we developed a coding scheme that describes students' cognitive processes in PF and VF based on their utterances during problem solving. It includes four categories of processes: task orientation, engagement with solution attempts, elaboration of solution attempts, and evaluation of solution attempts. Each of the categories includes sub-codes that describe specific processes within each category, with 44 codes in total (see Table 1 for examples). *Task orientation* features codes that specify the components or goal of the given task. The category *engagement with solution attempts* includes codes about the generation or observation of solution ideas. Additionally, it describes three variables that only apply to the VF condition: two codes refer to VF students comparing their own ideas to the one's of their PF model. A third one functions as a manipulation check variable that includes statements, which indicate that the handwritten solution attempts were not comprehensible to the VF student. *Elaboration of solution attempts* describes students' analysis and interpretation processes such as deduction from the results of a solution (i.e., in terms of which player might be the most consistent). The category *evaluation of solution attempts* contains the metacognitive processes of evaluation and monitoring of one's own knowledge as well as an additional VF code, which outlines the identification of errors in the PF model's solution.

Table 1: Example codes and statements for each coded category

	Category	**Example code for the category**	**Example statement**
1	Task orientation	Definition of the task	*All given data needs to be included in the calculations.*
2	Engagement with solution attempts	Identification of solution ideas	*I/The model calculate(s) the mean.*
		Comparison of VF and PF ideas	*I had the same idea. // I would not have done that.*
		Incomprehensibility of PF ideas	*I cannot make out anything from what is written here.*
3	Elaboration of solution attempts	Substantiated deduction from results	*Mario is the most consistent player as he scores almost the same number of goals each year!*
4	Evaluation of solution attempts	Positive evaluation of solutions	*The first solution was really good!*
		Identification of own knowledge gaps	*I do not know whether this solution will work or not.*
		Identification of errors in PF model	*The solution does not make any sense.*

We coded the audio data with the software MaxQDA 2020. Prior to coding, the data was segmented by an expert who preselected on-task utterances for coding. Due to the high number of codes, the coding process was divided into two steps. First, all on-task segments of a student were assigned to one of the four categories, then, for each category separately, the utterances of the segments were tagged with sub-codes. 20% of the data was coded by two independent raters, showing an excellent agreement on both coding levels (categories: *ICC* (*3, 1*) = .90, 95% *CI* [.70, .98]; sub-codes: *ICC(3, 1)* = .92, 95% CI [.80, .99]). For the analysis, we counted the frequencies of each sub-code and calculated the sum for each category. The category sums only included variables, which occurred in PF and VF, while the VF variables (i.e., the comparison of VF and PF ideas and identification of errors) were summed up as a separate variable.

Procedure and materials

In the following, we summarize the relevant methods of an experimental study by Hartmann (2020) that provided the data for the present inquiry. The procedure and materials followed the same methodological protocol as previous studies in PS-I (see Kapur, 2012 for design of the PF problem; Loibl & Rummel, 2014b for design of the direct instruction and knowledge test). The experiment took place during two regular mathematics classes (90 minutes each). Before the first activity, the students were asked to complete a prior knowledge test and report their prior abilities (20 minutes). After that, students were randomly assigned to two conditions and engaged in the preparatory activities (45 minutes): the students in the PF condition were instructed to generate as many solutions to the given problem as possible, while the students in the VF condition received live transmissions of their PF model's handwritten solution attempts on a computer screen. The students were in the same classroom, but not aware of the identity of their matched partners as they were seated apart and with their backs to each other. During the time of the preparatory activity both groups of students were instructed to verbalize their thoughts. After that, students filled in a questionnaire to assess their awareness of knowledge gaps (5 minutes). In the following mathematics class, both groups jointly received a direct instruction (30 minutes) on the components of the canonical solution. Both, the preparatory activity and the instruction were conducted by the same trained member of the research team. Finally, the students filled in a knowledge test (30 minutes).

The problem used in the preparatory activity targets the formula of standard deviation. It asks students to find the most consistent soccer player among three based on a data table that displays the players' goal scores across ten years. The final instruction was based on typical erroneous student solutions and explained the components of the canonical solution. Prior to the preparatory activity, we assessed the students' last two grades in mathematics, their prior knowledge, and their mathematical self-concept. The students' prior knowledge was measured with a knowledge test consisting of five tasks on descriptive statistics (i.e., mean and range) (Cronbach's alpha = .32; reliability measures for the whole sample). The low Cronbach's alpha value likely resulted from the fact that various mathematical concepts were tested that did not necessarily interrelate. The measures for mathematical self-concept were adopted from Rost and Sparfeldt (2002) and included the students' belief about their mathematical skills (e.g., '*It is easy for me to solve problems in mathematics.*') with eight items on a 6-point

Likert scale (Cronbach's alpha = .93). The final knowledge test after instruction included eight tasks on students' conceptual (Cronbach's alpha = .67) and four tasks on their procedural knowledge (Cronbach's alpha = .87). 20% of the students' knowledge tests were coded by a second rater, showing high reliability for all items (*ICC (2,1)* = .97, 95% *CI* [.93, .99]).

Results

Prior to the process analyses, we examined the VF manipulation check variable. The variable assessed whether students of the VF condition struggled to comprehend the PF model's problem-solving process. The analysis of the variable revealed no concerns for a failure of manipulation as only minor difficulties such as reading problems occurred, all of which were resolved later on in the activity. In total, we coded 1559 utterances. 1459 utterances referred to processes that could occur in both conditions and an additional 100 to processes unique to VF. Out of the 1459 utterances, students in VF produced 782 (M = 58.80; SD = 23.09) and students in PF 677 utterances (M = 45.13; SD = 16.98). Table 2 shows the ranges, means, standard deviations, and frequencies of each category of the coded processes for both conditions (excluding VF-only processes). In both conditions, utterances coded as *task orientation* occurred the least, *engagement with solution attempts* the most. The frequency of the processes varies a lot between individual students as shown by the high standard deviations. Descriptively, the analyses reveal that the quantity of cognitive processes per category was largely similar for both conditions, except for category 4, in which the average frequencies of PF and VF processes differed descriptively by 9.33.

Table 2: Descriptive statistics of the four categories of PF and VF processes (PF: n = 15, VF: n = 15, N= 30)

	Task orientation			**Engagement with solution attempts**			**Elaboration of solution attempts**			**Evaluation of solution attempts**		
	PF	**VF**	**Total**	**PF**	**VF**	**Total**	**PF**	**VF**	**Total**	**PF**	**VF**	**Total**
M	2.33	2.27	2.30	26.00	29.67	25.77	6.2	4.40	5.30	10.60	19.93	15.27
SD	1.80	2.76	2.29	10.17	12.91	10.46	3.65	2.75	3.30	7.03	9.85	9.66
range	0-6	0-8	0-8	12-52	10-54	9-52	1-12	0-9	0-12	4-26	1-36	1-36
freq (%)	35 (5.17%)	34 (4.35%)	69 (4.73%)	390 (57.61%)	383 (48.98%)	773 (52.98%)	93 (13.74%)	66 (8.44%)	159 (10.90%)	159 (23.49%)	299 (38.24%)	458 (31.39%)

Additional to the 782 VF processes above, Table 3 presents the descriptive data for the processes that were unique to VF, excluding the manipulation check variable as it does not provide further information about VF. The remaining three processes amounted to 62 utterances (7.03% of all VF processes). The first two VF variables can be assigned to category 2, *engagement with solution ideas*, and describe the comparison of a VF student's own solution ideas with those of their PF model (agreement vs. disagreement). The last variable describes the identification of errors in the solution attempts of the PF model and is part of the category 4: *evaluation of solution attempts*. Out of the three variables, the identification of errors appeared most frequently.

Table 3: Descriptive statistics for variables that could only occur in VF (n = 15)

	Comparison of PF and VF ideas (agreement)	**Comparison of PF and VF ideas (disagreement)**	**Identification of errors in PF solutions**	**VF-only processes (sum of all variables)**
M (SD)	0.93 (1.83)	0.67 (0.90)	2.53 (2.92)	4.13 (3.50)
range	0-6	0-3	0-9	0-12

We hypothesized that the quantity of utterances (i.e., students' cognitive processes) in each of the four categories would not differ between PF and VF pairs. To test our assumptions, we calculated four Bayesian paired samples t-tests, one for each of the categories (calculated in JASP 0.14.00, for information on Bayesian statistics see Wagenmakers, Love et al., 2018; Wagenmakers, Marsman et al., 2018). The paired sample tests assessed the mean differences for each of the 15 matched model-observer-pairs. Figure 1 shows the plotted results for categories 1 to 4. Panel A shows the results for the category *task orientation*. The Bayes factor indicates that based on the given data the assumption that the matched model-observer-pairs in PF and VF do not differ in the number of task orientation processes (BF_{01}; H_0) is 3.80 times more likely than the assumption that PF and VF pairs differ in this category (BF_{10}; H_1), presenting a moderate evidence for our hypothesis (cf. Wagenmakers, Love et al., 2018 for interpretations of Bayes factor). Panel B shows the plot for the category *engagement with solution attempts*. The Bayes factor gives an almost moderate evidence for the assumption that PF and VF pairs do not differ in the processes that deal with the generation and observation of solution attempts (BF_{01}; H_0), with a likelihood that is 2.65 times higher than the assumption of a difference between pairs (BF_{10}; H_1). Panel C shows with an anecdotal evidence for category 3 (*elaboration of solution attempts*) that the assumption that PF and VF pairs differ in analysis and interpretation processes is 1.56 more likely (BF_{10}; H_1) than the assumption that PF and VF pairs are similar (BF_{01}; H_0). Panel D represents the category *evaluation of solution attempts*. The Bayes factor indicates a moderate evidence for the assumption that PF and VF pairs differ in the frequency of evaluation and monitoring processes (BF_{10}; H_1), with a likelihood of 4.31 times higher than the assumption that they do not differ (BF_{01}; H_0).

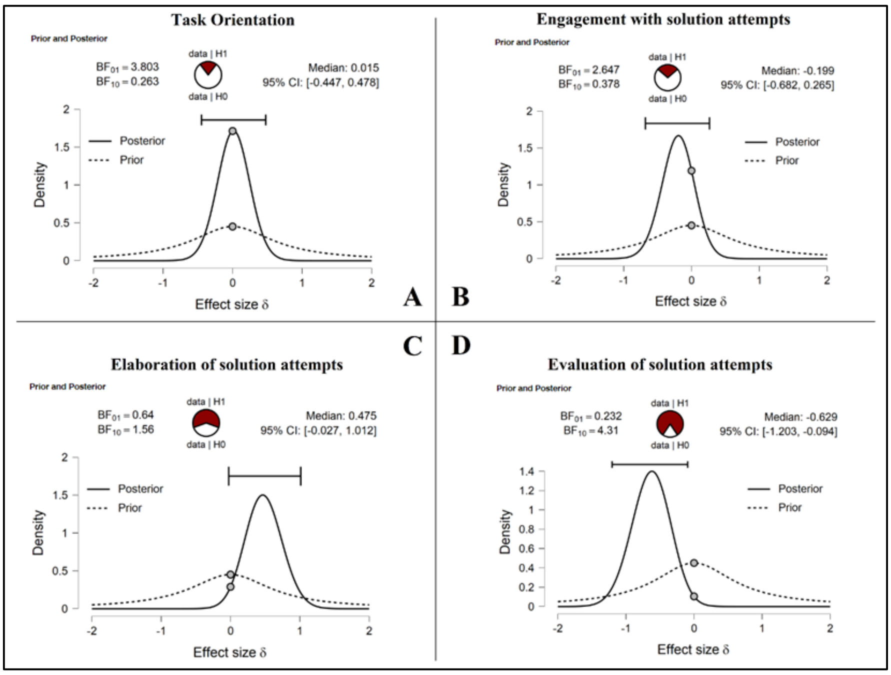

Figure 1: Plots of the Bayesian paired samples t-tests for all four categories

Discussion and conclusion

This paper explored the preparatory activities of two instructional settings in the field of PS-I: PF and VF. Research so far has presented mixed findings regarding the comparability of both activities, requiring further insights into the cognitive processes occurring in both PF and VF. We argued that students in both conditions show similar cognitive processes (i.e., prior knowledge activation and metacognitive evaluation and monitoring processes) as students in VF are encouraged to understand and follow the problem-solving processes of a PF model. We hypothesized that PF and VF model-observer-pairs would not differ in the quantity of verbalized cognitive processes in four categories: *task orientation, engagement with, elaboration of, and evaluation of solution attempts*. Our analyses confirmed our hypotheses for category 1 and 2 with moderate and near moderate evidence for the similarity of matched pairs in *task orientation* and *engagement with solution* processes. While our data indicated a difference between pairs for the category *elaboration of solution attempts*, this evidence was only anecdotal, meaning that it was almost as likely that students differ in this category as it was likely that they are similar. Descriptive statistics revealed that the conditions differed only by an average of two cognitive processes that were coded for this category. Taken together, these results indicate that indeed students in the PF and VF conditions display largely similar prior knowledge activation processes. Furthermore, the students' prior knowledge processes in the category *engagement with solution attempts* (i.e., the generation or identification of solution ideas) appear to constitute the largest part of students' processes, suggesting that the significance of prior knowledge activation as a preparatory mechanism might be higher than previously assumed.

Contrary to our hypothesis, PF and VF pairs differed in category 4, *evaluation of solution attempts*, which focuses on the metacognitive processes of evaluation and monitoring. Descriptively, students of the VF condition showed higher average amounts of evaluation and monitoring processes than students of the PF condition. Thus, VF students appear to not suffer losses in the preparation for subsequent learning but rather show additional metacognitive activities (i.e., evaluation and monitoring) compared to their PF models. Looking at the processes that only VF students can engage in such as the comparison of own ideas with those of the PF model and the identification of errors by the model, emphasizes the additional potential of the VF condition. The descriptive analyses revealed that the metacognitive process of error identification occurred most frequently out of the processes that were unique to the VF condition. Overall, the VF condition appears to show an additional engagement in evaluation and monitoring processes. This finding can be explained in the light of research on worked examples. Studies showed that problem solving imposes high cognitive demands on the learner as problem solving requires high working-memory resources when searching the problem space for potential solution steps (Sweller et al., 1982). Worked examples reduce the cognitive demands on the learner as they already present the correct solution steps (cf. Sweller & Cooper, 1985). Similarly, VF students do not have to engage in problem solving themselves, relieving them from the cognitive demands that come with the search of problem-solving operators (i.e., mathematical tools or ideas to solve the problem) or next steps in the generation of a solution. Thus, observing examples in VF might free students' cognitive capacities compared to the PF students, enabling them to engage in more evaluation and monitoring processes. Kapur (2014a) indeed found that PF students reported higher mental effort than students in VF. Further studies are needed to investigate the cognitive demands of examples of failure in the form of live-modeling examples on VF students as compared to a PF setting.

Overall, our inquiry confirmed a comparability of PF and VF with regards to their cognitive processes in our subsample. The model-observer-pairs largely did not differ in their prior knowledge activation processes. While PF and VF did differ in the frequency of evaluation and monitoring processes, this was due to a higher frequency in VF, which still enable comparability and indicate additional potentials of the VF condition. This allows concluding that PF and VF are comparable in their preparatory processes. The students of both conditions experienced not only similar preparatory processes, but also equal learning scores after instruction (see methods section for Bayes factor). These findings offer valuable information for future research and educational practice. Firstly, they take us one step further in identifying relevant aspects for the development of instructional designs that facilitate learning in PS-I. Future instructional designs can implement both PF and VF activities in order to afford the preparatory of prior knowledge activation. This offers new methodological possibilities to investigate PS-I preparatory mechanisms. For instance, so far, measuring and controlling the preparatory mechanism of prior knowledge activation has proven to be challenging. While different measures for prior knowledge activation were explored such as the quantity, quality, and diversity of solutions (i.e., the number of conceptually different solution attempts), only correlational relationships with learning were assessed and yielded mixed findings (e.g. Kapur, 2012; Loibl & Rummel, 2014a). However, the comparability of PF and VF enables future studies to employ VF conditions to experimentally variate prior knowledge activation by showing students of a VF condition different types of solution ideas. This could provide valuable insights for understanding the preparatory effects in PS-I. Secondly, in educational practice, learning from students' examples presents an efficient and resource-saving instructional approach compared to PF. Moreover, the generation of erroneous solutions usually deviates from students' socio-mathematical expectations (i.e., the instructional methods they expect in mathematics classes) and students might be more used to studying examples. Therefore, the latter could function as a more accessible preparatory activity (cf. Kapur & Bielaczyc, 2012).

We would like to highlight some limitations of our inquiry. The high standard deviations in the descriptive data indicate that the quantity of students' cognitive processes varied a lot between participants. As the processes were based on think-aloud data, this could indicate that the number of coded utterances could have been confounded by individual factors such as students' mathematical self-concept, how comfortable students were in verbalizing their thoughts, and general willingness to communicate. However, students' self-concept was not associated with the total number of utterances, $r(28) = .04$, $p = .84$.

In conclusion, the present research dealt with the preparatory activities in two PS-I settings: PF and VF. Previous studies examined whether students need to generate own solutions in order to be prepared for learning from instruction (e.g., Hartmann et al., 2020, 2021, Kapur, 2014a). Hartmann et al. (2021) found that VF students were equally prepared for subsequent learning than a PF condition. As a follow-up, this paper investigated the cognitive processes of PF and VF model-observer-pairs, hypothesizing that PF and VF students are equally prepared for subsequent learning. Our analyses revealed that the PF and VF pairs indeed showed similarities in their preparatory processes, specifically in their prior knowledge activation processes. Moreover, VF appeared to show additional potential for metacognitive evaluation and monitoring processes.

References

Brand, C., Hartmann, C., & Rummel, N. (2018). Exploring Relevant Problem-Solving Processes in Learning from Productive Failure. In J. Kay & R. Luckin (Eds.), *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018* (Volume 2, pp. 1125–1128). International Society of the Learning Sciences. https://doi.org/10.22318/cscl2018.1125

Brand, C., Massey-Allard, J., Perez, S., Rummel, N., & Roll, I. (2019). What Inquiry with Virtual Labs Can Learn from Productive Failure: A Theory-Driven Study of Students' Reflections. In S. Isotani, E.

Millán, & A. Ogan (Eds.), *Lecture Notes in Artificial Intelligence, Artificial Intelligence in Education: 20th International Conference, AIED 2019, Chicago, IL, USA, June 25-29, 2019, Proceedings, Part II* (1st ed., pp. 30–35). Springer International Publishing.

de Jong, T. (2006). Scaffolds for scientific discovery learning. *Handling Complexity in Learning Environments: Theory and Research*, 107–128.

Ericsson, K. A., & Simon, H. A. (1980). Verbal reports as data. *Psychological review*, *87*(3), 215.

Hartmann, C. (2020). *Productive Failure: Do students need to fail by themselves or does it suffice to observe someone else's failure?* [Unpublished doctoral dissertation], Ruhr University Bochum.

Hartmann, C., van Gog, T., & Rummel, N. (2020). Do examples of failure effectively prepare students for learning from subsequent instruction? *Applied Cognitive Psychology.* Advance online publication. https://doi.org/10.1002/acp.3651

Hartmann, C., van Gog, T., & Rummel, N. (2021). Preparatory effects of problem solving versus studying examples prior to instruction. *Instructional Science*, 1-21.

Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science*, *40*(4), 651–672. https://doi.org/10.1007/s11251-012-9209-6

Kapur, M. (2014a). Comparing Learning From Productive Failure and Vicarious Failure. *Journal of the Learning Sciences*, *23*(4), 651–677. https://doi.org/10.1080/10508406.2013.819000

Kapur, M. (2014b). Productive failure in learning math. *Cognitive Science*, *38*(5), 1008–1022. https://doi.org/10.1111/cogs.12107

Kapur, M., & Bielaczyc, K. (2012). Designing for Productive Failure. *Journal of the Learning Sciences*, *21*(1), 45–83. https://doi.org/10.1080/10508406.2011.591717

Likourezos, V., & Kalyuga, S. (2017). Instruction-first and problem-solving-first approaches: Alternative pathways to learning complex tasks. *Instructional Science*, *45*(2), 195–219. https://doi.org/10.1007/s11251-016-9399-4

Loibl, K., Roll, I., & Rummel, N. (2017). Towards a Theory of When and How Problem Solving Followed by Instruction Supports Learning. *Educational Psychology Review*, *29*(4), 693–715. https://doi.org/10.1007/s10648-016-9379-x

Loibl, K., & Rummel, N. (2014a). The impact of guidance during problem-solving prior to instruction on students' inventions and learning outcomes. *Instructional Science*, *42*(3), 305–326. https://doi.org/10.1007/s11251-013-9282-5

Loibl, K., & Rummel, N. (2014b). Knowing what you don't know makes failure productive. *Learning and Instruction*, *34*, 74–85. https://doi.org/10.1016/j.learninstruc.2014.08.004

Newman, P. M., & DeCaro, M. S. (2019). Learning by exploring: How much guidance is optimal? *Learning and Instruction*, *62*, 49–63. https://doi.org/10.1016/j.learninstruc.2019.05.005

Roll, I., Holmes, N. G., Day, J., & Bonn, D. (2012). Evaluating metacognitive scaffolding in Guided Invention Activities. *Instructional Science*, *40*(4), 691–710. https://doi.org/10.1007/s11251-012-9208-7

Rost, D. H., & Sparfeldt, J. R. (2002). Facetten des schulischen Selbstkonzepts. *Diagnostica*, *48*(3), 130–140. https://doi.org/10.1026//0012-1924.48.3.130

Schoenfeld, A. H. (1985). *Mathematical problem solving*. Academic Press.

Sweller, J., & Cooper, G. A. (1985). The Use of Worked Examples as a Substitute for Problem Solving in Learning Algebra. *Cognition and Instruction*, *2*(1), 59–89. https://doi.org/10.1207/s1532690xci0201_3

Sweller, J., Mawer, R. F., & Howe, W. (1982). Consequences of History-Cued and Means-End Strategies in Problem Solving. *The American Journal of Psychology*, *95*(3), 455. https://doi.org/10.2307/1422136

Wagenmakers, E.-J., Love, J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Selker, R., Gronau, Q. F., Dropmann, D., Boutin, B., Meerhoff, F., Knight, P., Raj, A., van Kesteren, E.-J., van Doorn, J., Šmíra, M., Epskamp, S., Etz, A., Matzke, D., . . . Morey, R. D. (2018). Bayesian inference for psychology. Part II: Example applications with JASP. *Psychonomic Bulletin & Review*, *25*(1), 58–76. https://doi.org/10.3758/s13423-017-1323-7

Wagenmakers, E.-J., Marsman, M., Jamil, T., Ly, A., Verhagen, J., Love, J., Selker, R., Gronau, Q. F., Šmíra, M., Epskamp, S., Matzke, D., Rouder, J. N., & Morey, R. D. (2018). Bayesian inference for psychology. Part I: Theoretical advantages and practical ramifications. *Psychonomic Bulletin & Review*, *25*(1), 35–57. https://doi.org/10.3758/s13423-017-1343-3

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Effective Middle-School Collaborative Geometry Learning: A Dialogic Discursive Lens

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Abstract: To understand how students' dialogic engagement contributes to their process of mathematics learning during collaborative work, we explored the learning process of two 9th grade students transitioning to the deductive discourse while solving a geometric task. Drawing on commognition, we found that dialogic engagement contributed to students' learning in two ways. First, the students were able to correct their initial procedures; second, they were using their partner's initial procedure as a stepping-stone to the deductive discourse. Our findings suggest that growth in mathematical discourses in collaborative learning may necessitate a specific kind of dialogic engagement that requires students to be able to question the meta-rules at the basis of discourses, to be selective in the steps they adopt and to actively make necessary adaptations. This kind of dialogic engagement may enable students to make critical transitions bolstered with a sense of ownership and agency.

Keywords: Collaborative learning, dialogic engagement, deductive geometry, routines

Introduction

In the past few decades, studies have shown that collaborative mathematics learning can be effective and more conducive to learning than individual learning (e.g., Schwarz et al., 2000; Schwarz & Linchevski, 2007). In contrast, other studies have questioned this effectiveness (e.g., Ben-Zvi & Sfard, 2007; Chan & Sfard, 2020; Sfard & Kieran, 2001). This may suggest that only some cases of mathematics collaborative learning are effective. One aspect that has been suggested as key to the effectiveness of collaborative learning is students' dialogic engagement (Sfard, 2020; Wegerif, 2011). However, studies examining students' dialogic engagement concomitantly with their mathematics learning processes are rare. Consequently, we do not know much about the ways in which students' dialogic engagement contributes to their mathematics learning process during collaborative work. It is this that we aim to explore in this study. We pursue our goal by focusing on collaborative problem-solving in middle school geometry. This, since a particularly critical transition is required from students in those years – the transition to deductive geometric procedures. In this transition, students who are used to performing visual-configural procedures for substantiating claims (such as showing congruence by placing one triangle on top of the other) are required to shift to using new deductive procedures based on given data and geometric theorems (such as congruence theorems) (Duval, 1998). This transition has been viewed as most challenging to effective learning (Duval, 1998; Harel & Sowder, 2007).

Theoretical framework

The theoretical framework which we will use to pursue our goal is commognition (Sfard, 2008). Commognition is a sociocultural discursive framework which has been shown to be productive for studying interaction and learning concomitantly (Ben-Zvi & Sfard, 2007; Heyd-Metzuyanim & Schwarz, 2017; Sfard & Kieran, 2001), as well as critical transitions in mathematics learning (Lavie & Sfard, 2019; Sfard, 2007). The commognitive framework views repetition as the gist of learning and conceptualizes learning as a process of routinization of students' actions (Lavie et al., 2019). Routines - repetitive patterns of actions – are thus the commognitive basic unit for analyzing learning.

A routine is performed by a given person in a given task-situation (a situation in which the person considers herself bound to act). It is defined as "the *task*, as seen by the performer, together with the *procedure* she executed to perform the task" (Lavie et al., 2019, p. 161). For example, an instructor may create a task-situation by presenting students a geometric problem containing two triangles and asking them to show that the two triangles have the same area. Students may use different procedures (series of actions) for the same task. One student may use a visual/configural procedure of placing one triangle on top of the other and showing that they are "the same"; a second student may use a meta-arithmetic procedure of expressing the areas of both triangles using the triangle area formula and showing that they are equal; and a third student, may use a deductive procedure using congruence theorems. Moreover, the same student may use these different procedures in different stages of her learning. For example, a student using the configural procedure may, a year later, after learning congruence theorems, use the deductive procedure. The student's routine, in this case, would develop from including only a configural procedure to including two procedures: a configural procedure and a deductive one. By studying mathematical routines, commognitive studies were able to show such developments in children's learning (Lavie et al., 2019; Lavie & Sfard, 2019).

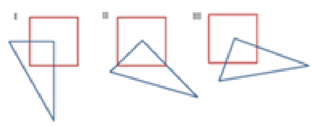
According to commognition, critical transitions, such as the transition to deductive procedures, are particularly challenging, since they go further than simply requiring students to shift from familiar procedures to new ones; they require a much more substantial shift – a shift between discourses (Sfard, 2007). A discourse is distinguishable by its routines and meta-rules. The configural and the deductive discourses are such distinguishable discourses. The configural discourse is based on the meta-rule that visual estimation is sufficient for substantiating claims. In contrast, the deductive discourse is based on the meta-rule that one must rely on data, axioms, definitions and theorems for substantiating claims, and that visual estimation is not sufficient. Such a conflict in meta-rules may create a difficulty when students attempt to transition from one discourse to another. To overcome this difficulty, students need to be dialogically engaged with the new discourse (Sfard, 2020).

Dialogically engaged students, according to Sfard (2020), show interest in their partner's discourse by: actively examining the possibility of differences between their discourse and that of their partner; acting as aspiring participants of their partner's discourse; and striving to fully individualize their partner's discourse. However, dialogic engagement with a new discourse is challenging in peer learning, since peer learning, by definition, often includes learners who are all novices in the new discourse (Ben-Zvi & Sfard, 2007). Students remain relatively novices in the new discourse even after exposure to the new meta-rules and often oscillate between the more familiar meta-rules and the less familiar ones (Sinclair & Moss, 2012).

In this study we focus on collaborative geometry problem-solving of middle school students, who are at this stage of oscillating between the more familiar configural meta-rules and the less familiar dedcutive ones. Drawing on Sfard's definition of dialogical engagement, we view dialogically engaged students as those showing interest in their partner's discourse, that is, in their use of words, visual mediators, narratives and routines. Based on this theoretical framework, we ask: how did students' dialogic engagement contribute to the development of their routines during collaborative work, particularly to the development of new deductive procedures?

Methodology

The participants of our study were 10 middle school students (six 8th graders; four 9th graders) who took part in a mathematical activity facilitated by the first author ("the instructor"). The design of the activity was based on videotaped lessons of the VIDEO-LM project (Karsenty & Arcavi, 2017) in which a geometric problem called *The three squares* was presented. The problem contained three drawings, in which identical right-angle triangles are placed in different orientations on top of identical squares (see drawings in Figure 1). The students in these lessons were asked to compare the shared areas in the three drawings. The canonical "correct" answer to the problem is that all the shared areas are equal. Based on these lessons, we designed a mathematical activity, which included: the presentation of the problem on the board; an individual work session in which students worked on a worksheet (see Figure1); and then a dyadic work session in which they collaboratively worked on the same worksheet.



1. In each drawing, color the shared area of the square and triangle
2. Line up the drawings according to the size of their shared area (from the smallest to the largest)
3. Circle the correct answer in each of the following claims and explain it:
   a. The shared area in drawing I is (smaller than /larger than/equal to/impossible to know) the shared area in drawing II
   b. The shared area in drawing II is (smaller than /larger than/equal to/impossible to know) the shared area in drawing III
   c. The shared area in drawing III is (smaller than /larger than/equal to/impossible to know) the shared area in drawing I

Figure 1. The worksheet

The individual session was designed to allow some access (albeit limited) to participants' initial routines before peer interaction, and to enable answering our research question regarding the development of their routines during peer interaction. Sections 2 and section 3 (and its sub-sections) were designed to allow students to return again and again to the same routine of comparing areas. To afford students maximal flexibility regarding their choice of procedures, the worksheet did not include any direct instructions on how participants should substantiate their claims (i.e., deductively). Additional data (i.e., the right angle of the triangle is located at the intersection of the square's diagonals) were given orally by the instructor upon request.

The activity was recorded by several cameras. Each pair had their own stationary camera and microphone; an additional camera was moving with the instructor. All five collaborative interactions were fully transcribed in a high-level resolution (i.e., gestures and facial expressions) and analyzed using footage from the different cameras. Students' ten individual worksheets and five dyadic collaborative worksheets were also collected and analyzed.

The analysis included first, analyzing students' individual worksheets (prior to peer interaction) and identifying their initial routines (task and procedure) for comparing the shared areas. Next, we analyzed students' peer interactions and identified their routines during these interactions. To examine students' development of routines during peer interaction – particularly, the development of new deductive procedures – we categorized the procedures of the students' routines (in individual session and peer interaction) into: configural; meta-arithmetic/configural and deductive (see table 1).

Table 1: Categorization of procedures

Procedure	Based on	Example
Configural	Visual estimation and manipulation of configurations	Visually estimating if shapes are congruent by placing them one on top of the other
Meta-arithmetic/configural	The use of formulas coupled with visual estimation	Employing an area formula in which the factors are visually estimated
Deductive	Given data, definitions, axioms, formulas or theorems	Proving that shapes are congruent by using congruence theorems, or employing an area formula in which its factors are based on the given

In addition, we analyzed students' dialogic engagement by identifying communicated interest in the partner's discourse, such as listening to partner's words, narratives and routines and attempting to clarify and examine them (e.g., "what do you mean by 'equal'?"; "what do you think?"; why do you think so?"), as well as looking closely at and examining partner's visual mediators (e.g., pointing at a drawing and asking "do you mean that triangle?").

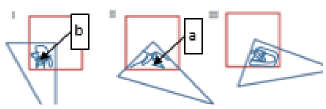
Findings

Our analysis, performed on all five collaborative episodes, identified only one episode containing a development of deductive procedures within the routine of comparing the shared areas. Full deductive proofs are being taught, according to the Israeli curriculum, only in 9^{th} grade. Therefore, the fact that deductive discourse did not appear in the three 8^{th} graders collaborative episodes did not come as a complete surprise. In what follows we focus on this one episode of 9^{th} grade students, containing a successful transition to deductive procedures. The two students participating in the episode were Orna and Tamara (pseudonyms), two relatively high achieving students, in a class which was on the highest mathematics track in their school. We begin by presenting the students' initial routines in their individual problem solving. We then present the ways by which dialogic engagement during peer interaction, contributed to the development and implementation of their routines.

Initial routines in individual problem-solving

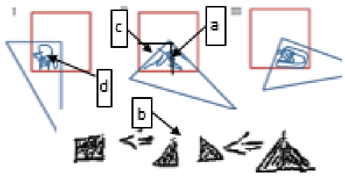
Analyzing Tamara and Orna's individual worksheets, we found that the two students used different procedures for the task of comparing the shared areas, none of which was deductive. Tamara used a configural procedure, while Orna used a meta-arithmetic procedure. These procedures resulted in different claims. Orna claimed that the shared area in drawing I is the smallest and the one in drawing II is the biggest (I < III < II), while Tamara claimed that the shared areas in drawings I and II are equal, and the one in drawing III is the smallest (III < II = I). Orna, in her explanation to the claim that I is smaller than II, wrote (in brackets: implied words and visual mediators; the squiggled figure to the right is used as a representation of visual mediators in worksheet after coloring the shared areas):

Because in order to calculate an area we need to multiply base by height, and because the triangle (a) in II has a bigger base (than the base in b), then I (b) is smaller than II.



Examining Orna's explanation to the claim that I is smaller than II as well as her written explanations to her other claims (III < II; I < III), we see Orna's procedure as including three basic steps: first, recalling area formulas ("multiply base by height"); second, visually estimating the relation between formula components in the two shared areas (equal heights; "II has a bigger base" than I); third, comparing the area formulas of the shared areas ("I is smaller than II"). Since Orna was basing her answer on her recollection of area formulas as well as her visual estimation of formula components, we categorized her procedure as meta-arithmetic/configural. The implementation of Orna's procedure was non-canonical (incorrect), since she was using the same area formula (base times height) for all shared areas regardless of their shape. Consequently, her resulting claim was non-canonical ("I is smaller than II"). In contrast, Tamara was basing her answer purely on visual estimation. In her explanation to her claim that shared areas I and II are equal, she wrote:

The (shared) area of drawing I is in a shape of a square, unlike the (shared) area of drawing II, which is in the shape of a triangle, so if we cut in half (a) the triangle of drawing II, we'll get two small triangles (b). We'll move one of the small triangles in order to get a square (c). The square we got is equal to the square in drawing I (d). (Tamara's visually mediated meanings are reconstructed in the top figure. Her written illustrations appear below).



Tamara's procedure included: first, dividing the shared areas into parts (arrows a and b); second, moving the parts from one place to another (arrow c) to form similar-looking areas (in this case, similar looking squares); and third, visually comparing the formed areas. Tamara was thus using a configural procedure based only on visual estimation and manipulation of shapes. Her implementation of this procedure resulted in the claim that the shared areas in drawings I and II are equal, and the one in drawing III is the smallest. Both girls thus arrived at the peer interaction stage with non-canonical, yet differing claims. Moreover, they were using different procedures to support their differing claims, none of which was deductive. Figure 2 presents side-by-side Orna and Tamara's routines in individual work. As seen, Orna and Tamara's procedures did not include even one step in common.

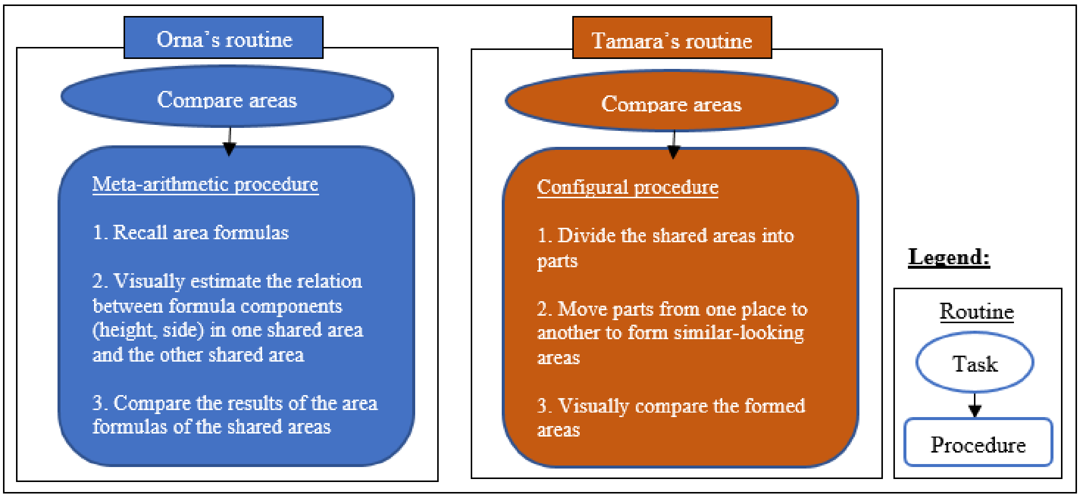


Figure 2. Students' initial routines in individual work

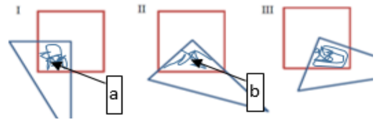
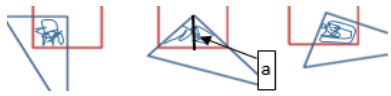
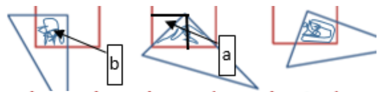
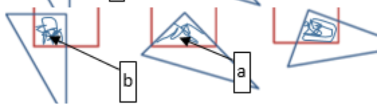
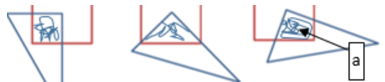
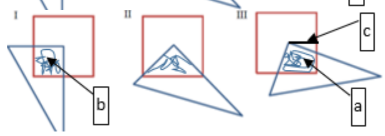
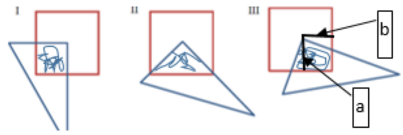
Contribution of dialogic engagement to the development of routines

Analyzing Tamara and Orna's collaborative session, we found that both students were dialogically engaged with each other's discourse at different times during the episode. Their dialogic engagement contributed to their learning in two ways. First, students were able to correct previous non-canonical implementations of their own initial procedures. Second, while the initial routines in individual session included only configural and meta-arithmetic procedures, the developed routines included new deductive procedures. In what follows, due to space constraints, we illustrate these developments by focusing only on Orna; yet, similar developments were found in Tamara's case.

Correcting implementation of one's own initial procedure

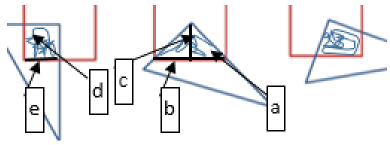
Orna and Tamara's peer interaction followed their individual session and thus began with the aforementioned differences between their solutions both at the level of their claims (Orna: I < III < II; Tamara: III < II = I) and at the level of their procedures (Orna: meta-arithmetic; Tamara: configural). The students noticed their differences right from the start of their interaction. Tamara responded to these differences by explaining her answer to why I is equal to II and presenting her configural procedure, as can be seen in the following excerpt.

Excerpt 1: (Implied words); [overlapping speech]; (n*on-verbal gestures/signals)*

No.	Speaker	What is said	What is done or pointed at
26	Tamara	So I said that, like, the area of I (a) is equal to the area of II (b)	
27	orna	O.k. (I'm listening)	
28	Tamara	Cause like, if you cu… imagine that you are cutting this triangle (a) in half	
29	Orna	Ahha (I'm listening)	
30	Tamara	And then you move one of the triangles (to place a), so like its … you get the same square (as b)	
31	Orna	Ah so this (a) is equal to that (b)?	
32	Tamara	Yes, that's what I think	
33	Orna	And this (a) is bigger than them (shared areas I and II) or smaller than them?	
34	Tamara	Amm (*not sure, smiling*), this needs ah… cause think as if this (a) is, say, the same area square (as b), so like you need to calculate this area (c)… (her voice is fading)	
35	Orna	It looks to me like this (shared area III) is [bigger]…	
36	Tamara	[Ah like] (*takes the sheet*), imagine, then, this part (a) (*draws a line to base*), o.k.? the one here (*strengthening the line she drew*) is like a supplement to this area (b) (meaning, the left triangle (a) can be moved to place (b) to form a square similar to the one in shared area I)… (*looking at the drawing*)… but I got that they are equal! (laughs, touches Orna's elbow, covers her mouth)	
37	Orna	Ah (*smiling, leaning forward, focused on the drawings*), they supplement, ok, but look, there is here, it's like a square and there is another triangle here (a)… Actually, it looks to me like they are all equal (*examining the drawings, nodding her head*).	
38	Tamara	That's what it is, that's it	
39	Orna	They're all equal (*decisively*, *leaning backward*), let's write that they're all equal	

Examining excerpt 1, we can see that Orna was dialogically engaged with Tamara's discourse. She listened to Tamara's explanation of her configural procedure (27, 29); clarified Tamara's narratives (31, 33); examined Tamara's procedure and questioned it (37); and all the while looked closely at the relevant visual mediators (the parts to which Tamara referred to in the drawings). By leaning forward, focusing on the drawings, and examining Tamara's visual mediators (pointing at small triangle (a) in line 37), it seems that Orna was trying to implement Tamara's procedure (with her eyes). At first, she seemed uncertain about it ("ok, but look…"), but after examining the drawings she decided that all shared are equal (37, 39). The word "actually" (37) coupled with her decisive tone when stating that all areas are equal (39), suggest that she had some kind of conviction in her newly endorsed claim and a sense of ownership. When the students turned to write their explanation, Orna said, “and like each one (of the claims) we explain…according to the ‘supplement’”. The word “supplement” first appears in line 32, when Tamara is explaining her configural procedure. Orna’s use of Tamara’s word signifies that she was suggesting that they use Tamara’s configural procedure. However, when Tamara suggested that they write what she had written in her individual sheet (the configural explanation), Orna said:

65 Orna Amm… Ok, so I’ll write that like here (a), that’s a triangle (shared area II), so you do: base (b) times height (c) and divide by two. Here (d, shared area I) you don’t divide by two. That’s (b, base of shared area II) is double the size (of e, base of shared area I).



Despite seemingly adopting Tamara's procedure, Orna reverts in line 65, to her previous meta-arithmetic procedure. Interestingly, she made no indication of her suggestion being different from Tamara’s configural explanation (such as “ok, but…” or “let’s do it this way”). On the contrary, her "Ok, I'll write", which followed smoothly from the conversation, masked the sudden return to her previous procedure. We interpret this masking of disagreement in two ways. First, it may be Orna’s quiet way of confronting disagreements. Alternatively, it may indicate that Orna was perceiving her suggested procedure as sufficiently similar to that of Tamara, or at least as drawing on Tamara’s suggestion. Indeed, Orna’s suggestion in line 65 was *not* an exact replica of her initial procedure; this time she was suggesting a canonical (correct) implementation. Rather than assigning the same formula to all shared areas as she had previously done, here Orna distinguished between the shapes of shared area II and I and consequently between their area formulas. Therefore, Orna changed her implementation of the first step of her meta-arithmetic procedure: the recollection of area formulas.

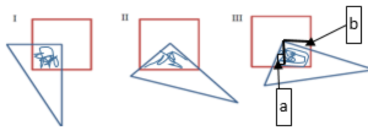
The change seems to have resulted from Orna’s dialogic engagement with Tamara’s discourse in two ways. First, Orna’s previous endorsement of Tamara’s claim that “all areas are equal” (39), seemed to have made her realize that “all areas are equal” should *also* be the resulting claim of her previous meta-arithmetic procedure. This made her examine her own initial procedure and correct it. Second, Tamara’s distinction between the two shapes of shared areas I and II (square and triangle) may have helped Orna realize what needs correction in her initial implementation, that is, that she was using the same formula for different shapes. Therefore, Orna’s dialogic engagement with Tamara's procedure contributed to the development of her own routine by improving the implementation of her initial meta-arithmetic procedure.

<u>Developing a new procedure based on partner’s procedure</u>

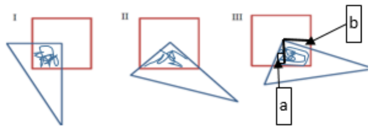
A second development in Orna’s routine occurred toward the end of the interaction when the students discussed why shared area I and III are equal. This time, Orna did not only adopt Tamara’s claim (that I=III), but also drew on the steps of Tamara’s configural procedure to suggest a new deductive version of this procedure. The following excerpt begins with Tamara suggesting again to use the configural procedure for comparing III and I:

<u>Excerpt 2:</u>

132 Tamara … you need to say that, like you move this part (a) to here (b) and then like [it will form a square]

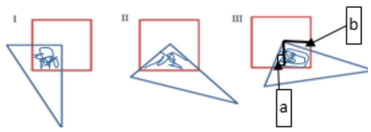


133 Orna [I have an idea], if we, like, show congruence (between) this (a) and that (b), then… (meaning: by showing that these triangles are congruent, they can show that their areas are “the same”)



…

141 Orna No, no look, you need to say that this (a) is like (meaning congruent to) this (b) in order for it to be ok to move the…



In line 132 Tamara repeated her configural suggestion to move part (a) so that it covers part (b) and form a square similar to the shared area in drawing I. In response to Tamara’s suggestion, Orna proposed that they use congruence theorems to substantiate that the areas of the triangles (a and b) are the same (“I have an idea, if we, like, show congruence" [133]). In line 141, Orna further explained that in order to claim that triangle (a) can be moved on top of the triangle (b) in a way that exactly covers it, they need to show that they are congruent ("you need to say… in order for…"). In other words, she did not agree ("no, no…") with the meta-rule of the configural discourse that visual estimation is enough. Rather, she drew on the configural procedure to develop it into a deductive congruence procedure. Therefore, Orna's dialogic engagement with Tamara's procedure contributed to the development of a new procedure in Orna's routine.

Figure 3 presents Tamara's configural procedure next to Orna's new deductive procedure. As can be seen, Orna adopted the three steps of Tamara's procedure. However, her new deductive procedure does not end with the last step of Tamara's initial procedure. Rather, it includes an additional final deductive step of substantiating the visual comparison using congruence theorems (step 4). This development is obviously a product of Orna's dialogic engagement with Tamara's discourse, since the basis of Orna's new deductive procedure is Tamara's configural procedure. It was only through following the steps of Tamara's procedure, that Orna adopted the claims, that the two triangles (a and b) are the same and that shared areas I and III are equal. The *adoption* of these claims, coupled with Orna's *non-adoption* of the meta-rule of the configural discourse, seem to have led Orna to come up with the "idea" (133) of using congruence theorems.

To summarize, examining Orna's dialogic engagement, it is clear that she did not simply adopt Tamara's procedure. Rather, there seems to be a gradual process of ownership of Tamara's procedure. First, Orna adopted Tamara's claim that all shared areas are equal; second, she reverted to her own initial procedure and corrected it; third, she adopted steps of Tamara's procedure; and forth she added a final deductive step to Tamara's procedure.

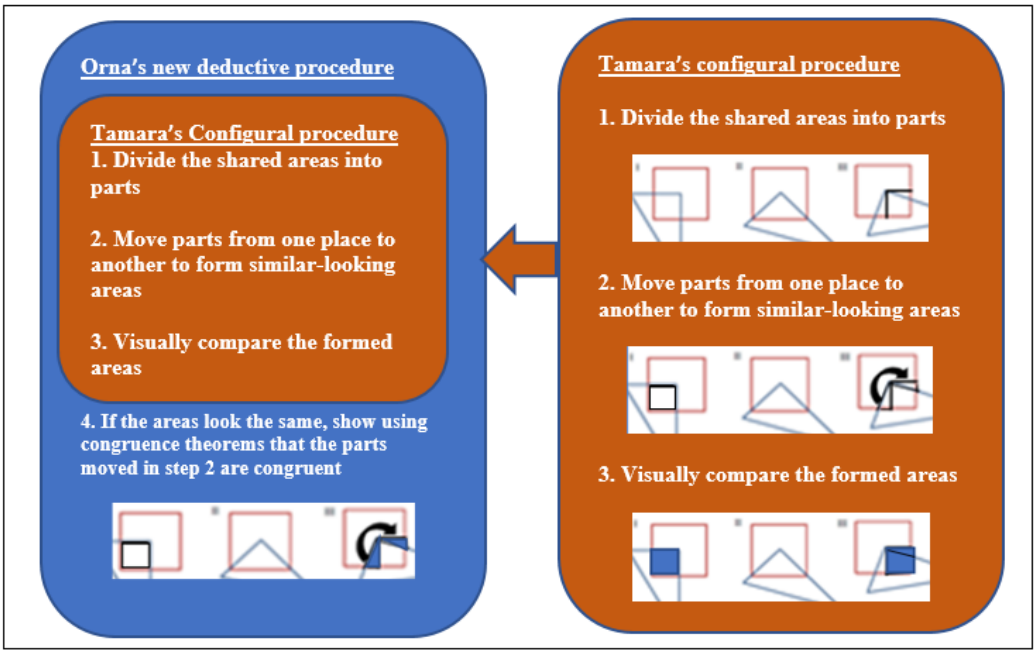


Figure 3. Orna's new deductive procedure built on Tamara's initial configural procedure

Discussion

Our goal in this study was to explore the ways in which students' dialogic engagement contributes to their process of mathematics learning during collaborative work. We pursued our goal by analyzing commognitively an effective collaborative geometry learning episode of two 9th grade students. We found that the students' dialogic engagement contributed to their learning in two ways. First, the students were able to correct previous non-canonical implementations of their own initial procedures. Second, the students were using their partner's initial procedure as a stepping-stone to the deductive discourse. This kind of growth in mathematical discourses during collaborative learning stands in contrast to previous studies showing mainly lack of growth in discourses during collaborative learning (Chan & Sfard, 2020; Sfard & Kieran, 2001). Our study, thus, not only supports the argument that collaborative mathematics learning can be effective and more conducive to learning than individual learning (e.g., Schwarz et al., 2000; Schwarz & Linchevski, 2007), but also shows *how* students' dialogic engagement can contribute to students' transitioning to more developed discourses. Rather than adopting their partner's procedure as is, students drew on their partner's initial procedure to suggest a deductive new procedure. Our findings may explain why growth in mathematical discourses is so rare in collaborative learning. It necessitates a specific kind of dialogic engagement that does not satisfy itself with listening and adopting the partner's discourse. Rather, it requires students to be able to question the meta-rules at the basis of discourses, to be selective in the steps they adopt (whether consciously or not) and to actively make the necessary adaptations. Our study suggests that this kind of dialogic engagement may enable students to make critical transitions bolstered with a sense of ownership and agency.

References

Ben-Zvi, D., & Sfard, A. (2007). Ariadne's thread, daedalus' wings and the learners autonomy. In *Éducation & didactique.* (Vol. 1, Issue 3, pp. 117–134). Presses Universitaire de Rennes.

Chan, M. C. E., & Sfard, A. (2020). On learning that could have happened: The same tale in two cities. *The Journal of Mathematical Behavior*, *60*.

Duval, R. (1998). Geometry from a cognitive point of view. In C. Mammana & V. Villani (Eds.), *Perspectives on the Teaching of Geometry for the 21st Century* (Vol. 5, pp. 37–52). Springer Netherlands.

Harel, G., & Sowder, L. (2007). Toward comprehensive perspectives on the learning and teaching of proof. In F. K. Lester (Ed.), *Second Handbook of Research on Mathematics Teaching and Learning* (Vol. 2, pp. 805–842). Information Age Publishing.

Heyd-Metzuyanim, E., & Schwarz, B. B. (2017). Conceptual change within dyadic interactions: the dance of conceptual and material agency. *Instructional Science*, *45*(5), 645–677.

Karsenty, R., & Arcavi, A. (2017). Mathematics, lenses and videotapes: a framework and a language for developing reflective practices of teaching. *Journal of Mathematics Teacher Education*, *20*(5), 433–455.

Lavie, I., & Sfard, A. (2019). How children individualize numerical routines: Elements of a discursive theory in making. *Journal of the Learning Sciences*, *28*(4–5), 419–461.

Lavie, I., Steiner, A., & Sfard, A. (2019). Routines we live by: from ritual to exploration. *Educational Studies in Mathematics*, *101*(2), 153–176.

Schwarz, B. B., & Linchevski, L. (2007). The role of task design and argumentation in cognitive development during peer interaction: The case of proportional reasoning. *Learning and Instruction*, *17*(5), 510–531.

Schwarz, B. B., Neuman, Y., & Biezuner, S. (2000). Two wrongs may make a right ... if they argue together! *Cognition and Instruction*, *18*(4), 461–494.

Sfard, A. (2007). When the rules of discourse change, but nobody tells you: making sense of mathematics learning from a commognitive standpoint. *Journal of the Learning Sciences*, *16*(4), 565–613.

Sfard, A. (2008). *Thinking as communicating: Human development, the growth of discourses, and mathematizing*. Cambridge University Press.

Sfard, A. (2020). Learning, discursive faultiness and dialogic engagement. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge International Handbook of Research on Dialogic Education* (pp. 89–100). Routledge.

Sfard, A., & Kieran, C. (2001). Cognition as communication: Rethinking learning-by-talking through multi-faceted analysis of students' mathematical interactions. *Mind, Culture, and Activity*, *8*(1), 42–76.

Sinclair, N., & Moss, J. (2012). The more it changes, the more it becomes the same: The development of the routine of shape identification in dynamic geometry environment. *International Journal of Educational Research.*, *51*, 28–44.

Wegerif, R. (2011). Towards a dialogic theory of how children learn to think. *Thinking Skills and Creativity*, *6*(3), 179–190.

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Designing for Compassion in Schools: A Humanizing Approach to Co-Design

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Abstract: Collaborative design as a participatory approach to organizing research and learning environments engages educators as partners in ways that draw on their lived experiences and identities (Bang & Vossoughi, 2016). This paper focuses on the co-design of a course for educators in compassion and dignity and explores co-design as a humanizing experience for educators, one that invites educators' whole selves into the process. We ask: a) *In what ways is the co-design of a compassion course a humanizing experience? b) How does a humanizing co-design process support the enactment of compassion across scales of practice?* The intentionality given to the co-design experience supported participants to see connections among meetings, professional contexts, and personal lives in new and expansive ways. As participants enacted learning across scales of practice, they were presented with new understandings of the content, and in turn designed a product that embodied expansive and compassionate learning.

Keywords: co-design, humanizing, compassion, expansive learning, educators

Introduction

Collaborative design, often referred to as co-design, as a participatory approach to organizing research and learning environments, engages educators as partners in ways that draw on their expertise, lived experiences, and identities (Bang & Vossoughi, 2016). Co-design processes can be both challenging and rewarding for educators as they explore new and unfamiliar roles and content (Frumin, 2019; Penuel, Roschelle, & Shechtman, 2007; Potvin, 2020). In this paper, we address Ehret and Hollett's (2016) call for attending to the "lived dimensions of learning and being that are just as essential to lasting, transformative change" (p. 251) within participatory design, which they argue have been overlooked. Specifically, we explore what we refer to here as the *humanizing* aspects of co-design, that is, the ways that the co-design experience is characterized by compassion and individual and collective agency for reimagining new possibilities for schools. A humanizing co-design environment is one that recognizes the complexity and multidimensionality of all participants, and where dignity and care are centered (Camangian & Cariaga, 2021; Paris, 2011).

The co-design project presented in this article was focused on the design of a digital compassion course for educators that addresses the essential dignity of educators and students, supports the wellness of educators through compassion practices and tools, and contributes to educators' capacities to imagine and create more just and compassionate schools. We define compassion as the recognition of another person's suffering coupled with a response to relieve that suffering (Ashar et al., 2016). Compassion can be practiced, cultivated, and sustained through specific training and community contexts that provide individuals with tools and resources to reduce the distress they feel when faced with another's suffering and increase their ability to respond (Jazaieri et al., 2014; Weng et al., 2018). Key elements include extending compassion to people perceived as difficult, investigating obstacles to extending care to them, and recognizing that everyone is deserving of compassion (Jinpa, 2015). Cultivating compassion has the potential to support educators and researchers to work toward equity and justice, and counter deficit views of students and families that often permeate schools (Cammarota & Romero, 2006; Conklin, 2008).

We analyze a co-design project focused on a novel context where educators and researchers had varied familiarity with the core content (compassion practice), specifically, where expertise was distributed across the research-practice boundary and variable across the whole team, and where there was significant uncertainty about how to link individual practices of compassion to the shared design goal of supporting collective action toward more equitable, just, and compassionate schools. We argue, through analysis of educators' perceptions and experiences, that the co-design process was a humanizing experience for educators involved. We examine the ways that the humanizing co-design process invited expansive learning across multiple scales of practice and in turn, how this impacted the designed product.

Theoretical framework

Co-design for expansive, humanizing learning depends on creating conditions for people to learn together, and to envision ways not just to develop personal insights but also to support collective action toward more just and compassionate schools. Expansive learning theory posits that learning occurs as "learners are involved in constructing and implementing a radically new, wider and more complex object and concept for their activity" (Engeström & Sannino, 2010, p. 2). It is an apt theory for analyzing co-design for compassion, as participants engaged in the design of a radically new compassion course for educators.

A key feature of expansive learning is that the content or skill is not predetermined. That is, the design or solution to a dilemma is not specified in advance, rather, the collective works together to develop novel designs and approaches. Learning occurs as people collaboratively develop solutions, such that co-designers learn together from creating, as they bring expertise to the experience that gets transformed in the process of designing something new. Through a facilitated process of co-design, new activity is created when participants negotiate and solve problems together and new possibilities emerge. It is through the process of forging new forms of activity and designs together that opportunities for transformative agency are ripe. Through the expansive learning process, these new forms of activity and design "carry future-oriented visions loaded with initiative and commitment by the learners" (Sannino et al., 2016, p. 603).

Transformative agency is not just an important indicator of the expansive learning process, it is also central to our conceptualization of humanizing design environments. Our notion of humanizing co-design is rooted in frameworks for compassionate organizations (Dutton et al., 2006) and expansive learning (Engeström & Sannino, 2010), which emphasizes that co-design experiences should recognize that members are more than their professional identities, encourage members to display their full humanity, care for one another, and support individual and collective agency in imagining radically different possibilities for their organizations. We draw upon these key features of compassionate organizations in our analysis.

In our analysis, we investigate the ways that humanizing approaches to co-design support expansive learning (Engeström & Sannino, 2010) across scales of practice. Expansive learning engages the entire activity system in which participants are situated, producing new forms of activity and possibilities for meaningful participation. From an activity theory perspective, where the collective ecology of activity is considered, the aim of co-design for compassion involves shifts in not only individual practices, but also a reorganization of ways of participating across scales of practice (Jurow & Shea, 2015). Generating learning that can be applied across physical, social, and temporal scales requires approaches to design that move from the individual level of change to systems level of change. We analyze the ways that co-design facilitation and participation supported a systemic approach to learning and design.

Methods

Our primary research questions are: a) *In what ways is the co-design of a compassion course a humanizing experience? b) How does a humanizing co-design process support the enactment of compassion across scales of practice?*

Co-design context

The co-design project was focused on the design of a digital course on teacher leadership in compassion and dignity. The goal of the course was to provide educators with resources for caring for themselves and cultivating and sustaining compassion for students, students' families, colleagues, and their school communities. Co-designers consisted of ten educators from a partner school district and five university-based researchers. Educators included teachers, counselors, and one principal from six elementary and middle schools. The team met weekly in-person for two hours between October 2019 through May 2020, for a total of 58 hours. We catalyzed our collaboration with a "bootstrapping event" (Penuel et al., 2007); the team of educators and researchers completed an 8-week compassion training together focused on the growing science of compassion and secular practices for cultivating compassion grounded in the Buddhist tradition. This experience served to establish a shared foundation and framework for compassion that informed the co-design process and the designed course. The team then met weekly in person until March 2020 when the COVID-19 pandemic resulted in statewide stay-at-home orders, and meetings moved to a virtual platform until May 2020. Meetings focused on applying compassion practices to support wellness, analyzing sources of suffering in schools, and designing content for a compassion course.

Data sources

We collected and analyzed data from 13 co-design meetings, including audio transcripts, fieldnotes, and artifacts created or modified during meetings (e.g., curriculum planning documents). In addition, we collected written educator reflections and we interviewed educators at the conclusion of the study using a semi-structured interview protocol.

Data analysis

Using qualitative methods, we developed a codebook by identifying deductive codes from our conceptual framework. We used Engeström and colleagues' (2014) approach to analyzing transformative agency in deductive coding to look for the ways in which educators demonstrated agency throughout the co-design process, coding for *resisting*, *criticizing*, *explicating*, *envisioning*, *committing to action*, and *taking consequential actions*. We also drew upon the compassion organizing framework (Dutton et al., 2006) in our deductive coding to surface when a school routine or policy was mentioned, a participant recounted a story of care, or named an emotion they experienced, and to explore how it is participants navigated moving from individual practice to collective action to transform their schools. The first two authors then coded two meeting transcripts together using the deductive codes and developing additional codes inductively, revising the codebook (Miles et al., 2014). The first two authors coded several transcripts individually until inter-rater reliability was established at 90% and then continued until all data were coded. They wrote analytic memos, summarizing emergent themes. The first author then engaged in second-cycle coding to consolidate codes and identify salient themes. They continued writing memos to summarize the themes and shared them with the other authors for review. Key themes were discussed among the author team and checked against the data corpus.

Findings

Within the co-design work, participants shared meals, discussed vulnerable experiences, engaged authentically with a wide range of emotions, and shared stories of their families. Participants were invited to bring their full selves to the collaborative process and to the curriculum design. Through bringing their full selves to the process, the team co-constructed a humanizing design environment that opened possibilities for agency, compassion, and imagination. This fostered a reciprocal form of engagement, whereby participants demonstrated agency, contributed to the co-design process, and engaged in new learning that they brought into other contexts (e.g., classrooms, schools, parenting). As co-design supported movement across scales of practice, the designed course thus embodied that same spirit to move beyond overly individualistic paradigms of compassion towards a more collective paradigm.

Co-design as humanizing

The co-design experience bridged personal and professional aspects of educators' lives

The team completed an 8-week compassion training and subsequently engaged in compassion practices together during co-design meetings. Educators shared that such practices had become integral to both their personal and professional lives. The compassion co-design supported them in developing a home compassion practice, in which they engaged in informal (e.g., bringing awareness to a daily routine) and formal (e.g., contemplative meditation) practices. As Jessica explained, "What we're talking about here [compassion practice] in terms of being a tool for teaching, this kind of bridges that gap of the personal development that becomes professional development" (Jessica Interview). In Jessica's view, the co-design experience and the compassion course designed offered skills beneficial to both her personal and professional life. The invitation to examine one's personal *and* professional life and to apply compassion practice in both contexts was a unique experience for Jessica. Educators used the compassion practices to deepen their relationships with friends and family members, such as their children, and they used these practices to improve their interactions with colleagues, students, and students' families who they viewed as challenging. In reflecting on her experience of the compassion training, Ruth highlighted the ways that the co-design experience bridged both personal and professional elements of her life. She shared that the training

> really affected me in a great way. Because I was starting from a baseline of not having a practice. So, the only place I could go is up. And the whole idea of understanding and really thinking about how we all have our moments of suffering and we're all really doing our best. It's not that that wasn't anything that I was aware of but just brought it to a new level of awareness and understanding for me. So that was really important. And I noticed that I was really in a more grounded place all Fall. Just really did affect me which carried over to my parenting, which carried over to my interactions with colleagues and my work with students, my understanding. (Ruth Interview)

For Ruth, engaging in compassion practices and establishing a routine of these practices marked new learning for her. She underscored the importance of learning about compassion and compassion practices, which impacted her parenting and relationships with colleagues and students and supported her to feel more grounded personally and professionally.

Several educators highlighted that they developed tools for self-compassion through the co-design process; self-compassion moved across social scales as educators applied these tools to their personal and professional lives. Self-compassion was an important design and discussion topic as the team worked to develop a compassion curriculum in the midst of the onset of the COVID-19 pandemic. The group often engaged in self-compassion practices and discussed both challenges to and tools for self-compassion. Bridgette, for example, spoke about how challenging self-compassion was for her, sharing that it was

> kind of the source of all my stress and, you know, teachers staying up at night just worrying about kids. It's all because we feel such a strong responsibility for, you know, all of these students. And we feel emotionally connected to them and it just can be like a really strong emotional toll and leads to that kind of burnout thing. And I think self-compassion is the first step and really dealing with that, and the more we kind of talked about that I saw how important that is for educators. And it's been really meaningful to me and helped me be better and more compassionate to my students when I am able to give myself a break and just not be in this obsessive thinking and worrying about how I'm perceived, or things like that. It's really a transformational thing, I think. (Bridgette Interview)

Bridgette, like other educators in the group, gave insight into how self-compassion was essential for her personal and professional wellness, sharing that when she learned to be more compassionate towards herself, she was able to demonstrate more compassion towards her students. For Bridgette, this was a profound and even "transformational" experience, and one that was deeply embedded within the humanizing co-design process.

Designing the compassion course was authentic and meaningful

Educators in this study experienced co-design as a process that supported their personal and professional development and wellness and reciprocally recognized that their personal and professional experiences were essential for developing the compassion curriculum. During meetings, educators shared both personal and professional challenges which helped shape the design of the compassion course. Mia, who shared on several occasions that she had been experiencing a challenging year, recognized that many other educators may feel similarly and thus her struggles were important to bring to the design: "my stress as an educator was so heightened that I could engage in the thinking of designing a course … I'm in it. I can really speak to burnout. I can really speak to stress from this very real currently lived experience" (Mia Interview). Educators not only recognized the importance of their lived experiences to the design, but also viewed one another's contributions as essential. Michael explained that team members "each had potent contributions to the whole and this in turn makes me have a ton of confidence that the end result will be accessible to all who choose to take the course" (EOY Reflection).

A couple of educators did not immediately recognize the expertise they brought to the process, but as they continued to show up, they gained more confidence in themselves and in the process. At the end of the year Ruth reflected that she was most proud that she "work[ed] through my anxiety that I wasn't going to be able to bring anything to the group or offer anything to the group because I was starting at a place where I wasn't sure about any of it … What can I offer? … But finding that the collective work and the collective energy and the collective conversations, everybody was able to add to it" (Ruth Interview). Both educators who expressed uncertainty about the process continued to attend meetings consistently and made significant contributions to the course design, suggesting that they, as Ruth stated, found support in the "collective work" and "energy."

For many educators, developing a compassion course with and for other educators was authentic and meaningful. At times, educators referenced the future students of the course and facilitators often encouraged the group to consider these future students in the design. Educators viewed the co-designed compassion course as a shared mission, one that "is going to try to bring more good into the world" (Bridgette Interview).

Co-design fostered connection and a sense of rejuvenation

Educators described the co-design process as one that fostered connection and rejuvenated them, suggesting that the environment was a humanizing one for educators. Educators found that connections forged through the co-design process served as an antidote to feelings of isolation. Feelings of isolation are prevalent in teaching (Schlichte, Yssel, & Merbler, 2005), and such feelings were exacerbated by the context of the global pandemic. Bridgette shared that

> One big takeaway from the codesign process was a strong sense of community. I can feel isolated sometimes in my job and it was amazing to work with so many people who have the common goal of bringing more compassion into the world. Especially in this time where there are so many things to be depressed about, this really restored my faith in humanity and helped me realize what is important in life and in my job. It helped to hear that others struggle with very similar situations in the educational world. I saw immediate impacts in my day-to-day life and my work. It has helped me bring a sense of compassion to every interaction with parents, students, and even my own family. (EOY Reflection)

Bridgette found comfort and connection within the co-design "community," and these connections offered her a different perspective on "humanity," her "life," and her "job," one that was hopeful and agentic. This in turn bolstered her to bring compassion to her school community.

Bridgette was not the only educator who felt buoyed by the co-design process. Nora described the meetings "like a support group every week for me" (EOY Reflection). Jessica explained that it "really reconnected me with kind of the ideals of teaching. I think the farther you get into your educational career, it can be so easy to be overwhelmed and kind of crushed by the minutiae of teaching that this was a nice re-centering for me in that personal and professional overlap" (Jessica Interview). Likewise, Mia explained,

> The co-design process has offered an opportunity to commit, to show up again and again, to work through resistance, to cultivate conscious and intentional community, and to finally rest in the nourishing comfort of a compassionate space with myself and with others. This process has been life-changing in that it has brought consistent mindful practice into a space that is usually so full and stressful. This process has transformed me, bringing self-compassion into a place that is often full of self-criticism. All of this allows me to step into my role as educator with more awareness and the ability to have compassion for others. (EOY Reflection)

For these educators, working together towards a shared goal of designing a compassion course for other educators with a vision of creating more compassionate schools, rejuvenated them, increased their hope, and prevented feelings of overwhelm and burnout.

Learning across scales of practice

A humanizing approach to co-design supported educators in applying and integrating learning across multiple scales of practice, including social, geographic, and temporal scales. While not a requirement of the co-design process, many educators practiced compassion outside of the meeting times, connected practices to their personal lives, and brought compassion into their schools, thus learning moved across scales of practice. It was this movement that helped the team begin to bridge between individual practices and changing schools in the design of the compassion course.

Educators reported engaging deeply in the inner work that supports compassion in action. For instance, educators spoke about being metacognitive about their emotions, changing the ways they reacted to situations, recognizing the suffering of those around them, and increasing self-compassion. Educators also identified particular practices that supported them to be more compassionate, such as bringing awareness to daily routines and interactions, setting intentions, and focusing on breathing during challenging situations. In several cases, educators already established a mindfulness or compassion practice prior to joining the team and these educators pointed to the co-design process as strengthening their practice.

Educators did not just keep compassion practices to themselves, but they also brought compassion into their own schools and relationships. Examples include teaching intention-setting and breathing practices to students, talking to colleagues and administrators about compassion, and using compassion tools to shift interactions with students, students' families, and/or colleagues who they considered challenging. Similarly, several educators reported bringing ideas from the co-design process into their schools — such as when one principal shared research articles with his staff that the co-design team had read together or when an educator began writing field notes, a practice that a subset of the co-design team engaged in, to reflect on her interactions at school. And, as we reported previously, educators applied compassion practices in their personal lives, using these tools to improve their interactions and relationships with family members and friends.

A key challenge for the design of the compassion course was to connect individual insight to collective action leading to change in schools. Facilitators situated design work within participants' school-based contexts and introduced readings/frameworks that sought to historicize and socialize suffering (e.g., Dutton et al., 2006; Garza, 2009; Ginwright, 2018). While shifting from individual insight to collective action in design was challenging, some members "got really excited" about the pivot to collective action and challenged others to accept responsibility for social and educational inequities by designing for more radically inclusive schools. Educators also began taking up compassion to shift structures and routines by engaging in actions such as starting staff meetings with a compassion practice, coaching colleagues who felt overwhelmed from the rapid transition to online teaching at the onset of the COVID-19 pandemic, and examining and revising grading practices. Further, educators discussed routines or policies in their schools and district that would benefit from change through a collective and compassionate approach, such as discipline, teacher evaluation, standardized testing, supports for students experiencing trauma, professional development, and classroom-level routines. Educators also identified existing practices in their schools as compassionate such as supporting student-led initiatives (e.g., student-organized school walkout for climate change), adjusting classroom discipline policies to work with students to develop a positive culture rather than removing students from the classroom, organizing a donation drive among faculty for personal and home items students in the school community needed (e.g., snow boots, kitchen items), and checking in with students more frequently through email and phone calls during remote learning due to statewide stay-at-home orders.

Cultivating a co-design environment that invited participants to bring their full selves was instrumental in supporting practices of compassion to be infused across multiple scales of practice. The approach centered the experiences of participants, supporting them to connect the learning to their personal and professional lives. As participants enacted new learning in diverse social settings, in varied physical spaces, and over time, the lens by which they understood compassion became oriented towards collective change of systems.

Designed course embodied co-design principles

The humanizing co-design process invited learning across scales, impacting the design of the compassion course. As educators engaged in expansive learning across multiple scales of practice, it made available novel forms of participation that expanded the possibilities for what could be designed. Educators brought their personal and professional lives to the co-design experience and demonstrated agency by taking new compassion ideas and practices back into their personal and professional spheres. These new experiences helped to inform the design of the compassion course as one that bridged individual practice and collective action. Ruth highlighted that the course was designed to support educators in establishing a personal compassion practice as well as to engage in compassionate action that moved across social and geographic scales. She explained, "this is a class that introduces and deepens one's understanding of compassion and the way that compassion is helpful on an individual, collective and global manner" (Ruth Interview).

Mia described the compassion course as unique, one that will impact educators' personal and professional lives: "It's just a personal shift in the way you live and see life that impacts everything. But definitely how you show up in the classroom, how you view your colleagues and parents and students. The entire learning community. It's an inside-out job…And that's what I think makes it really unique." She continued to describe the impacts of the designed course, "It's like this ripple out effect. You start with yourself and your understanding of all this and your lived experience and then it ripples out to impact the community, and hopefully if you're able to really bring in that leadership piece, impact your school staff and leadership. So that actually ripples out even further" (Mia Interview). Educators, like Mia, recognized the significance of designing a course to support other educators in learning across scales in a "ripple out effect;" one goal of the designed course was to support future educators taking the course to bring compassion and leadership to their school communities.

Some educators understood the compassion course to address professional challenges they experienced, such as a "stressful, results-driven culture in education" (Bridgette EOY Reflection) or "how we treat each other and treat ourselves" (Nora EOY Reflection). Jessica, for example, described the compassion course as addressing a sense of isolation and fostering a sense of connection.

> Teaching can be so isolating that I think this is a great tool for teachers in those moments of isolation. In those moments of losing your temper with a class, and those moments of staying awake at night suffering over "What do I do with this kid?" This is an excellent tool for teachers to have when they are just with themselves. So much of teacher professional development is "What can I do? How can I change this?" And this is just about "How am I, how do I be?" I've never had that addressed in education. And yet those ideas of staying awake at night of really emotionally investing are core. (Jessica Interview)

Jessica believed that the co-designed compassion course will help act as a bridge between educators' personal and professional lives, as it focuses on educators' wellness and addresses educators' relationships. Attending to the principles of compassion in the co-design process and not just the product changed how participants experienced co-design and in turn, generated a designed product that embodied the design principles more fully.

Implications

We sought to understand the ways that educators and researchers engaged in the co-design of a course to support educators to create more compassionate schools, and how they created a co-design space that centered humanizing interactions. Members brought their personal and professional joys and challenges to the co-design process. This authentic engagement encouraged educators to participate as their whole selves and supported connection and rejuvenation, informing the design of the compassion course and supporting co-design team members to carry practices of compassion across scales of practice. Educators felt confident to enact compassionate changes within their schools and personal lives and designed a curriculum that could support future educators to do the same. This study underscores the importance of attending to the process of co-design and experience of participants and suggests that doing so supports expanding participants' learning and experiences and generates designs for learning that are more powerful and sustaining. This study points to key structures that allowed for and encouraged a humanizing co-design environment to develop and offers practical suggestions for facilitators of collaborative design teams.

Reposition expertise through shared learning

A fundamental aspect of co-design holds that members of the design team bring their own knowledge, expertise, and experience to bear on the design (Penuel et al., 2007; Bang & Vossoughi, 2016). With the intention of repositioning researchers and educators so as to genuinely elevate the unique expertise of all team members, we engaged in shared learning. We participated in an 8-week course, where all participants were positioned as learners. The intentionality of designing experiences, such as participation in this course, where participants could learn together, share their knowledge, and expand their understandings was critical in the generation of humanizing co-design. We suggest that before embarking on a collaborative project, facilitators take stock of who holds expertise and power and plan for shared learning experiences to reposition participants.

Cultivate a community of care, compassion, and trust

The goal of the course promoted reflexivity and explicitly attended to prefiguring caring relationships within the co-design process that reflected how we hoped educators would engage in their schools. We integrated compassion practices into our weekly co-design sessions. Engaging in the compassion training and practicing compassion together supported the group in cultivating a community characterized by care, compassion, and trust and in developing shared language, goals, and experiences to build upon during co-design work. This foundation supported the enactment of compassion in the co-design space.

Center shared experiences of joy and suffering

Attention to context was essential for humanizing the co-design process, and this included explicitly acknowledging and making space for current global, personal, and professional events that impacted people's lives and caused both joy and suffering. The COVID-19 pandemic erupted in the midst of the co-design process, and it became a shared experience of suffering, one in which opportunities for compassion among our team arose. As meetings shifted to virtual and occurred in the context of participants' homes, pets and children became a regular part of meetings, in a way that invited joy and connection. There will always be events impacting co-designers' lives and providing opportunities for these realities to emerge within the process allows for fluidity of design, resulting in a product that continues to be responsive to the context and honor teachers' humanity.

Conclusion

We examined the ways that the humanizing co-design process generated expansive learning across multiple scales of practice. The intentionality given to the experience of co-design supported participants in engaging in the meetings, their professional contexts, and personal lives in new and expansive ways. As participants enacted their learning across scales of practice, they were presented with new understandings of the focal content, and in turn developed a designed product that embodied expansive and compassionate learning. Our analysis underscores that researchers and facilitators must attend to the process, not just the product, of co-design. To support the design of humanizing experiences, researchers and facilitators can (1) reposition expertise through shared learning, (2) cultivate a community of care, compassion, and trust, and (3) center shared experiences of joy and suffering.

References

Ashar, Y. K., Andrews-Hanna, J. R., Dimidjian, S., & Wager, T. D. (2016). Toward a neuroscience of compassion: A brain systems-based model and research agenda. In J. D. Greene, I. Morrison, & M. E. Seligman (Eds.), *Positive Neuroscience* (pp. 125–142). Oxford University Press.

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction, 34*(3), 173-193.http://dx.doi.org/10.1080/07370008.2016.1181879

Camangian, P. & Cariaga, S. (2021). Social and emotional learning is hegemonic miseducation: Students deserve humanization instead. *Race Ethnicity and Education*. https://doi.org/10.1080/13613324.2020.1798374

Cammarota, J., & Romero, A. (2006). A critically compassionate intellectualism for Latina/o Students: Raising voices above the silencing in our schools. *Multicultural Education*,*14*(2), 16–23.

Conklin, H. G. (2008). Modeling compassion in critical, justice-oriented teacher education. *Harvard Educational Review*, *78*(4), 652–674.

Dutton, J. E., Worline, M. C., Frost, P. J., & Lilius, J. (2006). Explaining compassion organizing. *Administrative Science Quarterly, 51*(1), 59–96. https://doi.org/10.2189/asqu.51.1.59

Ehret, C., & Hollett, T. (2016). Affective dimensions of participatory design research in informal learning environments: Placemaking, belonging, and correspondence. Cognition and Instruction, 34(3), 250–258. https://doi.org/10.1080/07370008.2016.1169815

Engeström, Y., & Sannino, A. (2010). Studies of expansive learning: Foundations, findings and future challenges. *Educational Research Review*, 1–24. https://doi.org/10.1016/j.edurev.2009.12.002

Engeström, Y., Sannino, A., & Virkkunen, J. (2014). On the methodological demands of formative interventions. *Mind, Culture, and Activity, 21*(2), 118–128. https://doi.org/10.1080/10749039.2014.891868

Frumin, K. (2019). Researchers and practitioners in partnership: Co-design of a high school biology curriculum [Doctoral dissertation, Harvard Graduate School of Education].

Garza, R. (2009). Latino and White high school students' perceptions of caring behaviors: Are we culturally responsive to our students? Urban Education, 44(3), 297–321. https://doi.org/10.1177/0042085908318714

Ginwright, S. (2018, May 31). The future of healing: Shifting from trauma informed care to healing centered engagement. *Medium*. https://medium.com/@ginwright/the-future-of-healing-shifting-from-trauma-informed-care-to-healing-centered-engagement-634f557ce69c

Jazaieri, H., McGonigal, K., Jinpa, T., Doty, J. R., Gross, J. J., & Goldin, P. R. (2014). A randomized controlled trial of compassion cultivation training: Effects on mindfulness, affect, and emotion regulation. *Motivation and Emotion, 38*(1), 23-35. https://doi.org/10.1007/s11031-013-9368-z

Jinpa, T. (2015). *A fearless heart: How the courage to be compassionate can transform our lives*. Avery.

Jurow, A. S., & Shea, M. (2015). Learning in equity-oriented scale-making projects. *Journal of the Learning Sciences*, *24*(2), 286-307. https://doi.org/10.1080/10508406.2015.1004677

Miles, M., Huberman, A.M, Saldaña, J. (2014). *Qualitative data analysis: A methods sourcebook*. SAGE Publications.

Paris, D. (2011). 'A friend who understand fully': Notes on humanizing research in a multiethnic youth community. *International Journal of Qualitative Studies in Education, 24*(2), 137-149. https://doi.org/10.1080/09518398.2010.495091

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning, 02*(1), 51–74. https://doi.org/10.1142/S1793206807000300

Potvin, A.S. (2020). "Students speaking to you": Teachers listen to student surveys to improve classroom environment. *Learning Environments Research*. https://doi.org/10.1007/s10984-020-09330-1

Sannino, A., Engeström, Y., & Lemos, M. (2016). Formative interventions for expansive learning and transformative agency. *Journal of the Learning Sciences*, *25*(4), 599–633. https://doi.org/10.1080/10508406.2016.1204547

Schlichte, J., Yssel, N., & Merbler, J. (2005). Pathways to burnout: Case studies in teacher isolation and alienation. *Preventing School Failure: Alternative Education for Children and Youth, 50*(1), 35-40. https://doi.org/10.3200/PSFL.50.1.35-40

Weng, H.Y., Lapate, R.C., Stodola, D.E., Rogers, G.M., & Davidson, R.J. (2018). Visual attention to suffering after compassion training is associated with decreased amygdala responses. *Frontiers in Psychology 9*, 1-12. https://doi.org/10.3389/fpsyg.2018.00771

Quantified Qualitative Analysis: Rubric Development and Inter-rater Reliability as Iterative Design

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Abstract: The objective in the current paper is to examine the processes of how our research team negotiated meaning using an iterative design approach as we established, developed, and refined a rubric to capture comprehension processes and strategies evident in students' verbal protocols. The overarching project comprises multiple data sets, multiple scientists across (distant) institutions, and multiple teams of discourse analysts who are tasked with scoring over 20,000 verbal protocols (i.e., think aloud, self-explanation) collected in studies conducted in the last decade. Here, we describe the iterative modifications, negotiations, and realizations while coding our first subset comprising 7,559 individual verbal protocols. Drawing upon work in design research, we describe a process through which the research team has negotiated meaning around theory-driven codes and how this work has influenced our own ways of conceptualizing comprehension research, theory, and practice.

Introduction

Learning from text involves a negotiation of meaning between multiple entities, including authors, instructors, and students. Students are often faced with the challenges of understanding and learning from text that exceed their prior domain knowledge and reading skills (e.g., Goldman & Bisanz, 2002; Moje & Speyer, 2014). Through a more robust understanding of these learning processes, researchers can develop activities and interventions that can help students to better learn from the challenging texts that they encounter. Thus, we aim to understand the various constructive processes that learners use when building and negotiating the meaning of texts. In our work, our overarching goals are to understand these processes and to develop adaptive technologies that provide individualized support for students as they learn from text.

One approach to understanding readers' comprehension processes is to have them produce verbal protocols as they read. Students may be asked to "think aloud" by reporting whatever thoughts come to mind. They may also be asked to "self-explain" in which they explain the text to themselves as they read. Prompting students to generate these verbal protocols as they read can be a means of enhancing learning, but such prompts also serve as a window through which researchers can better understand the processes that students engage in when they read (e.g., Chi, 1997; McNamara, 2004; Pressley & Afflerbach, 1995). Coding and quantifying these responses allows researchers to examine how different processes and strategies relate to students' individual differences (e.g., interest, prior knowledge, reading skill; e.g., Coté et al., 1998) and to learning outcomes (e.g., Magliano et al., 2011) as well as response to interventions (McNamara, 2004).

For the past few decades, members of our team have gathered approximately 20,000 verbal protocols in our various studies of learning from and with text. Our current objective is to code (or recode) these reader responses using a common rubric agreed upon by an interdisciplinary group of researchers and discourse analysts.

Qualitative approaches lend a rich understanding of discourse (e.g., Gee, 2014; Pressley & Afflerbach, 1995). To attempt to scale these approaches, many researchers quantify qualitative aspects of discourse to statistically relate these features to other factors such as individual differences or experimental variables (e.g., Chi, 1997; Coté et al., 1998). This coding process relies on rubrics designed to capture a theoretical construct of interest and reaching reliability between raters (Chi, 1997). Typically, a rubric is designed by scientists or experts, and raters adapt their codes to increase reliability, iteratively matching to the conceptual rules set by the expert and to each other. The rubric is more or less the stable entity, wherein examples are added and some wordings may be modified, but few substantive changes are made. In some cases, discussions can lead to non-trivial refinements in how the constructs are conceptually and operationally defined, but this seems rare, or at least opaque. The debates, discussions, and decisions surrounding the operationalization of constructs (if they occur) are generally left unreported when the main objective is to reach quantifiable reliability between raters. In many papers, this complex process is often distilled down to a single sentence (e.g., "*raters were trained to criterion and then coded the remainder of the data*").

Our objective in the current paper is to examine the *process* of how our research team negotiated meaning as we established, developed, and iteratively refined a rubric to capture these important comprehension processes. We describe a negotiation of meaning, but one different from that faced by the readers - one underlying the process of coding these protocols: a negotiation between the scientists (who developed the rubric) and the discourse analysts tasked with reaching agreement in their assessments of the nature of the processes revealed within the protocols. We examine how these interactions resulted in a deeper understanding of the student responses and the larger research goals.

The current project

There are two unique aspects of the current project. The first is its scope and scale. In most situations, a few hundred verbal protocols are scored by a pair or a small group of raters who are co-located and the data are coded within a small window of time. Our project, by contrast, included multiple data sets, multiple scientists across three (distant) institutions, and multiple teams of discourse analysts. Moreover, due to COVID-19, these negotiations have occurred predominantly in virtual space. A second unique aspect of this project was exploring the development and refinement of the rubric as both an iterative design task to create a functional educational tool and a learning opportunity in and of itself.

While the larger research project draws from cognitive theories of text and discourse comprehension (see McNamara & Magliano, 2009, for a review), the current work around the development and refinement of the rubric takes inspiration from both instructional design and design-based research. Although agreed-upon definitions of design-based research remain elusive, central considerations of DBR is that research is iterative, collaborative, and highly sensitive to its context (e.g., Barab, 2014). Of particular interest in the current work is the way in which expert researcher/scientists and novice rater/discourse analysts co-constructed meaning within small rating teams and across the larger project as they worked through the coding process. Establishing reliability often requires in-depth discussion about which codes are relevant to the research question and how those codes are operationalized. Modifying the rubric requires mutual understandings between the scientists and the discourse analysts. We iteratively adapted the rubric and our mutual understandings to increase not only reliability between the raters, but also to capture the unique perspectives of the raters. This "push and pull" between reliability and validity, wherein one objective is to maximize reliability between raters, and the other is to maintain some level of validity intrinsic to the fundamentally qualitative nature of the analysis, was a driving force in this process.

Context and data sources

The larger project relies on verbal protocol data from a series of large-scale studies. These data were collected from different regions of the US, included students reading at, above, and below grade levels, native and non-native English speakers, and students enrolled in both traditional college courses and those assigned to developmental education. Although the texts and tasks varied from study to study, the general procedure for collecting verbal protocols was the same. Students read a text and were prompted to type a verbal protocol at various target sentences (predetermined locations in which connections and explanations were likely to be fruitful for comprehension). Such typed protocols are easier to collect than spoken protocols and yield similar properties in terms of the strategies that readers demonstrate during reading (Muñoz et al., 2006). Some protocols were produced under the instruction to think aloud while others were instructed to self-explain. This varied both within and across studies. After reading and generating verbal protocols, students answered either multiple-choice or open-ended comprehension questions. In addition to the comprehension task, students also completed a variety of individual difference tasks including standardized comprehension tests, foundational reading skills tests, and various measures of interest such as working memory. In some studies, verbal protocols were collected in a single session, while in other studies, the verbal protocols were collected before and after reading comprehension interventions. The research team included four experienced researchers (the PI and Co-PIs of the project) and two teams of graduate students and research assistants spread across multiple research sites. A third team was brought into discussions, but due to practical limitations, especially in light of COVID-19, this team left the project. However, we wish to acknowledge their contributions to our thinking and the various revisions to the rubric.

In the current work related to the design and iterative refinement of the coding rubric, we relied on multiple data sources. We collected copies of each iteration of the rubric (including tracked changes and comments from version-to-version). The raters coded the verbal protocols in excel spreadsheets. Raters were asked to provide their codes as well as any notes or questions they had regarding specific responses. Thus, we had these excel files for each rater's initial independent pass and a second pass "corrected" after discussion. We also had combined excel files in which we compared rater scores and logged discussion notes. Additionally, we examined rater and researcher notes from the weekly meetings that occurred during initial training as well as email threads that include discussions around specific examples.

Design cycle

This work was inspired by instructional design (e.g., Silber, 2007) and design-based research (Design Based Research Collective, 2003; Easterday et al., 2014). This paper reflects our initial design cycle from preliminary problem conception through a first implementation, evaluation, and refinement of the coding rubric. Critically, in addition to the larger "design loop", we also focus on important rapid, iterative cycles that occurred throughout the process. These cycles involved both quantitative and qualitative analysis of the rubric and inter-rater agreements. Our design cycle appears in Figure 1. In the following sections, we outline each phase of the research in more detail to describe the process and how the discussions within rater groups and across the larger team led to refinements in the rubric as well as the team's understanding of the theoretical underpinnings and implications of the codes.

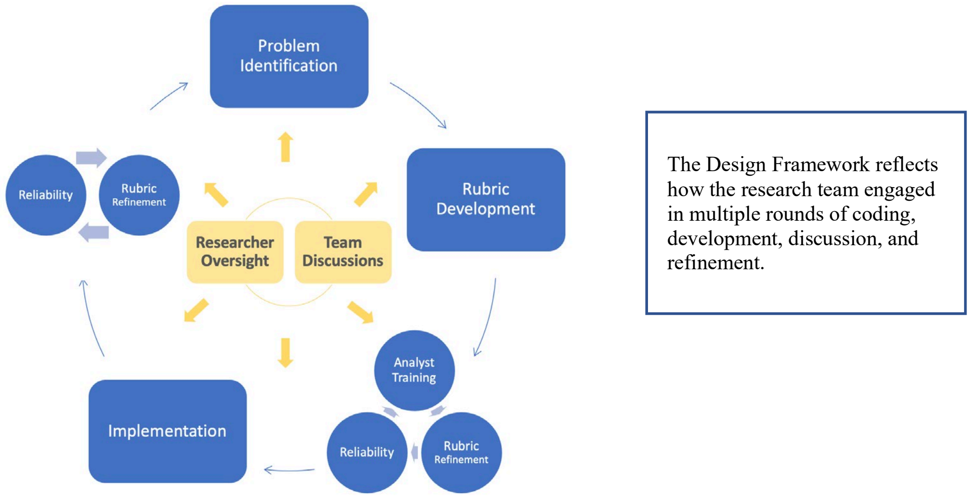

Figure 1. Design Framework

Phases 1 and 2: Problem identification and rubric development

Although these data sets have been scored by human raters in previous studies, the protocols have been scored by a number of different raters using similar, but not identical rubrics. Thus, in order to be able to draw meaningful conclusions and to make comparisons between datasets, the research team agreed that we needed to develop a common rubric. While our team has expertise in quantified qualitative protocol analysis, the scope of this project brought to light interesting theoretical and practical issues. Our data sets include different age groups and skill levels, different types of texts (history, science), reader tasks (e.g., self-explain, think-aloud), and different methodological aims across studies. Thus, we were tasked with developing a rubric that was (1) sensitive to different texts and tasks, but general and *flexible* enough to be applied across a number of contexts and (2) reflected strong enough criteria (e.g., rules) for consistent operationalization, but not so rigid that the codes no longer reflected authentic human judgments.

Our ideation process revolved largely around developing an initial rubric. Our initial rubric was adapted from a number of extant rubrics that have been designed based on theories of discourse comprehension (see McNamara & Magliano, 2009). These theories assume that readers engage in a number of comprehension processes and strategies that support the construction of a coherent and elaborated mental model. The rubrics used in this area of research tend to include three broad categories of strategies: paraphrasing, bridging, and elaboration. *Paraphrasing* is a process in which students reproduce content from the texts. *Bridging* is a process of establishing how the current sentence is related to prior discourse context and provides the primary basis for achieving coherence in a mental model. Finally, *elaboration* is a process that involves integrating information from prior knowledge with information provided by the text. Bridging and elaboration are *inferential processes* that are critical for mental model construction. It was also important to us, theoretically, to not categorize each protocol as *either* paraphrase, bridging, or elaboration, but rather the extent to which these processes were apparent in students' protocols. Thus, our rubric included three broad dimensions: presence of the strategy, nature of the strategy, and an overall quality score. Table 1 shows the questions that each of the codes were designed to address. Additional codes were included to capture other common behaviors (e.g., inaccurate statements, life events, direct copy and pasting).

Table 1: Questions driving the three dimensions of interest for paraphrasing, bridging, and elaboration

Dimension	Paraphrase	Bridging	Elaboration
Presence of Strategy	How much of the target sentence is captured? *(none; some; most)*	To what extent is information from previous text present? *(none, little, some, much)*	To what extent does the reader bring in outside information to make sense of the text? *(none, little, some, much)*
Nature of Strategy Use	-	Are connections made to ideas in previous sentence (*local bridge*) or other previous sentences (*distal bridge*)?	Is the outside information relevant to understanding the text?
Overall Quality	What is the overall *quality* of the response? *(Poor, Fair, Good, Great)*		

Phase 3: Training and rapid iterative refinement

The initial data set (Magliano et al., 2020) included verbal protocols from 597 college students. Students wrote verbal protocols for two texts. The history text (Louis XVI) included six think aloud locations and the science text (Erosion) included seven think aloud locations. In total, the data set comprised 7,559 individual verbal protocols. The verbal protocols were left segmented "as is" in the sense that the totality of what a student wrote in response to a given target sentence was coded as a single response.

We randomly selected a subset of 20% of the verbal protocols for training and refining the rubric. This subset of protocols was randomly selected at the participant by text level and then divided into three training phases. The research sites engaged in both intra-team and inter-team discussions. Given time constraints, Team 1 was working full time, while Team 2 was working part time. Raters were encouraged to make notes in the coding files and to bring issues to group discussions. Evaluating and discussing common disagreements led to additions and refinements to the rubric. Major modifications included: a) the addition of a metacognitive *monitoring* code reflecting occasions when students expressed clarity or confusion, b) addition of codes that reflected the nature of a students' paraphrases (*lexical change*, *syntactic change*), c) the simplification of an *accuracy* code from four levels to a dichotomous *misconception* code, and d) modifications of language related to presence and quality of elaborations.

After the third round of coding to obtain reliability, Team 1 demonstrated good reliability on overall (0-3) score (k = .71) and the presence scores (paraphrase presence = .74, bridge presence = .73, elaboration presence = .77). Reliability estimates on the nature of the verbal protocols scores were often lower, but acceptable (syntactic change = .64; lexical change = .81; bridge contribution = .73, elaboration relation = .64). Additional codes (e.g., too short, copy/paste) ranged from .73 to full agreement.

Phase 4: Implementation

Once the first team of raters had established sufficient reliability, the remaining responses were divided amongst the raters, with a random set of 10% of their total assigned responses for post hoc reliability calculations. The raters sent their scores at the end of each week. Coding this data set took approximately 4 months to complete (with some delays due to COVID-19). At the same time, the second team was continuing to establish reliability and to confer with the first team about ongoing disagreements. There were no major changes made to the rubric during this time.

Phase 5: Evaluation and refinement

In most projects, coding the remainder would reflect the "end" of this process. However, given our overarching objective to understand the nature of the protocols, we continued into a second phase of evaluating reliability. Once the first team of raters completed scoring the data set, we examined reliability across the randomized overlap to explore rater drift. The reliability calculations illustrated that most codes were markedly lower than the initial benchmarks, with overall score k = .46 and other scores ranging from k = .48-.73. In order to identify systematic inconsistencies between the raters, we used confusion matrices to identify common mismatches across the raters. Table 2 shows a confusion matrix for the presence of paraphrasing for one of the training phases. The diagonal (green) shows where raters agreed, and the other cells indicate discrepancies. The confusion matrices allowed the research team to identify systematic differences across raters (indicated here in red). These instances became the basis for discussion that led to insight into the construction of meaning by students and is reflected in the rubric.

Table 2. Example confusion matrix for paraphrasing.

		Coder 2		
		0	1	2
Coder 1	0	116	20	0
	1	5	50	7
	2	1	10	98

Examining confusion matrices also revealed that elaboration had become overgeneralized to include *any* information that could not be found in the text and that this had resulted in inflated overall scores for statements that were unrelated to the semantic content of the text. Through discussion across the teams of raters, it was agreed that *elaboration apparent relation* code would be removed and to instead add a more general *nonsense* code to capture statements that were *irrelevant* or off-task. There was also an addition of an *evaluative statement* that seemed to emerge frequently in the history text. These statements tended to follow an "x should have done y" format. While such responses are on task, they did not align with notions of paraphrase, bridging, or elaboration in ways exhibited by other types of statements. As a result of these discussions and changes to the rubrics, raters' reliability increased on *elaboration presence* from k = .48 to .80 and the new codes showed good reliability (evaluative = .74; irrelevant = .83; monitoring = .78).

Lessons learned

Examination of our rubrics and meeting notes (as well as discussions related to the development of this paper) revealed a number of important lessons that we carry forward into our next cycle of refining and implementing this rubric on the next set of data. Our lessons-learned span issues pertaining to the construction of meaning, sensitivity to contexts, the iterative process of refinement, and how consideration of this task as design work led to important insights and valuable changes to our research more broadly.

Negotiating and co-constructing meaning

There were inherent challenges in developing operational definitions that allowed coders to draw upon a shared understanding of the processes of paraphrasing, bridging, and elaboration. These challenges included the negotiation of the underlying meaning of various constructs and the operationalization of these constructs.

Negotiating constructs

The co-construction of knowledge occurred in the context of differences in disciplinary knowledge, epistemological perspectives, and experience coding protocols for both the research scientists and coders. This occurred even in the context of the senior researchers on this project who have an extensive history of collaboration, share a common theoretical perspective, and have implemented similar coding protocols over the past 20 years (e.g., Best et al., 2004; Kopatich et al., 2019; Magliano et al., 2011; McNamara, 2004). While there was a shared understanding of the constructs delineated in Table 1, there were non-trivial differences in how they have been operationalized across studies. For example, both Magliano et al. (2011) and McNamara (2004) used rubrics that were intended to identify the presence of elaboration. However, Magliano et al. (2011) did not evaluate the extent to which elaborative processes reflected the process of knowledge building, whereas McNamara (2004) advocated sensitivity to identifying the role of elaboration in support of knowledge building. These differences were revealed in the early stages of refinement and training of coders, but required several rapid iterations to uncover. The lack of common ground on this issue was only discovered with intense qualitative discussions on coding disagreements between separate teams. These discussions laid bare not only gaps in our rubric, but also helped the researchers to co-construct the meaning of these definitions and how they related to comprehension processes.

Negotiating operationalization

There are tensions inherent to transforming qualitative natural language into quantitative scores. One objective is to reach reliability between raters. This process requires constructing a well-defined rubric, with examples and rules. There are two particular tendencies that we have observed. These two stances toward the coding task became apparent to us because one team of analysts approached this task from one direction, while the other team approached it from the other. On one side, we observed a tendency for raters to seek absolute rules and guidelines, (e.g., exact number of words necessary to qualify as a paraphrase, number of words beyond the target sentence qualify as an elaboration). We have found it challenging to convince coders that humans will have disagreements, but if one relies solely on 'counting' words, the element of human judgment is lost (i.e., we might as well have a computer count words). On the other side of the continuum, coders sometimes "read into" protocols rather than basing judgments on the explicit content of the protocols. Such a tendency is natural because we cannot stop the activation of our own prior knowledge. Thus, coders make inferences using their own knowledge while coding. However, the coders sometimes expressed notions that the student producing the protocol should be "given credit" for an attempt. This was particularly true for protocols that were relatively short (e.g., *Erosion are bad.*), had mechanical and grammatical errors that made them difficult to understand, or were ultimately idiosyncratic (e.g., *Too much water isn t [sic] also good for crops people and mostly, Houston. it floats every time it rains so the people are mostly homeless*.). As a consequence, there emerged a propensity to identify the presence of more sophisticated learning strategies than those reflected in the explicit content of the protocols. Establishing agreed upon ways of scoring protocols required our team(s) to reevaluate and refine their understanding of the task writ large and its role in addressing the larger research question.

At the same time, emergent and persistent disagreements led us to reconsider our constructs. For example, our original coding scheme included four levels (0-3) of elaboration presence. Raters indicated that they were able to clearly understand the difference between a 1 (one or two *words* from outside the text) as compared to 2s and 3s (*ideas* from outside the text). However, they struggled to discern a 2 (an idea from outside the text that is vaguely conveyed) from a 3 (an idea from outside the text that is complete and clearly conveyed). As a result, we collapsed 2 and 3 into a single code that reflected any idea from outside the text. This inability to achieve reliability brings into question the extent to which this distinction is construct-relevant or theoretically important.

Multiple aspects of context

Those who have written about quantified qualitative analysis (e.g., Chi, 1997; Vogel & Weinberger, 2016) note that context is an important consideration for evaluating discourse. In our work, we further identified the need to consider multiple contexts simultaneously.

Tensions between sentence context and participant context

The purpose or quality of a given protocol is context dependent and each protocol exists within multiple contexts. For example, the protocol *Erosion are bad* is, in comparison to other reader responses, relatively poor in quality. However, this protocol nested within a struggling reader's other protocols, may reflect a breakthrough or at least preliminary evidence that the reader is making some sense of the text. Our different coding teams adopted different preferences for sorting and coding the protocols. Some of our raters found it easier to code protocols linearly by student. That is, the rater would code Student A's protocols in response to target sentences 1-9 before coding Student B's responses. These raters indicated that the context in which the student made the utterance helped to make sense of the students' intended meaning in ambiguous responses. By contrast, other raters found it easier to code by target sentence, such that they would code target sentence 1 for Students A-*n* and then code target sentence 2. These raters found that the comparison across multiple students talking about the same sentence made the distinctions between codes more apparent. Both approaches have obvious advantages. However, the end result was that the different approaches resulted in different ratings. Our solution was to adopt aspects of both. Our current approach is to first code by participant to leverage the knowledge that the moment-to-moment context provides. Once the rater has scored a number of participants (e.g., at the end of the week), the rater resorts the data file by target sentence, examines their own intra-rater reliability, and makes changes based on any discovered inconsistencies.

Tensions between operationalization and generalizability to text context

Our data sets include different texts from multiple genres, including science and history. Thus, our texts vary not only in terms of task, but also in terms of content, genre, and text-specific features. The operational definitions in our rubric needed to be broadly conveyed so that they could be reliably applied to multiple types of texts. This led to protracted discussions regarding text and sentence-specific patterns that impacted how students expressed their thoughts. For example, both texts within the training corpus included cause-and-effect relations. However, responses within the history text included comments about "character" intentionality, which were not evoked within the science texts; and vice versa, science texts evoked particular phrases and sentence structures that were not present in the history texts. These differences forced us to reconsider the extent to which a statement was semantically-related and relevant to the broader context of the text. Such concerns have led us into continuing discussions regarding the extent to which these processes are similar or different across tasks, contexts, and genres and what these differences say about comprehension more generally.

Iterative refinement within a larger design-based framework

The final set of insights pertained to the benefits of our design loop. The multiple rapid cycles of discussion and refinement without the larger design cycle were particularly helpful in a project of this scale. As illustrated in Figure 1, we have emphasized rapid cycles of evaluation and refinement at multiple points throughout the coding process. This flexibility in approach has allowed us to quickly respond to concerns and adjust to issues as they emerged. Those who are well-versed in instructional design and design-based (implementation) research are aware that these processes occur and can be crucial to the success of an intervention. However, cyclical, reactive iterations are often not considered within the context of coding verbal protocol responses.

In most verbal protocol coding projects, the objective is to capture the target construct, but the focus is on establishing and maintaining reliability between coders. Once reliability has been achieved, there is little consideration of how changes that may have occurred during training influence the larger project. By checking our reliability during the implementation phase, we were able to identify stark drops in reliability, which forced us to consider the ramifications of the issue, including its theoretical implications. Discussions amongst the team highlighted the value of the quantitative data as a means to drive qualitative understandings. The quantification of discrepancies between coders provided a basis for discussing how constructs were defined. Frequent use of reliability metrics and confusion matrices allowed us to more quickly identify and diagnose points of disagreement, confusion, and misconception. These quantitative metrics afford a valuable way to engage in rich discussion, allowing the team to be more responsive to issues of both reliability and validity as coding continued.

By contextualizing this work within a design cycle, we were able to capitalize on the notion of "closing the loop" (e.g., Liu & Koedinger, 2017). In much design work, tools and systems are built, deployed, and evaluated, but many fall short of subsequently capitalizing on the discoveries made during evaluation to improve the design moving forward. Closing the loop refers to making sure that the data derived from one evaluation is used to inform the next cycle of problem identification. In light of increased cross-institutional collaborations and the growth of large-scale and big data, framing coding procedures as design work affords a way to structure the development and refinement and, perhaps most importantly, the documentation of the iterative nature of rubric development. We continue to use these methods of discussion and iterative refinement as we progress through additional data sets. One question that remains for us is the extent to which it is appropriate and feasible to reopen closed loops. That is, as we progress through our data sets, to what extent might we revisit "completed" data sets when we have a new discovery that changes our rubric. We continue to consider these implications, including their costs and their benefits.

Conclusion

Learning scientists and educational researchers more broadly often rely on rubrics and inter-rater reliability to identify and evaluate learning processes and behaviors. Through exploring our own process of iterative development and refinement, we observed critical tensions between theory and real-world implementation, as well as reflexivity regarding our own assumptions about comprehension processes. We encourage those who engage in these types of coding tasks to similarly step back from the process and flexibly respond to breaks in the coding process as opportunities for knowledge co-construction and negotiation of meaning.

References

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 151-170). Cambridge University Press.

Best, R., Ozuru, Y., & McNamara, D.S. (2004). Self-explaining science texts: Strategies, knowledge, and reading skill. In Y. B. Kafai, W. A. Sandoval, N. Enyedy, A. S. Nixon, & F. Herrera (Eds.), *Proceedings of the Sixth International Conference of the Learning Sciences: Embracing Diversity in the Learning Sciences* (pp. 89-96). Mahwah, NJ: Erlbaum.

Chi, M. T. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *The Journal of the Learning Sciences, 6*(3), 271-315.

Coté, N., Goldman, S. R., & Saul, E. U. (1998). Students making sense of informational text: Relations between processing and representation. *Discourse Processes*, *25*(1), 1-53.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5-8.

Easterday, M. W., Lewis, D. R., & Gerber, E. M. (2014). Design-based research process: Problems, phases, and applications. Boulder, CO: International Society of the Learning Sciences.

Gee, J. P. (2014). *An introduction to discourse analysis: Theory and method*. Routledge.

Goldman, S. R., & Bisanz, G. L. (2002). Toward a functional analysis of scientific genres: implications for understanding and learning processes. In *The psychology of science text comprehension* (pp. 19-50).

Graesser, A. C., & McNamara, D. S. (2012). Automated analysis of essays and open-ended verbal responses. In *APA handbook of research methods in psychology, Vol 1: Foundations, planning, measures, and psychometrics.* (pp. 307-325). American Psychological Association.

Kopatich, R. D., Magliano, J. P., Millis, K. K., Parker, C. P., & Ray, M. (2019). Understanding how language-specific and domain-general resources support comprehension. *Discourse Processes*, *56*(7), 530-552.

Liu, R., & Koedinger, K. R. (2017). Closing the Loop: Automated Data-Driven Cognitive Model Discoveries Lead to Improved Instruction and Learning Gains. *Journal of Educational Data Mining*, *9*(1), 25-41.

Magliano, J. P., Higgs, K., Santuzzi, A., Tonks, S. M., O'Reilly, T., Sabatini, J., Feller, D., Kopatich, R., Ray, M., & Parker, C. (2020). Testing the inference mediation hypothesis in a post-secondary context. *Contemporary Educational Psychology*, *61*, 101867.

Magliano, J. P., Millis, K. K., Levinstein, I., & Boonthum, C. (2011). Assessing comprehension during reading with the Reading Strategy Assessment Tool (RSAT). *Metacognition and Learning*, *6*(2), 131-154.

McNamara, D. S. (2004). SERT: Self-explanation reading training. *Discourse Processes*, *38*(1), 1-30.

McNamara, D. S., & Magliano, J. (2009). Toward a comprehensive model of comprehension. *Psychology of learning and motivation*, *51*, 297-384.

Moje, E. B., & Speyer, J. (2008). The reality of challenging texts in high school science and social studies: How teachers can mediate comprehension. *Best Practices in Adolescent Literacy Instruction*, 185-211.

Muñoz, B., Magliano, J. P., Sheridan, R., & McNamara, D. S. (2006). Typing versus thinking aloud when reading: Implications for computer-based assessment and training tools. *Behavior Research Methods*, *38*(2), 211-217.

Pressley, M., & Afflerbach, P. (1995). *Verbal protocols of reading: The nature of constructively responsive reading*. Routledge.

Silber, K. H. (2007). A principle-based model of instructional design: A new way of thinking about and teaching ID. *Educational Technology*, 5-19.

Vogel, F., & Weinberger, A. (2018). Quantifying qualities of collaborative learning processes. *International handbook of the learning sciences*, 500-510.

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Objects to Debug with: How Young Children Resolve Errors with Tangible Coding Toys

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Abstract: Debugging is an important skill all programmers must learn, including preliterate children who are learning to code in early childhood settings. Despite the fact that early learning environments increasingly incorporate coding curricula, we know little about debugging knowledge in early childhood. One reason is that the tangible programming environments designed for young children entail a layer of material complexity that we have yet to account for in terms of learning to debug. In our study of young children learning to program, we found that in the midst of solving programming tasks and learning to debug, tangible toys presented bugs of their own. This paper analyzes video of Kindergarteners learning to debug errors in the program and errors in the physical materials. We argue that concurrent physical and programming bugs present opportunities for young children to learn about the broader computational system in which they are learning to code.

Introduction

Debugging is known to be an important programming skill (Pea, 1986; Pea et al., 1987), and studies of debugging are seeing a resurgence in the learning sciences (DeLiema et al., 2020; Fields et al, 2016; Brady et al., 2020; Kafai et al., 2020). While much of this work deals with the knowledge and computational thinking of novice programmers, there has been less emphasis on how very young children learn to debug. Despite the fact that early learning environments increasingly incorporate coding curricula and CS standards, we know little about programming and debugging knowledge in early childhood (Wang & Choi, 2020). One reason for this gap is that language-dependent frameworks for debugging do not necessarily apply to preliterate programmers. The novel programming environments designed for young children entail a layer of material complexity that we have yet to account for in terms of learning to debug.

Rather than screen-based environments like Logo (Papert, 1980) or block-based tools like Scratch Jr., preschool and Kindergarten children frequently use tangible and hybrid coding toys (e.g. Bers, 2018; Horn, 2018). These types of programming tools include components that can be shared amongst a group of early learners, supporting collaborative debugging activities (Fields et al., 2016). They also introduce a number of new issues for collaborative work, because the materials are distributed and manipulable. Often, in the midst of solving programming tasks and learning to debug, tangible toys present bugs of their own. In this paper, we refer to these types of issues as "physical bugs," and we examine how children reconcile solving bugs in the domain of the program with concurrent bugs in the physical, material domain.

First we review how physical materials have been treated in studies of debugging, drawing a through-line between Papert's (1980) floor turtles and today's tangible toys. Next we briefly describe our design-based study of Kindergarteners learning to code using robot coding toys. We present our analytic process and initial findings that discriminated between buggy problems with the *program* and buggy problems with the *physical materials*. Then we illustrate what resolving these types of bugs looked like when they occurred in isolation and then concurrently, during a series of debugging tasks that a group of Kindergarteners worked to solve in the course of a 30-minute lesson. We show how the objects they used to resolve the coding errors introduced bugs of their own, and we highlight how children debugged both orders of problems. We argue that, rather than constraining or complicating children's debugging skills, tangible toys present opportunities for children to learn about the larger coding frame or system in which programming occurs.

Framing perspectives: Tangible coding toys and young children's debugging

Papert's (1980) floor turtle was one of the first tangible coding toys. Prior to the standard screen-based Logo version, children programmed the turtle to draw basic shapes using a pen that was fitted to its body. Although the floor turtle was more practical for connecting young programmers to the physical world, the robots were expensive, and few made it out of MITs Media Lab and into Kindergartens (Bers & Horn, 2010; McNerney, 2004). No longer tethered to the computer and now increasingly affordable, today's coding toys bear some resemblance to the first turtles. A growing suite of tangible programming robots can be found in early learning settings (Yu & Roque, 2018).

Describing how children resolved errors in turtle programming, Papert (1980) wrote that "the process of debugging is a normal part of the process of understanding a program" (p. 61). Commonplace as debugging may be among novice programmers, we do not yet have an understanding of what the process of debugging looks like for young children. Some early tangible programming tools that grew out of the Media Lab, such as Perlman's Slot Machine, required children to re-code entire sequences rather than editing buggy programs (McNerney, 2004), a fairly inefficient strategy when the program grows to more than a few commands. In his studies of young children programming in Logo, Pea (1986) referred to a "superbug," the idea that, independent of programming language, novice programmers learn that some meanings need to be expressed explicitly in code, while others do not. Already hardwired, beyond the programming domain at the level of electronics, lies another layer of encoded problems to solve, black-boxed within the robot the children are programming (Resnick et al., 1998; 2000). For young children, debugging using tangible toys involves solving problems at the level of the program and at the level of physical materials (Fields et al., 2016).

Study design: Coding in kindergarten

This study took place in the context of a larger design-based research project called Coding in Kindergarten (NSF #1842116) where we are investigating early childhood computational thinking using commercially available robot coding toys (Clarke-Midura et al., 2021). Participants were 48 children in 3 schools, divided into groups of 3-4 children for coding lessons. Lessons occurred twice per week for one month, and children were assessed following implementations. Coding lessons were designed to elicit knowledge and skills associated with computational thinking (i.e. algorithmic thinking, sequencing, pattern recognition, decomposition, and debugging). During lessons, groups of children and a teacher interacted with a series of tangible robot coding toys and other materials included in the coding kits, such as large floor grids used for planning robot paths. Lessons involved programming a robot to travel on a path through the grid, and "codes" consisted of directional arrows placed in a sequence of movement commands. The tangible programming environment- color-coded directional commands, large floor grids, and multiple manipulatives- supported groups of preliterate children to build and debug programs.

The focal cases in this paper illustrate children's interactions with Botley, a coding robot that operates by entering directional codes into a remote control connected to the agent through Bluetooth (see Figure 1). Botley's kit comes equipped with a set of directional arrow tiles that can be sequenced to build a program. Botley can be used with or without its "arms," which guide a small ball into a goal. We observed that it was sometimes difficult to keep the kit's directional arrow tiles in order when sequencing algorithms, thus we iteratively designed means of organizing the codes, making them easier to manipulate. In the first two cases, children used magnetic code tiles on a metal sheet to build their program. In the third case, they built programs using the code tiles that came equipped with the coding toy kit, along with a paper program organizer designed by members of our research team. One minor detail, important for Botley's operation and for interpreting the cases, is that you must press the "trash" button on the remote control to clear Botley's program before programming and executing a new one.

Data and analytic methods

Approximately 30 hours of classroom coding lessons were video recorded and then content logged (56 individual lessons) (Jordan & Henderson, 1995). We then conducted qualitative coding, which consisted of iterative rounds of open coding for characteristics of bugs and debugging activity followed by axial coding according to an emergent relationship between (1) bugs in the program and (2) problems with the materials (Glaser & Strauss, 1967). Within these two broad categories, we identified types of bugs/problems and strategies for resolving/repairing them, and we conducted frequency counts. Further analyzing patterns in frequency and occurrence of bugs, we found that, rather than discrete bugs solved serially, programming and physical bugs frequently co-occurred. For this paper, we selected two cases that illustrate what it looked like when children only needed to address a programming or a physical bug and contrasted these with a third case of a 30-minute lesson which elicited multiple co-occurrent bugs. We conducted interaction analysis of these debugging episodes, focusing on participants' talk, gesture, and coordinated use of materials (Jordan & Henderson, 1995).

Frequency of bugs and strategies for resolving/repairing

Table 1 summarizes the results of the types and frequencies of bugs and strategies for debugging in both the program and bugs related to physical errors (i.e., physical domain). Overall, bugs in the program most often involved turn errors and missing codes, and errors related to the materials most often involved controller errors. Students' strategies were frequently related to the type of bug. For example, if the students' program was missing a forward code and the robot did not make it to the goal (i.e., *Missing Code*), the debugging strategy was usually to *Add on to End*. In the cases below, while we mention the strategies students used, we focus our analysis on the ways students addressed programming and physical bugs. Case 1 illustrates a situation in which students encountered a *Wrong Start Code* bug (programming bug), and Case 2 provides an example of an *Initializing Robot* bug (physical bug). We use Case 3 to illustrate students' ways of resolving and repairing multiple concurrent bugs.

Table 1: Bug types and strategies for Programming and Physical bugs

PROGRAMMING BUG TYPES: semantic errors when specifying code sequence
Turn Errors (56) *Misunderstanding turn unit (turn-rotate, not turn-turn) or specifying opposite direction*
Wrong Start/End/Middle code (23) *Positional bug errors requiring switch at location in sequence*
Missing Code (63) *Children skip a code or miscount a number of needed rotations or forward moves*
Spurious Code (29) *Inserting or specifying an unneeded, extra code or codes*
Sequencing Error (9) *All codes are present, but out-of-order*
Goal/Path Problem (36) *Losing track of path being sequenced or lack of clarity about endpoint*
DEBUGGING STRATEGIES: process of diagnosing and resolving semantic errors
Swap Codes (46) *Removing a code or codes and replacing them with other codes*
Remove/Add on to End (76) *Editing the end of the program by making the sequence longer or shorter*
Clear Program, Start Over (30) *Removing all codes from the program board and/or pressing delete button*
Remove Code, Move Codes Down (10) *Shortening the program by removing a start or middle code error*
Accommodate Bug (9) *Transform a bug into a feature of the program, change the goal or path*
PHYSICAL BUG TYPES: physical errors in material or mechanical apparatus
Material Mishap (24) *Incidental issue with grids, tiles, or accessories (i.e. robot wheel snags on rug)*
Initializing Robot (38) *Forgetting to reposition robot on start position; false start; mis-orienting robot*
Controller Errors (130) *Remote control, program board (i.e. incomplete button press; forgot to "trash" out)*
Mechanical Issues (35) *Problems with motor, batteries, Bluetooth pairing, or on/off buttons*
Building in a Bug (29) *Intentional user error for pedagogical or personal reasons (i.e. sabotage)*
REPAIR STRATEGIES: process of operating and repairing physical errors
Halt and Re-run Program (56) *Interrupting program execution when a physical bug is identified, restarting*
Work-arounds (12) *Swapping out robot units or materials that are malfunctioning*
Just-in-time Fixes (18) *Catching, mitigating an issue with the physical apparatus before it causes a problem*
Sweeping a Bug under the Rug (35) *Quickly moving on, re-running the program, ignoring physical issue*
Accounting for Technical Issue (12) *Explicitly addressing the physical cause of a failed program*

Case 1: Resolving a programming bug without mechanical interference

Typically, when we think of debugging, we imagine programmers fixing a problem *in the program*. At times during coding lessons, children resolved programming bugs in this commonsense manner, without the materials interfering in debugging. We designed a task called *What Happened?* to explicitly teach debugging strategies for resolving common programming errors. The *What Happened?* task involved giving children buggy code that failed to get the robot to its goal and asking them to debug the program. In one such task, Lacey and Max worked together to diagnose and fix the broken code LEFT FORWARD FORWARD, where the bug was a wrong turn in the start position. The appropriate debugging solution was to swap the start code, replacing LEFT with RIGHT.

[a] Lacey: You have to turn him this way and get him to

[b] Max: No, no, no, the blue

[c] Lacey: That one? Oh, yeah!

[d] Max: We had to change it to blue

Figure 1. Lacey and Max debug a programming bug

Start position bugs involving rotations proved particularly challenging for children; many children applied strategies such as adding on to the end or removing the start code altogether to resolve this bug, resulting in multiple failed debugging attempts. After simulating how they wanted the robot to move, Lacey initially appeared to *re*apply the same wrong turn in their debugged program (Figure 1, a). Max quickly intervened, asserting that they needed the "blue" (i.e. the RIGHT) turn (b). Lacey clapped her hands excitedly to indicate agreement, and they compared their program with the buggy program to specify the location of the bug (c,d). With the robot turned off, Max and Lacey then demonstrated what their debugged code would make Botley do by simulating the movements. They were able to focus on the programming error, since no mechanical issues interfered in their debugging.

Case 2: Reorienting to a physical bug as a potential problem source

Programming bugs are a ubiquitous part of building algorithms, especially for novice programmers, who, in addition to learning a programming language, must also learn language-independent conventions for expressing meanings within a formal system of mechanistic rules (Pea, 1986). One thing all beginning programmers must determine is how much the computer "knows" and how explicit to make their commands in light of the built-in constraints. Tangible coding toys are built to make 90 degree turns, therefore establishing the correct starting orientation before initiating a program is paramount. Regardless of design, all tangible coding robots we use have a "face" that assists children in establishing robot starting positions. Still, forgetting to set the robot's orientation before running a program over multiple debugging attempts was a continuous source of physical bugs. We refer to these bugs as "initialization bugs"; however, rather than written code that would declare and clear variables and set initial states, initialization bugs take place *in the physical, tangible domain* where they represent failures to re-set the robot itself on the proper trajectory.

Figure 2. Jessica reorients the robot (left) and then reenacts this strategy (right). *Counter-clockwise from Jessica: Penelope, Paulo, Max, Lacey*

While reviewing Botley's movement-code correspondences during one lesson, the teacher Jessica used a just-in-time re-orientation to probe children's understanding of the critical concept of initializing the robot (Figure 2). The group was about to run a program LEFT FORWARD that was intended to land Botley on the blue tile. However, the robot was mis-oriented from a previous program; in the direction it was facing, LEFT FORWARD would have landed it *off* the tiles and on the carpet in front of Max (a frequent mishap that was a source of endless amusement for children). Just as Paulo pushed the button on the remote to run the program, Jessica realized that the robot needed to be re-oriented and swiftly rotated Botley 90 degrees to the right. After the program successfully reached the blue tile, she then paused to reenact her last-minute rotation, asking the children why they thought she had re-oriented it. Max suggested that Jessica was trying to "control" it (she was) and Lacey offered that it "didn't work" (it did). The children's reasoning about physical problems that require their own sort of debugging was still developing. It was, therefore, important that Jessica prompted them to examine the physical requirements of the programming environment. Doing so at a moment like this, when there was no concurrent problem in the program, supported them to develop repair strategies they would need when programming and physical bugs co-occurred.

Case 3: Reconciling concurrent programming and physical bugs

While the first two episodes show how young children address and resolve bugs, debugging was rarely this simple, and often involved a cascade of recurrent- and concurrent- bugs. Most coding lessons included multiple target programs, each of which required debugging over some number of attempts, which involved resolving both physical and programming bugs. When physical and programming bugs co-occurred, children and teachers needed to find both a debugging strategy that fixed the code *and* a repair strategy that mitigated physical bugs. More often than not, teachers intervened and interrupted physical bugs before they caused the whole program to miscarry, for example, when Jessica applied a just-in-time fix to a potential initialization problem. As children worked together to learn how to program *and* how to use the robots, bugs proliferated, compounding their problem-solving.

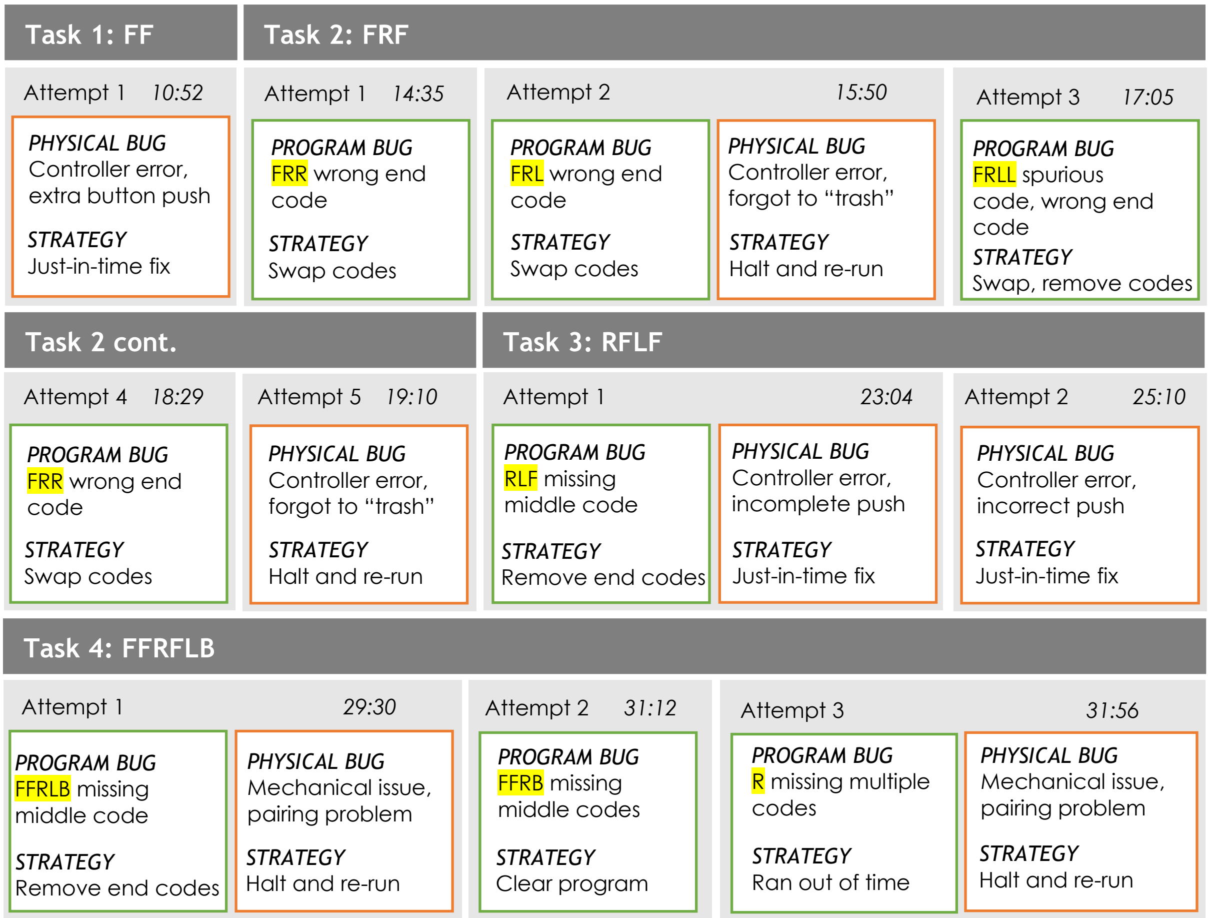

Figure 3. Outline of debugging during a 30-minute coding lesson.

Next, we sketch the anatomy of a coding lesson (comprised of a series of tasks, target programs, attempts, concurrent bugs, and debugging discussions) (Figure 3). We then zoom in on a single task in the lesson to show how the group organized their shared work and materials to handle programming and physical errors. This particular lesson involved an activity design called *Crack-the-code*, in which children attempted to program one Botley to run the hidden code of another Botley after they watched its movements. The children alternated between planning the program, sequencing the arrows, and pushing the commands on the remote control, sharing the materials and rotating roles between tasks. After solving a number of concurrent programming and physical bugs in the previous two tasks and cracking the code for the programs FORWARD FORWARD (FF) and FORWARD RIGHT FORWARD (FRF), the children attempted to crack a third target program: RIGHT FORWARD LEFT FORWARD (RFLF). After watching the first Botley run the program several times, Eli attempted to replicate it, instructing his programming assistant Stanley to sequence the codes RIGHT LEFT FORWARD (RLF).

At this point, they had produced a single programming bug; the program was missing a middle FORWARD code, for which the most efficient debugging strategy was to move the two end codes down and insert the missing code. However, before they ran the buggy program to test it, they first had to avoid potential user errors. After Joey reminded Christian to "trash out" the remote to delete the previous program, Christian began to enter the three codes into the remote, but Joey noticed that Christian pushed one of the buttons only half-way (the robot lights up when a full button push is registered). Joey stopped Christian inputting commands and instructed him to "push it harder." Joey called out the colors that corresponded with the arrows, and Stanley assisted Christian by pointing to the buttons (Figure 4, a). Joey's and Stanley's assistance with the physical material prevented user errors that would potentially have muddled Eli's programming bug.

After they ran this first buggy program and the robot failed to land where they intended it to, Stanley exclaimed excitedly that they get to do some "re-bugging" (b), coining a term that aptly describes children's recurrent attempts to debug with robot coding toys. When Joey asked Eli if there was anything he wanted to "fix" or "change," Eli was initially unsure. He began to demonstrate over the robot which way he wanted it to turn, referencing directions and colors of the tiles (c). As part of the process of learning to debug, children often described what they wanted the robot to do by referencing the physical grid space before blending these movements with the relatively unfamiliar and abstract domain of the program (Silvis et al., 2020). Eventually, Joey suggested that they remove the end codes and test each code one-by-one (d). This was a basic strategy teachers used with novice coders, who were more successful debugging programs when they could simply incrementally add onto the end of the sequence, fixing codes one at a time as necessary.

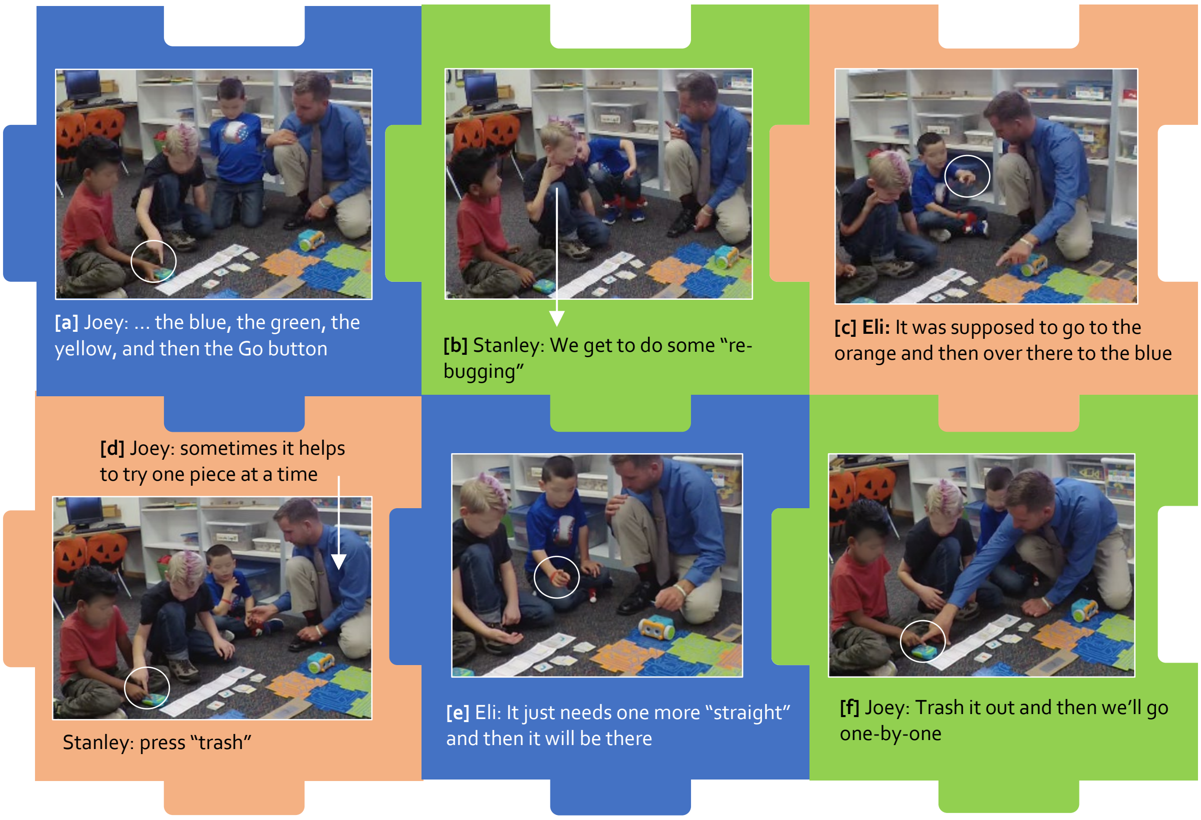

Figure 4. Debugging during Task 3

Following instruction from Stanley about trashing out the program in the remote control and pushing the Go button, Christian ran a single RIGHT command. Having isolated the initial movement, Eli then sequenced the remainder of the new program with Stanley's help (e). It was again time for Christian to program the codes into the remote control. Having observed multiple remote control-related user errors, the whole group was by then carefully monitoring Christian's operation of the remote. He successfully pushed the blue (RIGHT) and green (FORWARD) buttons, *but then mistakenly pushed another forward button* before the right turn button. Joey told him to press trash and start over, a just-in-time repair strategy in the physical domain that circumvented program failure. Joey pointed to the trash button and then told Christian to push the buttons "one-by-one" (f). Stanley pointed to each of the arrows in the program as they called out the arrow colors to Christian. In the course of the RFLF task, the children had applied both debugging strategies to the program and repair strategies to the physical materials. One-by-one coding and one-by-one button pushing were required to resolve errors in the program *and* prevent errors in the physical materials. We turn in the discussion to the ways in which tangible programming involves learning to debug both domains.

Discussion: Objects to debug with

In this paper, we presented the idea that tangible programming lends itself to forms of debugging at the level of the program and in the domain of the physical materials. Because coding robot toys are comprised of multiple, manipulable components, bugs occurring in the physical domain, such as forgetting to delete the previous program or pressing the wrong button on the remote control, can make it challenging for children to tease out errors in the program. Teachers' just-in-time strategies for addressing physical bugs- and for making technical requirements more transparent for children- may partly mitigate confusion; however, children must still grapple with the relationship between errors in their programs and errors due to the materials. As such, tangible toys can be thought of as "objects to debug with," which introduce novel orders of problems to solve. In a programming context where the success of a program hinges as much on accurately sequencing as it does on reliably inputting codes, operating materials and tangible programming go hand in hand.

Another characteristic of this particular computational environment that is consequential for coding involves the semantics of the coding language. The operative symbol system is a collection of color-coded arrows, a language that instantiates the meaning of directional commands in a symbolic form legible to preliterate children. However, Kindergarten children are also developing early spatial reasoning skills that implicate these same directional symbols; thus, learning the movement conventions of tangible toys (i.e. how the robots operate in 3D space) is entangled with learning the movement-symbol correspondence (i.e. how the symbols operate within a program) (Silvis et al., 2020). This complexity is compounded when the physical materials malfunction, or when there are user errors. The children in the cases we presented above are simultaneously learning *at least* the following concepts and conventions: (1) to perform mental rotation in 3D space (2) that the turn commands do not move the robot to another square, but merely rotate them on the same square (3) that the sequential actions of the robot depend on a precise sequence of codes and (4) how to input this same planned sequence of codes into the remote control.

Given the constraints built into the robots and this series of correspondences children are learning, concurrent physical and programming bugs require children to grapple with the larger programming environment or computational system. Whereas coding toys may appear straightforward and "user friendly" compared with screen-based or hybrid alternatives, tangible programming often involves solving both semantic (i.e. programming) and pragmatic (i.e. environmental) problems. Rather than a design flaw of tangible toys, we see this complexity as a resource for learning to debug, because it forces children to consider the broader relationship between all the components of the computational system: the codes; their meanings; their function (i.e. to give instructions to the robot); the robot and its movement constraints; coding robot accessories like the remote control (how does it "talk" to the robot, anyway?). Learning to coordinate these computational components to solve problems is a tall order in Kindergarten- especially when groups of children program collaboratively- but one that we see as productive for learning and consequential for their engagement with computing down the road.

Finally, while we focused in this analysis on the relationship between concurrent programming and physical bugs and the consequences of these co-occurring bug *types*, we also see a need for more study of the corresponding *strategies* students and teachers used to resolve bugs in both domains. Successfully resolving bugs requires an alignment between bug type and solution strategy. When children attempt to debug a programming bug in the middle of the program by adding onto or removing codes from the end, they fail to debug the program. Teaching children to apply particular debugging strategies to particular types of bugs is important across programming environments, no less in tangible programming (Klahr & Carver, 1988; McCauley et al., 2008). However, coding robot toys also require learning to apply a strategy to fixing the programming bug that teases out and takes into account the presence of concurrent physical bugs. This means placing pedagogical focus on the technical requirements/constraints of toys and teaching children not only how to fix problems with their programs but also how to diagnose and repair problems with operating the robots. Tangible programming environments expose how learning to debug does not simply follow from learning to program. We need to design for debugging (e.g. Fields et al., 2016), and treat tangible coding toys as objects to debug with.

Conclusion

The recognition that debugging is an important skill for programming has led to a number of studies. However, most of these studies focus on older students who are literate and interacting with computer screens. Very few studies focus on how young, preliterate children learn to debug. Integrating CS into early childhood requires a deeper understanding of the context and materials with which young children engage while learning to program. Preschool and kindergarten aged children often use tangible and hybrid coding toys that use directional arrows as a syntax. Programming these robot toys requires children to push buttons or manipulate tiles, often external to the toy. Thus, understanding how young children debug requires understanding the level of complexity the materials introduce and the nature of both the programming and physical bugs they encounter. Insofar as young children are learning how to operate these materials while they are learning to code, interactions with the toys are consequential for learning. More study is needed of the pedagogical approaches that support children to align their debugging strategies with the types of bugs they encounter. As learning designers, attending to tangible programming toys as objects to debug with provides insight into young children's thinking and supports them developing valued computational skills and knowledge.

References

Bers, M.U. (2018). *Coding as playground: Programming and computational thinking in the early childhood classroom*. Routledge.

Bers, M. & Horn, M.S. (2010). Tangible programming in early childhood: Revisiting developmental assumptions through new technologies. In I.R. Berson & M.J. Berson (Eds.), *Childhood in a Digital World*. Information Age Publishing.

Brady, C, Gresalfi, M., Steinberg, S., Knowe, M. (2020). Debugging for art's sake: Beginning programmers' debugging activity in an expressive coding context. ICLS 2020.

Clarke-Midura, J., Silvis, D., Lee, V., Shumway, J., Kozlowski, J. (2021). Developing a Kindergarten computational thinking assessment using evidence-centered design: The case of algorithmic thinking. *Computer Science Education*, doi.org/10.1080/08993408.2021.1877988.

DeLiema, D., Dahn, M., Flood, V.J., Abrahamson, D, Enyedy, N. & Steen, F. (2020). Debugging as a context for collaborative reflection on problem-solving processes. In E. Manolo (Ed.), *Deeper Learning, Dialogic Learning, and Critical Thinking: Research-Based Strategies for the Classroom*, p. 209-228. Routledge.

Fields, D., Searle, K.A., & Kafai, Y.B. (2016). Deconstruction kits for learning: Students' collaborative debugging of electronic textile designs. In P. Blikstein, M. Berland, & D.A. Fields (Eds.), *Proceedings of the 6th Annual Conference on Creativity and Fabrication in Education (pp.82-85). New York, NY: ACM.*

Glaser, B.G. & Strauss, A.L. (1967). *The discovery of grounded theory: Strategies for qualitative research.* Aldine Publishing.

Horn, M. (2018). Tangible interaction and cultural forms: Supporting learning in informal environments. *Journal of the Learning Sciences, 27*:4, 632-665.

Jordan, B. & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences, 4*(1), 39-103.

Kafai, Y. et al. (2020). Turning bugs into learning opportunities: Understanding debugging processes, perspectives and pedagogies. ICLS 2020.

Klahr, D. & Carver, S.M. (1988). Cognitive objectives in a LOGO debugging curriculum: Instruction, learning, and transfer. *Cognitive Psychology, 20*, 362-404.

McCauley, R., Fitzgerald, S., Lewandowski, G., Murphy, L., Simon, B., Thomas, L. & Zander, C. (2008). Debugging: A review of the literature from an educational perspective. *Computer Science Education, 18*:2, 67-92.

McNerney, T.S. (2004). From turtles to tangible programming bricks: Explorations in physical language design. *Personal Ubiquitous Computing, 8*: 326-337.

Papert, S. (1980). *Mindstorms*. Basic Books.

Pea, R.D. (1986). Language-independent conceptual "bugs" in novice programming. *Journal of Educational Computing Research, 2*(1), pp. 25-36.

Pea, R.D., Soloway, E., Spohrer, J.C. (1987). The buggy path to the development of programming expertise. *Focus on Learning Problems in Mathematics, 9*(1), pp. 5-30.

Resnick, M., Berg, R. & Eisenberg, M. (2000). Beyond black boxes: Bringing transparency and aesthetics back to scientific investigation. *Journal of the Learning Sciences, 9*:1, 7-30.

Silvis, D., Lee, V., Clarke-Midura, J., Shumway, J., & Kozlowski, J. (2020). Blending everyday movement and representational infrastructure: An interaction analysis of Kindergarteners coding robot routes. In M. Gresalfi & L. Horn (Eds.), *Proceedings of International Conference of the Learning Sciences (ICLS).*

Wang, X.C. & Choi, Y. (2020). Teacher's role in fostering preschoolers computational thinking: An exploratory case study. *Early Education and Development*. https://doi.org/10.1080/10409289.2020.1759012.

Yu, J. & Roque, R. (2019). A review of computational toys and kits for young children. *International Journal of Child-computer Interaction, 21*, 17-26.

Friends as Flowers: How Perspective-Taking and Empathy Transform Children's Relationships to Science and Nature

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Abstract: While science education has traditionally privileged detached and "settled" inquiry of natural phenomena (Bang & Marin, 2015), in this paper we discuss instances in which children leverage perspective-taking to explore the phenomenon of pollination through a more relational stance. We focus on two days of an eight-day mixed reality (MR) enhanced, embodied modeling curriculum where students play the roles of bees and flowers. We illustrate how the MR inquiry process supported students to take perspectives that they might not have otherwise. These different perspectives demonstrated a range of relationships to science and nature (e.g., friends, protectors, etc.). Our findings indicate that children disrupted traditional third-person views on scientific phenomena by taking the perspectives of and building empathy towards bees and flowers. Implications include the potential to further leverage perspective-taking and empathy-building towards desettling nature-culture relations (Bang et al., 2012) in future designs.

Keywords: perspective-taking, play, science education, mixed-reality, nature-culture relations

Major issues and significance

Science is a sense-making tool we use to examine and understand the world. Some definitions of science focus on the systematic organization of knowledge, while others define science in terms of the methods and practices used to produce knowledge such as observation, modeling, argumentation, and experimentation (NGSS Lead States, 2013; Ford & Forman, 2006). In most Western industrialized constructions of science, humankind is positioned apart from the object of study. We study the world, but we are not part of the world we are studying (Berkovich-Ohana et al., 2020). Our conceptions of science and objective truth lead us to take a spectator's position. However, this is not the only way to understand the world. Indigenous practices offer alternative epistemologies of science and the production of knowledge (e.g., Cajete, 1999; Bang & Medin, 2010; Bang & Marin, 2015) where humans attempt to better understand the world by positioning themselves as interconnected with the phenomena of interest.

Recent advances in digital technologies, such as mixed reality and augmented reality, are creating opportunities to learn science in new ways that invite students to study a phenomenon by becoming the phenomenon and taking a first-person perspective on the world rather than an observer's third-person perspective (Keifert & Stevens, 2018). One can study the orbits of planets and comets by becoming them (Lindgren & Johnson-Glenberg, 2013) or better understand pollination by becoming bees (Tu et al., 2019). To date, the majority of research in this emerging sub-field of the learning sciences has investigated how embodying the phenomenon creates new resources and metaphors for understanding the content (Enyedy et al., 2015; Lindgren & Johnson-Glenberg, 2013), but less attention has been paid to how perspective-taking may lead to more empathetic and less human-centric relationships to the content (for an example of a study that moves towards these design goals in technology-enhanced learning environments, see Lyons et al., 2013).

In this paper, we investigate how learning about pollination through the eyes of bees (and flowers) in a mixed-reality environment titled Science through Technology Enhanced Play (STEP) led students to think about the interdependence of bees and flowers from a first-person perspective and how that created space for alternative constructions of science and nature. We argue that the shift from third-person observer to first-person experiencer of natural phenomena not only supports scientific sense-making, but also emphasizes relationality and empathy with more-than-humans. Such relationality and empathy help to dismantle the nature-culture divide—the importance of which cannot be understated given the current moment of the Anthropocene (Guyotte, 2019).

Theoretical approach

The design of STEP is premised on the fact that socio-dramatic play is often a form of informal inquiry where one can explore a phenomenon by stepping into and playing a role. When people think of children's pretend play, they often think of the type of play chronicled by Vivian Paley (2004)—playing superheroes, school, or house—where children take on roles with power and authority that they do not have access to in their daily lives. Most of these contexts are familiar to children, but not fully understood by them. For example, when children play "house," they take on culturally meaningful roles such as mothers, fathers, and babies. They place these roles in a specific context often by saying, "*Let's pretend that* [you are the mommy and I am the baby and I am sick]." Notably, when the children begin the scene, they do not fully understand all of the dynamics at play, such as gender roles or the rules of parenting. It is through play that they attempt to make sense of what parents do and why. This is why play is a form of first-person inquiry: through play, children are able to inquire into an aspect of their lives they do not fully understand by inhabiting different perspectives than their own. STEP leverages play as inquiry to explore scientific phenomena.

Previous studies of STEP have explored the relationship between rules in play and embodied scientific modeling (DeLiema et al., 2019; Tu et al., 2019), and have demonstrated that embodied modeling in STEP supported learning gains in challenging complex systems concepts (Enyedy et al., 2015; Danish et al., 2018). In this paper, we are interested in the connection between emotion and cognition in play. Nicolopoulou (1993) argued that "play can mobilize emotions to achieve cognitive ends" (p. 16) and discussed this primarily in relation to how children come to understand their social worlds. We extend this idea to consider how emotions evoked by play in STEP supported students to develop understanding of and new ways of relating to the natural world.

Given our interest in students' conceptions of and relationality with nature, we found perspectives from environmental psychology and Indigenous scholars to be helpful for our analysis as well. With regard to the former, Schultz (2000) proposed a three-factor structure for environmental concerns: egoistic (motivated by rewards/harm to self), altruistic (motivated by rewards/harm to other people), and biospheric (motivated by rewards/harm to living things and the biosphere), with each factor linked to a person's notion of self as independent, interdependent with other people, or interdependent with all living things, respectively. He found that taking the perspective of animals being harmed led to increases in individuals' biospheric concern. With regard to the latter, Indigenous scholars critique traditional views of humans as independent and separate from nature. Bang and Marin (2015) argue that settled expectations of nature-culture relations, which position humans as distinct from the natural world and ignore non-humans' agency, dominate science education and restrict learning. They discuss how recognizing the presence of Indigenous ways of knowing and constructing non-humans as agentic enables "distinct and expanded forms of agency, perception, explanation, and ultimately meaning-making" (Bang & Marin, 2015, p. 541). Engaging students with heterogenous ontologies and epistemologies opens up new ways of understanding science and nature and has the potential to empower marginalized learners whose ways of knowing are typically repressed (Bang et al., 2012; Bang et al., 2017). Though the STEP curriculum was not intentionally designed to transform nature-culture relations, reviewing our data led us to identify vignettes where young children took varied perspectives, sometimes seeing humans as separate and other times blurring the nature-culture boundary, as they made sense of pollination. A close look at students' negotiation of different perspectives in their play yields insight into ways of understanding natural-cultural systems and nature-culture relations that are not often seen in traditional science classrooms.

Methodological approach

This study focuses on two episodes from an eight-day curriculum on bees and pollination in the STEP environment, a mixed-reality learning environment designed to leverage play and embodiment as resources in scientific modeling and inquiry. The STEP environment uses motion sensors to track students as they move about the space and embody honeybees. A virtual simulation is superimposed over the live video feed of the classroom and shows each student's digital bee avatar as it interacts with a virtual beehive and flower patch on a projector screen (see Figure 1).

Figure 1. Students move around the STEP space as bees while their bee avatars move between flowers and their hive on the projector screen at the front of the room.

The overall STEP project took place in two schools, one in Indiana and one in California, in a total of six classrooms. This was the second iteration of STEP in both schools and was the second time the teachers had implemented these lessons in their classrooms (although new features of the environment led to some lesson revision). The 25 participants in this analysis were from one first- and second-grade mixed-age Spanish-English bilingual classroom at a progressive elementary school in California. Although the participants were multilingual and the classroom was a dual immersion classroom, according to the teachers' preference, the STEP activities for this classroom were conducted in English. Data sources for this analysis included the video recordings from Day 6 and Day 8 of the intervention. The focal class engaged in the STEP environment in two separate groups and we reviewed video of both groups. We found similar themes across the class as a whole, and in this study, we present an analysis of Day 6 video with one half of the class and an analysis of Day 8 video with the other half. This class was initially selected to pursue a research question concerning how non-linguistic resources were employed and valued in a bilingual setting. The analysis here emerged from our observations while pursuing that initial research question.

Prior to Day 6, students engaged in approximately four hours of sociodramatic play from the perspective of bees, exploring different strategies for collecting nectar from flowers. On Day 6, the focus shifted to pollination. Students explored the difference between nectar and pollen through the “Bridge to Pollination” game. In this game, some students sat in the STEP space and acted as red, blue, or yellow flowers who gave pollen (red, blue, or yellow stickers) to their classmates, who acted as bees foraging for nectar. Within a 1–2 minute time limit, bees were tasked with visiting their flower friends to collect nectar, while flowers distributed pollen to each bee who visited them. While students engaged in the game, the projector screen showed the bees moving around the flower patch, leaving pollen trails behind them as they moved from flower to flower. After the time ran out, the researcher advanced time forward in the projected environment to show which flowers grew or died. Flowers that were pollinated (i.e., flowers that were visited by bees who had already visited a flower of the same color) grew and were replaced by a cluster of flowers on the screen, while flowers that were not pollinated died and were replaced by a wilted flower on the screen. Students debriefed the embodied activity with the goal of understanding that a flower can only be pollinated and grow if there are other flowers like it, and if bees distribute pollen from one flower to another flower of the same kind. On Day 8, the last lesson of the curriculum, students engaged in more embodied activities on pollination and discussed the interdependence between bees and flowers.

The research team watched video recordings of Days 6 and 8, time indexed the two lessons, and reviewed the data to identify shorter clips that highlighted students' perspective-taking. The research team then watched these selected interactions repeatedly, both individually and collectively, looking closely at the micro-interactions to iteratively develop and refine our conjectures about how perspective taking was playing out in student talk and actions (Erickson, 2006). These clips were also transcribed, and the transcriptions were edited by members of the research team to include important paralinguistic behavior (e.g., facial expressions, pointing, laughter; Jefferson, 2004). At this point in our theory building, we have not returned to the larger corpus to see how our findings generalize to other classrooms. Instead, consistent with the early phases of grounded theory (Charmaz, 2006), we have focused on making sense of the student experience by examining student arguments and explanations on Day 8 of the unit for which perspective it centered. While our project design did not explicitly include Indigenous epistemologies, during our analysis we found this line of research important and helpful to consider as we investigated the following research question: How did learning about pollination through the first-person perspectives of bees and flowers contribute to students’ empathy for and understanding of the interdependence of bees and flowers?

Major findings

We found several episodes where the technology of STEP encouraged students to take a first-person perspective as bee and flower agents acting out the phenomenon of pollination. This perspective-taking led students to pursue a different line of inquiry than if they were limited to the outsider human perspective traditionally taken in science classrooms. By analyzing the moments when students expressed less human-centric perspectives, we found evidence of more holistic and empathetic stances towards nature.

Episode 1: Developing empathy for nature through the blurring of nature’s systems and interpersonal relationships during play

The first episode occurred during the “Bridge to Pollination” activity on Day 6. As noted above, this was the first lesson in which students acted as flowers. In this instance, two students embodied blue flowers, two embodied yellow flowers, and one embodied a red flower, although up until this day the color of the flowers had never mattered because a flower’s nectar quality and quantity had no relationship to color. When the game concluded, the bees returned to the hive for winter, and the researcher asked the flowers to make a prediction about their prospects. If they thought they would reproduce and survive the following spring, they were told to stand; if they thought they would die, they were told to sit down. Andrea, the red flower, was the only student to stand, exclaiming, "I'm full of nectar!" (Figure 2). In former lessons, as a bee, being full of nectar would have signaled survival, so it seems Andrea may be conflating that experience with her role as a flower, for which being full of nectar actually means she was visited less often by bees.

Figure 2. Andrea predicted she would grow while the other flowers remained on the ground (left). When time was advanced, the projector screen showed that the red flower died while the blue and yellow flowers grew (middle), and the students embodied this as flowers (right).

The researcher then advanced time forward and the red flower on the screen died while the yellow and blue flowers turned into bunches of flowers (see Figure 2). In a moment of recognition, Andrea groaned and fell to the ground in a dramatic play-death, her arms and legs spread out like a snow-angel. Zara, who had predicted she herself would die in a similarly comically splatted death pose, with arms to the sides and one knee turned inward, suddenly registered that her flower on the screen had in fact grown. She jumped up exclaiming, "Oh I actually grew!" and the other flowers followed suit with cheers of "I grew!" One student, Maria, was so excited she began jumping and dancing in circles. Meanwhile, Andrea, still splayed on the ground, stated matter-of-factly, "I'm dead," and two students at the back of the room called out, "Andrea died."

At this moment, amidst the commotion of Maria dancing, laughter, talk at the back of the room, and the teacher asking, "What do you notice about the flowers that grew and the one that didn't?" Dylan, a student who had been clustered at the back of the room, launched himself into the space, chest first, exclaiming, "Oh!" He ran to Andrea and gingerly placed a sticker on her outstretched arm, as she laugh-lamented, "I'm de-he-head," then ran back to his teacher. Dylan turned to point toward Andrea and loudly announced, "Everybody give pollen to Andrea!" The teacher, seemingly precluding a mad rush to Andrea, said, "Well, let's talk about why that happened. Why do you think that happens? All the flowers grew except for Andrea." Dylan looked up at the screen for a few moments, taking in the imagery. Meanwhile, a researcher at the front of the room approached Andrea to sympathize with her, announcing playfully, "You're dead! I'm sorry." Dylan's gaze shifted from the screen, to the researcher, and then he turned to his teacher to explain, "Cause she didn't have any flowe= she didn't have any pollen left." The teacher began to question Dylan's reasoning, noting the pollen trails that led to and from the red flower on the projection screen, but their conversation was cut short as the teacher had to quell the rising volume of multiple students talking at once.

There are multiple noteworthy aspects of this episode. First, students' embodied experiences of playing flowers reveal an emotional connection to the phenomenon of pollination. We see this impact in Andrea's mournful groan and withering to the floor as she realized her flower had died, and in the other students' exuberant jumps up to standing as they realized their flowers had grown. One could dismiss this affective engagement as immaterial to what the students were learning but we argue below that it plays an important role in fostering students' empathy for more-than-humans and supports their sense-making. As Nicolopoulou (1993) describes, "play is a form of symbolic action, with a significant ritual element, which may thus have a powerful emotional impact on participants" (p. 16).

Second, in both their language and actions, students seem to blur the nature-culture divide that dominates most science learning environments (Bang & Marin, 2015). When students shared what they noticed, they did not say, "Andrea's flower died," but rather, "Andrea died." While students certainly knew that Andrea was playing a flower and had not herself died, their language blurred the barrier between humans and nature. This blurring seems to have invited more expansive forms of scientific sense-making (Bang et al., 2017) as students' emotional connection to their friend became a resource and motivation for understanding a natural system. Specifically, Dylan's immediate impulse to help Andrea by giving her pollen and urging his peers to do the same suggests that his orientation toward his friends had, at least for the moment, been extended to nature. Relating to Andrea, the flower, as a friend that should be helped, Dylan's empathy for people was extended to nature and this deepened his understanding of flowers' dependence on bees. The blurring of the nature-culture divide that is evident in Dylan's actions suggests that engaging in science inquiry through play created space to make sense of the natural system of bees and flowers through a desettled lens in which more-than-humans are agentic (Bang & Marin, 2015). Furthermore, drawing from Schultz's (2000) finding that taking the perspective of harmed animals increased biospheric concerns, we see Dylan's empathy, which was spurred by assuming bee and flower perspectives, as a possible impetus for increased biospheric concern. We discuss relationships between perspective-taking and environmental concern further in relation to Episode 2 below.

Episode 2: Understanding interdependence by expanding sense-making resources to include perspective-taking

On Day 8, a different group of students from the same class continued to explore pollination in the STEP space. This time, rather than sprouting more flowers, the flowers turned into fruits, vegetables, or cotton when they were pollinated. After the embodied activity, students sat down to debrief when a researcher posed the question: "Do you think pollen or nectar is more important?" Initially, there was an emphatic chorus of "Nectar!" with one girl noting, "You can make honey," and a lone quiet, "I think pollen." After a student named Oscar defiantly exclaimed that he'd already asked this question, the researcher reiterated it, asking, "What did you guys decide on?" This time, a few students tentatively whispered, "Nectar," followed by more vocal responses of "Nectar," a sole assertive, "Pollen," from a student named Ramona, and an "I don't know" from Oscar. Ramona was then the only student to raise her hand when the teacher asked who thought pollen is more important. The following discussion transpired when the teacher asked Ramona to explain her thinking:

Ramona: When the pollen goes to the other flower, um, it pollinates.
Teacher: It pollinates. So your=
Oscar: Yeah but if bees don't have nectar then [the bees won't survive.].
Isabelle: [We don't have honey.] And we don't have honey.
Oscar: But there is also other pollinators…
Matthew: But it's good for the[… plants.]
Oscar: [but it's also,] they also need nectar.
Teacher: So what do you think Matthew? Do you, do you think it's nectar or=
Matthew: It's kind of both cause=
Teacher: =pollen?
Oscar: It's like more or less, they're both [pretty important. They're both pretty important cause for the bees to survive=]
Matthew: [Yeah, cause it's better… I was gonna say it's better for the bees.]
Teacher: Hold on one person at a time. Go ahead Matthew.
Matthew: It's also good for the bees and for the plants, and the flowers right.
Oscar: (quietly) The plants are giving the bees something and the bees are giving the plants something.
Teacher: Ah, say that nice and loud.
Oscar: The plants are giving the bees something and the bees are giving the plants something.
Matthew: That's what I was saying.
Teacher: That's what you were saying.
Oscar: So they're both really important, pollen and nectar.
Teacher: So you think they're both just as important?
Oscar: Yeah because, first of all, if they don't have, if flowers didn't have pollen they would never be able to fertilize the seeds and they wouldn't

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                    grow into plants. And if bees didn't have nectar
                    then they would all die. And other pollinators
                    need nectar.
Teacher:            Hmmm.
Isabelle:           So it's technically both and balanced because we can't
                    choose one over the other. Because if we get rid of
                    one, something won't survive, and if we get rid of
                    the other one something won't survive. So we need them
                    both to survive.
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Considering this discussion in the context of the eight-day curriculum, during which students primarily took the perspective of bees, reveals much about students' responses to the pollen versus nectar question. From the bee perspective that they had been taking, it makes sense that most students privileged nectar at the beginning of the discussion; as bees, students experienced how critical it was to collect enough nectar to survive through the winter. This makes Ramona's contrasting insistence that pollen is more important all the more significant. Ramona, having played a bee for the majority of the unit, chose the more altruistic option of pollen—the resource that is critical to flowers rather than bees. We should note that during one round of the "Bridge to Pollination" game on Day 6, Ramona embodied a flower that did not get pollinated and died, so it is possible that she is recalling the perspective of being a flower in her "pollen" response. However, given the predominance of her experiences as a bee, and the fact that she witnessed the demise of her friends as flowers in multiple other rounds of the game on Day 6, it seems plausible that she chose pollen out of altruism, perhaps spurred by an empathy similar to Dylan's in Episode 1. Either way, her thinking seems to be biospheric (Schultz, 2000), as she expressed the importance of pollen for the flower's sake. Moreover, it makes us wonder if the collective perspective-taking in the "Bridge to Pollination" game, and in particular the opportunity to interact with friends in more-than-human roles, may be an especially potent recipe for developing empathy and biospheric concern. In other words, witnessing friends (in the role of more-than-humans) in trouble may inspire empathy and biospheric concern in similar ways to Schultz's (2000) finding that taking the perspective of animals being harmed increased biospheric concern. After all, our desire to help our friends is sometimes even stronger than our desire to help ourselves.

Oscar's varied contributions to the discussion further reveal the nuance, as well as the fluidity of students' ideas. Reading Oscar's comments through the lens of a more expansive set of science sense-making practices (Bang et al., 2017), which include the positioning of more-than-humans as agentic (Bang & Marin, 2015), helps us to understand the trajectory of his ideas from uncertainty, to nectar being more important, to both pollen and nectar being important. Oscar's initial leaning toward nectar being more important reflects an affinity for the bee's perspective. Furthermore, his comment, "But there is also other pollinators…" (line 8) seemed to abdicate the responsibility of the bees to pollinate flowers. His later reflection, "The plants are giving the bees something and the bees are giving the plants something" (lines 29–30), gave agency to both bees and flowers. Here, he described their relationship in reciprocal terms reminiscent of kids' lunch-time trades in the cafeteria ("I'll give you a cookie if you give me some chips"). This led to his recognition that "they're both really important, pollen and nectar" (lines 33–34), and his final explanation (lines 36–41), which is more detached and "scientific" and focuses on survival rather than a reciprocal relationship. Therefore, it seems that taking the perspective of agentic bees and flowers mediated his sense-making about the interdependence of bees and flowers. He even expanded beyond bee-flower interdependence to acknowledge how other organisms depend on the survival of flowers, noting, "And other pollinators need nectar" (lines 40–41). Oscar was able to generate this expanded and sophisticated conclusion by drawing on his own prior knowledge, inquiry experiences in the STEP space, and importantly, a more expansive set of sense-making practices (Bang et al., 2017) that blurred the nature-culture boundary. It is also notable that throughout Oscar's perspective-taking and sense-making, he, like Ramona, seemed to evaluate the importance of pollen and nectar from a biospheric stance (Schultz, 2000), placing value on the mutual survival of bees and flowers.

On the other hand, Isabelle engaged in the discussion from a human-centric stance. Her interjection of, "And we don't have honey" (line 7) in tandem with her conclusion, "So we need them both to survive," (lines 46–47), contrasts with the biospheric perspectives shared by other students, attributing value from an egoistic perspective (Schultz, 2000) of resource extraction. This egoistic perspective was echoed by several other students as the conversation continued. They named several products that depend on pollination, for example strawberries dipped in chocolate and cotton clothing. One student summarized her classmates' ideas stating, "I think it's an important thing that we have bees because they need to pollinate everything we own and a lot of things we care about." These comments are unsurprising given that the design of the STEP environment in this lesson intentionally focused students on the pollination of familiar agricultural crops on which humans depend.

Nonetheless, their reflection of settled expectations of nature-culture relations (Bang et al., 2012) presents a striking contrast to the blurred nature-culture boundary evident in Episode 1 and in some of Oscar's sense-making.

It is important to note that students' discussion of humans' relationship to bees and flowers was not solely from an extractive, egoistic stance. In addition to exploring how humans depend on pollination for everyday products, they discussed how humans sometimes harm bees, but ought to protect them. For example, they shared personal stories of witnessing pesticides kill bees and other animals, as well as suggestions that people ought to plant more flowers and not pick plants they find in order to help bees. Through this discussion, students acknowledged how humans are part of the natural system, both dependent on and having the potential to either harm or protect bees and flowers. Ramona summed this up, reflecting, "Basically we depend on bees to give us life and they depend on us to help them." This synthesis reflects a notion of self as interdependent with all living things, and thus suggests biospheric concern (Schultz, 2000). That said, it falls short of the desettled nature-culture relations that Bang et al. (2012) discuss—Ramona and many of her classmates conveyed a view of humans as separate and having power over nature's well-being, even as they expressed the need to protect bees.

Conclusions and implications

In this paper we have discussed how students engaged in play and perspective-taking to understand the phenomenon of pollination in ways that enabled more expansive sense-making opportunities (Bang et al., 2017) and disrupted normative nature-culture relations (Bang & Marin, 2015; Bang et al., 2012). In Episode 1, Andrea enacted a full-bodied emotional death as she played a flower, and this spurred Dylan's empathetic response of running to give Andrea/the flower the sticker/pollen he thought would save her. We argue that taking the perspectives of flowers and bees blurred the nature-culture boundary in this moment as empathy often reserved for other people was extended to the more-than-human world. In Episode 2, students fluidly leveraged different perspectives (bee, flower, human) as they debated whether nectar or pollen is more important, and in doing so revealed biospheric concern (Schultz, 2000) for bees and flowers. This discussion organically led into a conversation about humans' roles in the bee-flower system. Although students' discussion of humans centered around humans as extractors/protectors, thus somewhat perpetuating human-centric ways of thinking, we still believe that recognizing the interdependence of humans and nature was an important step towards desettling nature-culture relations.

It is important to note again that the STEP environment was not intentionally designed to explore or desettle nature-culture relations. Indeed, we recognize the irony of discussing an indoor technology-enhanced environment's potential to bring people closer to nature. Nonetheless, noticing the ways students expressed empathy for their friends as flowers, the fluidity of students' perspectives during the discussion of interdependence, and the spontaneous sharing about humans' roles in the system led the research team to consider STEP's potential to engage in this critical work. In future research and designs, we hope to probe these issues more deeply to realize this potential. Additionally, an important question lingers about the transferability of students' environmental concern and understanding of interdependence to other contexts. With regard to the transferability of environmental concern, Sevillano et al. (2007) found that taking the perspective of a particular animal being harmed led to biospheric concern for living things more broadly, and while this is promising, a need for further research remains. Future design implications include pairing experiences in the STEP environment with outdoor experiences, focusing on other natural systems, explicitly privileging heterogeneous ontologies and epistemologies, and intentionally using perspective-taking as a tool for building empathy with more-than-humans. In the midst of climate change, a perennial ethos of resource extraction, and the persistent separation of people from nature, efforts to repair and desettle nature-culture relations are paramount.

References

Bang, M., Brown, B., Calabrese Barton, A., Rosebery, A. S., & Warren, B. (2017). Toward more equitable learning in science: Expanding relationships among students, teachers, and science practices. In C. V. Schwarz, C. Passmore, & B. J. Reiser (Eds.), *Helping students make sense of the world using next generation science and engineering practices,* (pp. 33-58). National Science Teachers Association.

Bang, M., & Marin, A. (2015). Nature-culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*(4), 530–544. https://doi.org/10.1002/tea.21204

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education*, *94*(6), 1008–1026. https://doi.org/10.1002/sce.20392

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*(5–6), 302–318. https://doi.org/10.1159/000345322

Berkovich-Ohana, A., Dor-Ziderman, Y., Trautwein, F. M., Schweitzer, Y., Nave, O., Fulder, S., & Ataria, Y.

(2020). The hitchhiker's guide to neurophenomenology – The case of studying self boundaries with meditators. *Frontiers in Psychology*, *11*(July). https://doi.org/10.3389/fpsyg.2020.01680
Cajete, G. A. (1999). *Igniting the sparkle: An Indigenous science education model*. Skyland, NC: Kivaki Press.
Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis*. London: Sage.
Danish, J., Enyedy, N., Humburg, M., Saleh, A., Dahn, M., Lee, C., Tu, X., Davis, B., & Georgen, C. (2018). STEP-bees and the role of collective embodiment in supporting learning within a system. In J. Kay & R. Luckin (Eds.), *International Conference of the Learning Sciences*, *2*, 1249–1250. https://repository.isls.org//handle/1/600
DeLiema, D., Enyedy, N., & Danish, J. A. (2019). Roles, rules, and keys: How different play configurations shape collaborative science inquiry. *Journal of the Learning Sciences*, *28*, 513–555. https://doi.org/10.1080/10508406.2019.1675071
Enyedy, N., Danish, J. A., & DeLiema, D. (2015). Constructing liminal blends in a collaborative augmented-reality learning environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(1), 7–34. https://doi.org/10.1007/s11412-015-9207-1
Erickson, F. (2006). Definition and analysis of data from videotape: Some research procedures and their rationales. In J. L. Green, G. Camilli, & P. B. Elmore (Eds.), *Handbook of Complementary Methods in Education Research* (pp. 177–192). Washington, DC: American Educational Research Association.
Ford, M. J., & Forman, E. A. (2006). Redefining disciplinary learning in classroom contexts. *Review of Research in Education*, *30*(1), 1–32.
Guyotte, K. W. (2019). Toward a philosophy of STEAM in the Anthropocene. *Educational Philosophy and Theory*, *52*(7), 769–779. https://doi.org/10.1080/00131857.2019.1690989
Jefferson, G. (2004). Glossary of transcript symbols with an introduction. In G. Lerner (Ed.), *Conversation Analysis* (pp. 13–31). Philadelphia, PA: John Benjamins Publishing Company. https://doi.org/10.1075/pbns.125.02jef
Keifert, D., & Stevens, R. (2018). Inquiry as a members phenomenon: Young children as competent inquirers. *Journal of the Learning Sciences*, *28*(2), 240–278.
Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher*, *42*(8), 445–452. https://doi.org/10.3102/0013189X13511661
Lyons, L., Silva, B. L., Moher, T., Pazmino, P. J., & Slattery, B. (2013). Feel the burn: Exploring design parameters for effortful interaction for educational games. *Proceedings of the 12th International Conference on Interaction Design and Children*, 400–403. https://doi.org/10.1145/2485760.2485791
NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.
Nicolopoulou, A. (1993). Play, cognitive development, and the social world: Piaget, Vygotsky, and beyond. *Human Development*, *36*(1), 1–23. https://doi.org/10.1159/000277285
Paley, V. G. (2004). *A child's work: The importance of fantasy play*. Chicago, IL: The University of Chicago Press.
Schultz, P. W. (2000). Empathizing with nature: The effects of perspective talking on concern for environmental issues. *Journal of Social Issues*, *56*(3), 391–406. https://doi.org/10.1111/0022-4537.00174
Sevillano, V., Aragonés, J. I., & Schultz, P. W. (2007). Perspective taking, environmental concern, and the moderating role of dispositional empathy. *Environment and Behavior, 39*(5), 685–705. https://doi.org/10.1177/0013916506292334
Tu, X., Danish, J., Georgen, C., Humburg, M., Davis, B., & Enyedy, N. (2019). Examining how scientific modeling emerges through collective embodied play. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), *Computer-Supported Collaborative Learning Conference*, *2*, 676–679. https://repository.isls.org//handle/1/4486

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On the Impact of Differing Content Progressions in Genetics on Modeling Practices

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Abstract: Learning progressions present hypothetical pathways for learning concepts. Some progressions focus on instructional order while others focus on content. One of the open questions in the field attends to the interaction of content and practice. We investigated this interaction in genetics by: (1) comparing the order in which students access core genetics concepts, and (2) comparing the order of progressions in concert with model practices. We discuss data from model construction tasks in a modeling-based unit in genetics. In this instruction, 11^{th} grade students (n = 271) were provided five weeks of molecular genetics (n = 127) or classical genetics (n = 144), provided an assessment, which included the model construction task, and then moved to the alternate task. We present data from each of the modeling tasks. While students leveraged roughly the same amount of evidence in both conditions, *how* students used evidence differed in the two instructional conditions.

Background

Learning progressions (LPs) can help capture how students conceptualize their understanding of a practice or content. These establish what students are expected to learn in hypothetical paths as they develop increasingly sophisticated ways of reasoning in a domain over extended periods of time (e.g., Alonzo & Gotwals, 2012; Corcoran, Mosher, & Rogat, 2009; Duncan, Rogat, & Yarden, 2009). LPs are grounded in research on how students actually come to understand core ideas in the domain (rather than simple analyses of normative knowledge in the domain). Most LPs focus on the developmental understanding of either a practice or a set of core ideas. Fewer LPs systematically address the development of understandings and competencies in both of these dimensions and how they influence each other.

In order to explore the intersection of content and practice, it is necessary to consider whether different content LPs result in different understanding of the practice. In science, LPs strive to combine content and practice. There are a few key examples that demonstrate this integration (see, e.g., Songer, Kelcey, & Gotwals, 2009). However, the nature of this relationship is not always clear. Currently, how practice and content are married to each other depends on the intuitions of the researchers, as there is less work specifically evaluating the relationship between practice and content. In order to extend this work, we investigated this issue through the content lens of genetics. In this study, we investigated how two alternative progressions, which addressed the same core ideas, interfaced with modeling practice when the curriculum used to teach genetics ideas was model-based instruction. We bridge this gap in two ways: we (a) examine models constructed to explain genetic phenomena, and (b) examine how competing learning progressions impacts evidence usage, coherence, and overall model complexity.

Theoretical framework

Within the content realm of genetics there are multiple LPs that result in learning the core topics. These LPs differ in the assumptions about the sequence and levels through which these ideas develop. Stewart et al. (2005) identified three major models of genetics to compose genetics literacy. These include: (a) *the inheritance model*, which describes the pattern of inheritance between parents and offspring, (b) *the meiotic model* which describes the mechanism by which genes move from parents to offspring through sperm and egg (gametes), and (c) *the molecular model* which describes how genes are translated into protein which bring about physical traits. Stewart et al. (2005) argued that genetic literacy entails understanding and connecting all three of these major models. While students may be able to understand and articulate an aspect of each of these genetics models individually, they tend to have the greatest difficulty describing the mechanisms that underly each model, as well as connecting each model to one another (e.g., Duncan, Choi, Castro-Faix, Cavera, 2017; van Mil, Boerwinkel, & Waarlo, 2013).

One of the open questions in genetics instruction is related to the order of instruction—essentially what model should be taught first, to facilitate genetics understanding. Two separate research groups have independently worked with the Stewart et al. (2005) genetics literacy model to develop LPs that differ in their assumptions about the sequence and levels through which these ideas develop (Duncan, Rogat, & Yarden, 2009; Roseman, Caldwell, Gogos, & Kurth, 2006). Roseman et al. (2006) argue that the central concepts of genes, chromosomes, and alleles are abstract concepts and can be better conceptualized once students understand the structure and function of concepts like DNA and proteins. Understanding the *mechanism* at the cellular and molecular level by which genes bring about observable traits can serve as a way to support student understanding of the relationship between genes and traits across multiple generations. This, therefore, supports the connection between the genetic literacy model proposed by Stewart et al. (2005). Comparatively, Duncan et al., (2009) progression proposes that genetics concepts should be introduced in tandem and that a parallel learning model would facilitate better understanding. We note that the discrepancy in these suggested LPs comes, in part, from the current gaps in the research, especially in attending to student understanding of molecular genetics concepts.

The genetics LP used as the theoretical and analytic framework for this study is the Duncan et al., progression (2009). This framework combines the meiotic and inheritance model to comprise the Classical genetics model. The LP comprises eight primary ideas that map onto the Classical and molecular models. For example, the molecular model included that genes are instructions for making proteins while the Classical model included the idea that egg and sperm cells have half the genetic information, and that there are predictable patterns between an individual's genes and their traits. While both LPs make a fair argument for why their progression would better support content understanding, it is not obvious which content LP is best for supporting modeling. If traits and patterns of inheritance are somewhat familiar, perhaps it will be easier to model them as a starting point for students. Alternatively, understanding the molecular basis of genetics can help students understand inheritance patterns. LPs on modeling have provided valuable insight about student performance in terms of how models are constructed, revised, and evaluated (e.g., Passmore & Svoboda, 2012). Whether students discuss communicative or epistemic features of how models communicate (e.g., details, visuals), or epistemic standards are important to understand what students value within their models. What students value when creating models within genetics has been explored (e.g., Puig, Ageitos, & Jiménez-Aleixandre, 2017). However, there is less work on how it ties into the progression of understanding genetics content as it interfaces with modeling practice. Therefore, our research questions are: (1) does the order of instruction of learning Classical then molecular or molecular then Classical genetics influence model construction? (2) what kind of models do students construct during two parallel modeling tasks?

Methodology

Study context

The present study was conducted for ten weeks with five biology teachers and their 11^{th} grade students (n = 271) in a suburban high school in the North Eastern United States. The school was relatively diverse and 34% of students were eligible for free or reduced lunch. The school consisted of 47% African American, 22% Caucasian, 19% Hispanic, and 11% Asian students. In this district, students learn physics in 9^{th} grade, chemistry in 10^{th} grade, and biology in 11^{th} grade. Students took part in a modeling-based curricular unit in genetics (~10 weeks of instruction) that engaged students in the construction, evaluation, and revision of models of genetic phenomena. Students were assigned to a condition based on their prior scores in chemistry classes provided by the teachers in the study. Class conditions were counterbalanced within teachers.

Curricular Design and implementation

Students were engaged in five weeks of molecular-focused lessons that included topics about the central dogma of DNA and the role of proteins. The other five weeks of instruction covered concepts related to patterns of inheritance. Students were given both sets of instruction, half of the students (n =144) were given the *Classical* unit first (*Classical-first*) while the other half were given the molecular unit first (*Molecular-first*, n = 127). Both instructional learning modules included multiple modeling opportunities. For example, a Molecular-first student would complete five weeks of molecular instruction, then would complete five weeks of classical instruction while a Classical-first student would complete five weeks of classical instruction and then five weeks of molecular instruction (see Figure 1).

Prior to and after instruction students were given *content tests*. These were ordered multiple-choice (OMC) tests that assessed student understanding of core topics in genetics (Duncan, Castro-Faix, & Choi, 2016). Students were also given pre- and post-domain-general *modeling assessments* to assess their modeling practices (Cavera, Duncan, Chinn, Castro-Faix, 2018; Cavera, El-Moslimany, Duncan, Chinn, 2020). Students constructed and revised a model, and wrote an evidence-based argument with respect to a non-genetics topic that differed at the beginning and end of the study and were randomly assigned by condition. At the close of each curricular unit students were given a *content modeling assessment* which is the focus of this analysis. We report data from students who completed all of the modeling assessments and content tests (n = 271).

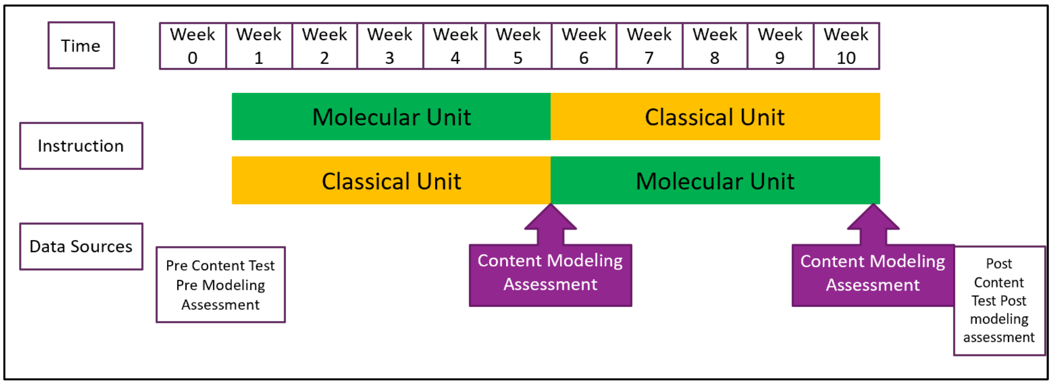

Figure 1. Instructional Order

Instrument design and data collection

The content modeling assessments were similar in structure and design, included two parts, and took sixty minutes to complete. Both assessments followed the same stylistic format in that the first part of the assessment tasked students with developing an evidence-based model of a phenomenon. Students were provided with three evidence pieces. In the Molecular Modeling Assessment (*MMA*) students were asked to develop a model that explained the biological mechanism underlying a hypothetical skin disorder (*DEB*) in which individuals had gaps between their dermis and epidermis skin layers resulting in painful blisters. The evidence provided to students included the identification of a genetic mutation as the cause of the disorder that may impact a protein (evidence 1), a description of the symptoms as gaps between the skin layers (evidence 2), and a picture of the layers of skin in normal skin (evidence 3) (Figure 2). Students were expected to construct a model to identify and predict if a genetic mutation was involved.

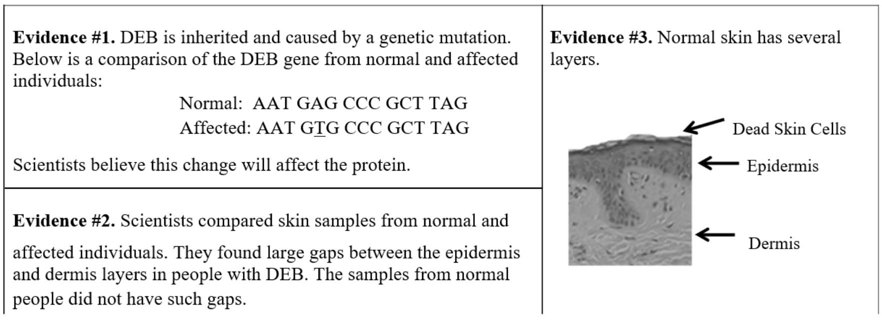

Figure 2. Evidence provided in the Molecular Modeling Assessment (MMA)

The Classical Modeling Assessment (*CMA*) tasked students with developing an explanatory model for the inheritance pattern that caused an irregular heartbeat (*FHD*). They were provided three evidences (Figure 3). These again included a description of the symptoms (evidence 1), a pedigree or family tree (evidence 2), and a ratio of healthy, affected, and offspring who died before birth (evidence 3). In both cases, the evidences were designed to provide clues about the underlying mechanism but not give away the actual mechanism itself.

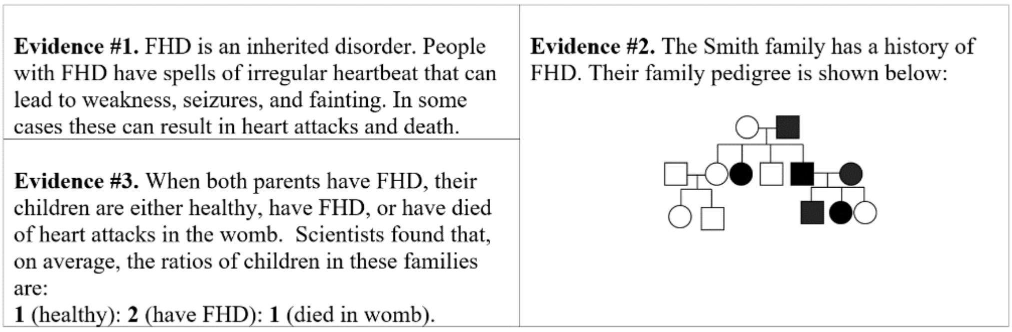

Figure 3. Evidence provided in the Classical Modeling Assessment (*CMA*)

Coding and analysis

Models from the content model assessments were coded along two major dimensions: evidence usage and a propositional analysis of domain knowledge (Duncan, Choi, Castro-Faix, Cavera, 2017). Evidence usage was counted in each model. While students were provided with three evidence pieces for the model construction task, we noted that students focused on specific aspects or parts of each evidence. For example, in the *CMA*, evidence 2 provided students with a family tree (pedigree) (see Figure 2). Students focused on the third *generation* of the tree where they explored the combination of affected and unaffected children; some focused on the disorder's appearance in each generation, while some students combined these ideas. Students who focused on the *children* in the third generation of the pedigree often discussed what the children's alleles must be so that they did not present the disease. For example, students could state that, *if the genotype of the child is* $F^H F^H$ *they will be healthy,* focusing on the genes of the possible children. Students who discussed the *generations* focused on the disease over generations in the family, for example, *FHD is inherited from Parent to Offspring…someone in each generation has it.* Some students *combined* these ideas discussing the *pedigree as a whole*. In this case students could describe the previous concepts, *FHD is passed down through your genes* (generational)…*if you look at the second family generation it shows parents who both have it. It shows 3 kids but 2 have FHD the 3rd does not* (children). In the *MMA*, evidence 1 (see Figure 3) described a mutation in a gene which may impact a protein. Some students focused on the *genetic* portion of the evidence, *the gene is mutated* and describing how that would impact the skin layers or drawing skin layers. Others focused on the possibility of the *protein* change, stating *People with DEB are missing a certain protein which in turn causes them to not produce enough Epidermis, causing large gaps.* Finally, other students used the evidence as a whole, *there was a genetic mutation with the gene, the protein was not able to be made. The missing protein caused there to be missing aspects of the skin since the skin is missing sections.* We captured how students discussed each of these mechanisms within student models.

Three independent coders coded 34% of the *CMA* data and 31% of the *MMA* data. Interrater reliability was 89% and 91%, *CMA*, *MMA*, respectively.

Results

We begin our analyses by comparing average evidence use by assessment and implementation order (Table 1). In the pre-modeling and post-modeling domain-general assessments there was little difference in which evidence students used or how the evidence was used to describe the phenomenon under investigation. In the *CMA*, students on average incorporated the same evidence the same number of times regardless of instructional order. However, we noted differences in *how* students used these evidences in their models and to what effect. Students who used evidence 2 (the family tree) or evidence 1 exclusively, developed largely phenomelogical models. This means they transcribed the symptoms (describing evidence 1), or focused on a largely phenomelogical aspect of the evidence or the generational aspect of the evidence. Students who combined evidence 2 with evidence 3 (23% *Classical-first*, 43% *Molecular-first*) were 1.7% more likely to develop a biologically plausible model. This indicates that students in the *Molecular-first* condition, while not leveraging more evidence than their *Classical-first* peers, used the provided evidence in ways that were more productive.

Table 1. Evidence use in both conditions during the modeling assessments

		Classical-first	Molecular-first
Pre-modeling assessment*	Average number of evidences	1	1
Classical-Modeling Assessment (*CMA*)	Average number of evidences	1.5	1.5
	Most frequently used evidences	E2(generations) and/or E3	E2(generations) and/or E3
Molecular Modeling Assessment (*MMA*)	Average number of evidences	2	3
	Most often used evidence	E2/and or E3	E1(central dogma) and/or E2
Post-modeling assessment*	Average number of evidences	1.5	1.5

*Pre/post modeling tests were randomly assigned by condition and class assignment.

In the *MMA*, *Classical-first* students on average used two evidences pieces while *Molecular-first* students used, on average, three evidences. We also note differences in *how* students leveraged these evidences and which evidences they used. First, students in the *Classical-first* condition tended to use evidence 2 or evidence 3 alone. Both evidences described the symptoms of the disorder (gaps in the skin), without discussing any underlying protein, gene, or cellular issue that could be at play (33%). Another feature of interest is that evidence 2 compares the skin layers between normal and affected individuals. Students can use this comparison as the structure of their model, essentially comparing the normal and affected individuals at the gene or protein level, and getting at the underlying mechanism. That said, *Molecular-first* students tended to take this tact (14% *M-first*, 4% *C-first*, resp.), applying evidence 1 which described a genetic change which could cause a change to protein 3.5% more often than *Classical-first* students during the *MMA*.

Model complexity during the Classical Modeling Assessment

So far, we have discussed modeling from the perspective of evidence counts as it impacts the underlying mechanism in models. Next, let's look at a typical model from each condition constructed during each assessment, starting with the *Classical Modeling Assessment*. The goal during this assessment was for students to construct a model which described the underlying biologically plausible model that explained why individuals developed a heart condition (*FHD*). We expected students to discuss why sick individuals had such combinations of alleles.

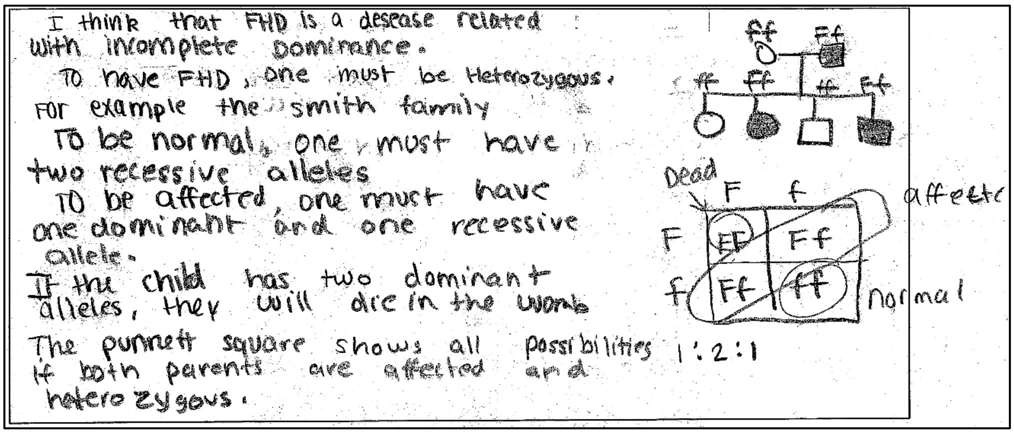

Figure 4. *Molecular-first* model constructed during the *Classical Modeling Assessment*

This first model represents a typical model constructed by *Molecular-first* condition student during the *CMA*. In this model, the student uses two of the provided evidence to describe the phenomenon presented in the assessment. First, the student describes the underlying inheritance pattern: *I think that FHD is a disease related with incomplete Dominance.* (Seen on the left, Figure 4). The student leverages evidence 3 by stating: *to be normal, one must have two recessive alleles, to be affected one must have one dominant and one recessive alleles. If the child has two dominant alleles, they will die in the womb*. The student took the evidence which described a ratio and reinterpreted this information to include a biologically plausible mechanism as well as a Punnet square (on the right, Figure 4, box drawing), which is another representation of this data. The student also reinterpreted evidence 2 (the family tree) with more information and connected this information together between these two interpretations (top right and bottom right figures, Figure 4).

Next, we look at a typical model constructed by a student in the *Classical-first* construction during the *Classical Modeling Assessment*. In this model, the student leverages evidence 2, describing the family tree at a superficial, phenomelogical level: *In evidence #2 there's a diagram that shows one of the parent having FHD which would lead to their children having FHD because the parents gives one gene from each of them to make a child* (Figure 5). The student describes the underlying story (mechanism) of inheritance when they describe the alleles (alleles are different versions of genes) and this student also draws a representation of alleles (Hh x hh, representation bottom of Figure 5).

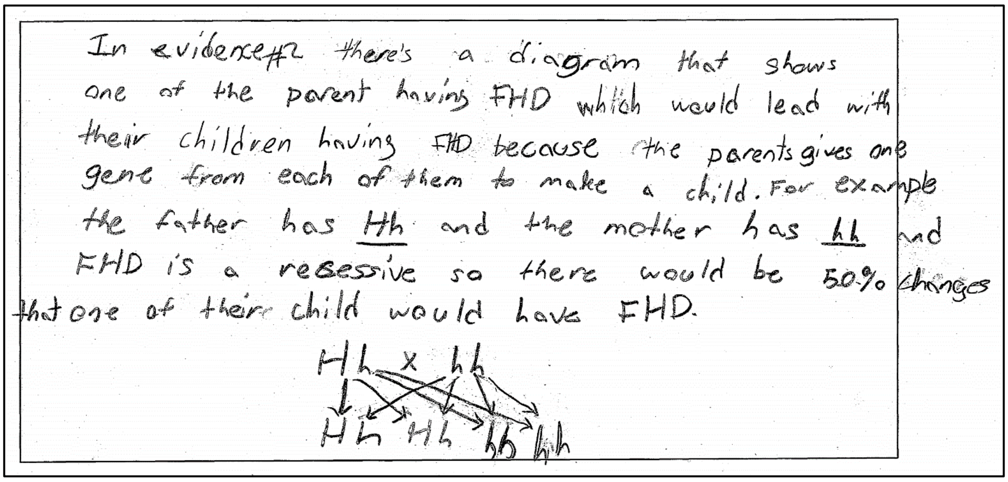

Figure 5. *Classical-first* model constructed during the *Classical Modeling Assessment*

Models constructed during the Molecular Modeling Assessment

Moving to the *Molecular Modeling Assessment*, we start with a *Molecular-first* student. The goal of this task was to construct models that explored the connection between a mutated gene resulting in a changed protein resulting in a skin disorder (*DEB*). We expected students to explain this mutated (changed) protein, make a connection between genes, proteins, and symptoms (the central dogma). The student provides a comparison between a normal and abnormal person (Figure 6). This student uses all three evidences, evidence 1 when they show the mutated gene and non-mutated gene, and normal and dysfunctional protein (on left). The student also describes *normal protein forms much of the structural component of the layer between the epidermis and dermis* (evidence 3). The student uses evidence 2 to compare normal and affected individuals at the gene and protein level, demonstrating a mechanistic explanation underlying the phenomenon.

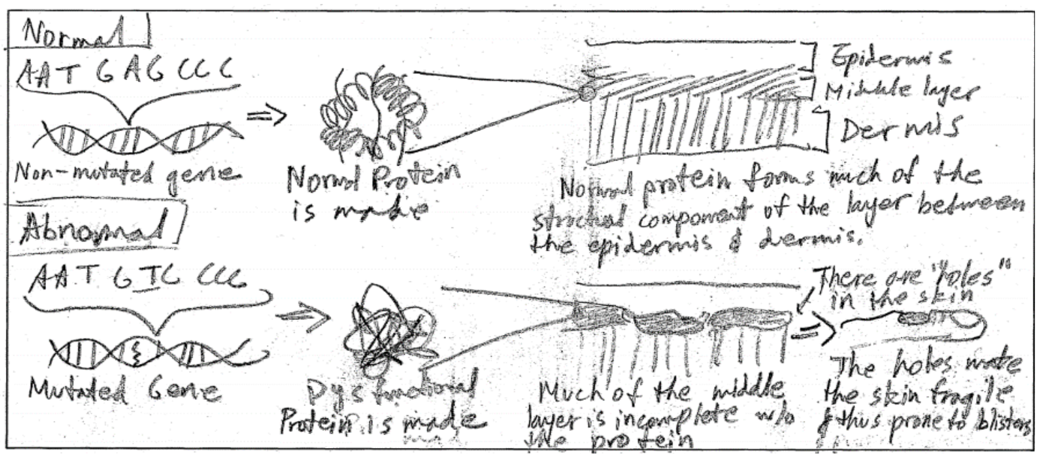

Figure 6. *Molecular-first* model constructed during the *Molecular Modeling Assessment*

We next look at a *Classical-first* student's model. This student uses all three provided evidence to compare a person with the disorder and someone who does not have the disorder, what the student refers to as normal skin and affected skin (Figure 7). The student describes the skin layers (evidence 3), and by comparing the differences in the *skin* this student is using evidence 2 as well, albeit in a superficial way. This student also uses evidence 1 to describe the underlying cause of the disorder. *This thymine is the wrong part…Because of this mutation, it's causing the skin to be fragile and dry, resulting is painful blisters.* (Figure 7, on right) This student draws the reader's attention to the mutation (changed DNA) as the cause of the symptoms of the disorder but does not discuss the underlying protein. Understanding the protein piece is central to the molecular module of genetics.

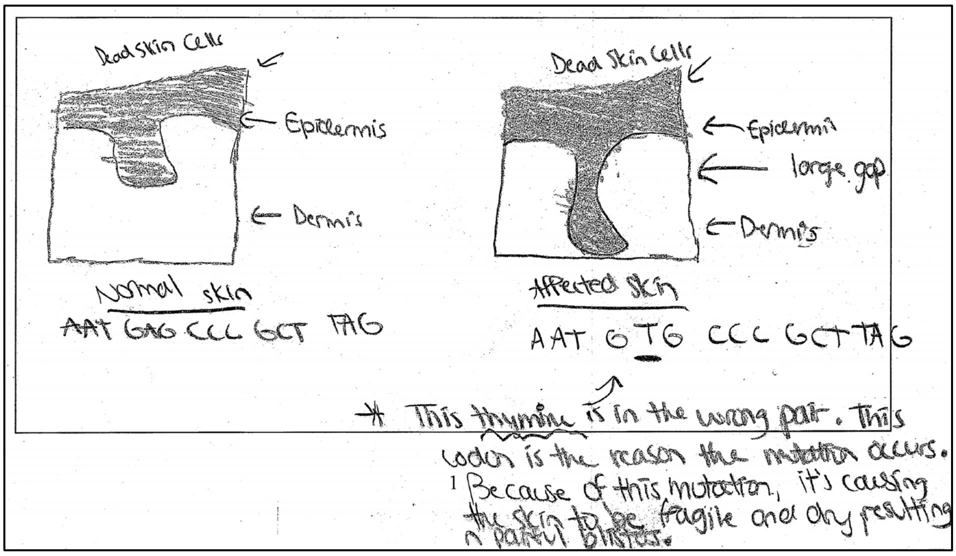

Figure 7. *Classical-first* model constructed during the *Classical Modeling Assessment*

Measures of model complexity

We see that Molecular-first students developed more mechanistic models in *both* the *Molecular Modeling Assessment* and the *Classical Modeling Assessment*. While it could be argued that students should perform better in their second modeling activity—essentially *Molecular-first* students should have a stronger showing in the *Classical Modeling Assessment* and *Classical-first* students should have a stronger showing in the *Molecular Modeling Assessment* due to a recency effect, this was not observed. *Molecular-first* students overall developed more mechanistic models in both assessments as compared to the Classical-first peers.

Similarly, we observed no evidence of student connections between the two genetics modules. Meaning, students who had completed a unit then completed the other unit did not bring knowledge from the preceding module into the following unit. For example, a *Classical-first* student did not bring knowledge of multiple generations and alleles into the *Molecular Modeling Assessment* nor did any *Molecular-first* students bring information about proteins into the *Classical Modeling Assessment*. Therefore, some aspect about the way the content was presented or relayed to students conferred a benefit to student modeling practice.

Discussion

This work extends our understanding of LPs of genetics by demonstrating that teaching molecular concepts first may support a bootstrapping effect related to modeling practice. Students in the molecular-first condition constructed models that were more mechanistic and fit with more of the provided evidence. This demonstrates a level of domain-competency and practice competency greater than that of their *Classical-first* peers. It was previously demonstrated that understanding genetic knowledge develops simultaneously and at a similar rate over time. It has also been demonstrated that a modest correlation exists between students who learned molecular genetics first with respect to learning future genetics concepts, suggesting a preparation for future learning effect. In other words, students in the *Molecular-first* condition may have experienced a bootstrapping effect for future genetics concepts (Duncan, Castro-Faix, Choi, 2016; Duncan, et al., 2017). However, we were unsure if this LP would have an impact on students' modeling practices. We wanted students to develop models which included mechanistic explanations of an underlying genetic phenomenon. While it could be argued that students built increasingly robust models in their second content modeling assessment (which was observed), overall *Molecular-first* constructed models were more mechanistic. *M-condition* students tended to use more evidence in more nuanced ways to produce more mechanistic models across both assessments. This kind of knowledge within a domain is key and helps inform how to approach and construct complex models. By noting that *M-condition* students generated models that were also more mechanistic in the *MMA* and more likely to identify the underlying content in the *CMA,* we add to this notion that learning molecular genetics first may improve not only content understanding, but also support an integration of practice with content understanding. We hope to expand these findings by exploring a follow up model evaluation task.

Expanding on how students leveraged evidence based on order of instruction helps explore the kinds of models generated by students. We noted that students generated two kinds of models as dependent on the task. In the *MMA* students generated temporal models, or those that showed how a mutated gene caused the symptoms of the disorder. Students with more mechanistic models included the protein level of the model. In the *CMA*, students constructed models that were structured as more cause-and-effect statements with more powerful models leveraging multiple evidences to explore the underlying mode of inheritance. What is key in both assessments is how students relied on at least one "hinge" evidence in a way that students can when supporting an argument (e.g., Cavera, et al., 2018; Puig, et al., 2017). Students built robust arguments simultaneously while generating models within a genetics construct.

This work demonstrates that learning molecular genetics first helps inform more mechanistic modeling practices within the domain. Stewart et al. (2005) argued that genetics literacy entails understanding both the classical and molecular models and their interrelationship. Previous genetics LPs have argued for teaching either the Classical or the molecular model first in order to support better understanding of underlying mechanisms, but less research explored the interface of content with modeling practices. Stewart et al., (2005) have argued that we need to provide sufficient and explicit opportunities for students to investigate and explain patterns of inheritance at the molecular level. Thus, supporting the bridges between the genetic literacy models is necessary to help students develop sophisticated understanding of how molecular and Classical models function. By focusing on the molecular aspect first, before moving to the more abstracted Classical piece, this may have made it possible for students to conceptualize and construct models across both domains.

References

Alonzo, A. C., & Gotwals, A. W. (Eds.). (2012). *Learning progressions in science: Current challenges and future directions*. Springer Science & Business Media.

Cavera, V. L., Duncan, R. G., Chinn, C., & Castro-Faix, M. (2018). Developing Assessments That Measure Core Ideas and Scientific Practices: Challenges and Insights. International Society of the Learning Sciences, Inc.[ISLS].

Cavera, V., El-Moslimany, H., Duncan, R., & Chinn, C. (2020). Differences in Rhetorical and Refutational Argument Complexity by Grade Level. International Society of the Learning Sciences, Inc. [ISLS].

Corcoran, T. B., Mosher, F. A., & Rogat, A. (2009). Learning progressions in science: An evidence-based approach to reform.

Duncan, R. G., Castro-Faix, M., & Choi, J. (2016). Informing a learning progression in genetics: Which should be taught first, Mendelian inheritance or the central dogma of molecular biology?. *International Journal of Science and Mathematics Education*, *14*(3), 445-472.

Duncan, R. G., Choi, J., Castro-Faix, M., & Cavera, V. L. (2017). A study of two instructional sequences informed by alternative learning progressions in genetics. *Science & Education*, *26*(10), 1115-1141.

Duncan, R. G., Rogat, A. D., & Yarden, A. (2009). A learning progression for deepening students' understandings of modern genetics across the 5th–10th grades. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *46*(6), 655-674.

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education*, *34*(10), 1535-1554.

Puig, B., Ageitos, N., & Jiménez-Aleixandre, M. P. (2017). Learning Gene Expression Through Modelling and Argumentation. *Science & Education*, *26*(10), 1193-1222.

Roseman, J., Caldwell, A., Gogos, A. & Kurth, L.A. (2006). Mapping a coherent learning progression for the molecular basis of heredity. Paper presented at the Annual Meeting of the National Association of Research in Science Teaching, San Francisco, CA.

Songer, N. B., Kelcey, B., & Gotwals, A. W. (2009). How and when does complex reasoning occur? Empirically driven development of a learning progression focused on complex reasoning about biodiversity. *Journal of Research in Science Teaching*, *46*(6), 610-631.

Stewart, J., Cartier, J. L. & Passmore, P. M. (2005). Developing understanding through model-based inquiry. In M. S. Donovan & J. D. Bransford (Eds.), How students learn (pp. 515–565). Washington, DC: National Research Council.

van Mil, M. H., Boerwinkel, D. J., & Waarlo, A. J. (2013). Modelling molecular mechanisms: A framework of scientific reasoning to construct molecular-level explanations for cellular behaviour. *Science & Education*, *22*(1), 93-118.

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Computational Bodies: Grounding Computational Thinking Practices in Embodied Gesture

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Abstract: Computational thinking (CT) is increasingly becoming a part of classrooms across the K-12 spectrum. While we have a sense of what it looks like for older learners to engage with CT, it is less clear what authentic CT practices look like for learners in K-5 classrooms. Part of the challenge of identifying CT in earlier grades is learners' lack of prior experience with computing and limited language to describe computational processes and practices. This study provides insights into how young learners use gestures as they engage in a set of CT-enhanced mathematics activities. This work focuses on a fourth-grade mathematics activity in which learners work to control a spherical robot as it navigates a mathematical maze. Our analysis reveals various ways that learners use gesture to complement existing virtual and physical tools available for expressing and enacting CT concepts and practices. In doing so, this work suggests both methodological and pedagogical opportunities for understanding CT with younger learners and advances our understanding of the role of gesture and embodiment as a means of supporting young learners' engagement with CT.

Introduction

Computing, and the technologies it enables, is playing a growing role in the lives of today's learners both in schools and beyond. As such, the skills, concepts, and practices associated with using computational tools to help solve problems, collectively captured under the term "Computational Thinking" (CT), are becoming increasingly important for all students to develop (Grover & Pea, 2013; Shute et al., 2017; Wing, 2006). In response to the recognition of the growing importance of CT, a growing number of efforts are seeking to bring CT into K-12 classrooms (Guzdial, 2008; Lee et al., 2014; Weintrop et al., 2016; Yadav et al., 2014). This integration takes a number of forms. One common approach for bringing CT into K-12 classrooms is the introduction of programming into curricula, either as stand-alone computer science classes or integrated into other disciplines (e.g. Franklin et al., 2020; Lee et al., 2014). A second approach to integrating CT into classrooms focuses less on having learners author programs and instead has learners interact with technological tools to help deepen disciplinary learning. This can include computational models and simulations, data analysis and visualization software, or physical computing kits or robots (Bers et al., 2014; e.g. Brady et al., 2015). A third approach to bringing CT into classrooms relies on unplugged activities where learners employ CT concepts and practices but do so without direct interaction with a computational device (e.g. Brackmann et al., 2017). Central to all three of these CT integration approaches is providing opportunities for learners to enact CT practices and communicate with and about CT ideas. In each of these forms of CT integration, what it looks like to engage with CT differs.

In older grades, where learners have more prior computational experiences and a larger vocabulary to express computational ideas, identifying authentic use of CT practices can focus on the ways learners express their ideas verbally, written, and in the computational artifacts they produce. In earlier grades, where learners have little or no prior experience with programming and relatively limited experience with computational devices and software tools, it becomes more difficult to identify CT concepts enacted based on verbal explanations, written responses, or the artifacts produced during the learning activity.

Building on work investigating how learners navigate the interconnectedness of STEM learning grounded in the embodied, material, social, and cultural contexts in which learning occurs (Jordan & Henderson, 1995; Kozma, 2003), this work explores the embodied ways that learners move and gesture as a means to express and communicate CT concepts. For this work, we ground our conceptualization of CT in the PRADA (pattern recognition, abstraction, algorithms, and decomposition) framework (Dong et al., 2019). In attending to learners' embodiment of CT ideas and practices, we can see younger learners' reason about CT concepts and employ CT practices as a means to solve problems that would otherwise not be noticed if focusing on only verbal explanations or external representation (e.g. authored programs). In doing so, this work shows how an embodied perspective can serve as a useful analytic approach for identifying and understanding CT practices in younger learners. At the same time, supporting teachers in attending to gesture and action in CT activities can serve as a productive pedagogical approach for nurturing seeds of CT as they begin to take shape with younger learners.

To explore how young learners embody CT ideas, this paper presents data from the implementation of a fourth-grade CT-enhanced mathematics curriculum based around the Sphero robot (Bih et al., 2020). In particular, we present two vignettes of learners working to write short programs to get the Sphero robot to navigate a maze composed of prime and composite numbers. Through these vignettes, we show how an embodied lens reveals ways learners reason about and employ CT concepts and how they use their bodies as a means to communicate CT ideas. Specifically, we show how one learner enacts iterative logic through repeated gestures and how a second learner uses her own body as a resource for figuring out how to computationally encode her desired intentions into a computational form for her robot to execute. This work contributes to our understanding of the form that CT can take in K-5 classrooms and seeks to help equip teachers and researchers to better identify and support embodied enactments of CT in their work.

This paper continues with a discussion of the literature this work draws from before discussing the context in which the study took place and the methodological approach used. We then present a pair of vignettes showing how an embodied lens can reveal the ways that fourth-grade learners engage with and communicate about CT through the use of their bodies. Finally, we discuss the implications of this work, the contribution it makes to the literature on embodiment and CT, and share the next steps for this line of inquiry.

Prior work

Computational thinking in elementary grade classrooms

One of the central contributions of Papert's work was showing that computers can serve as powerful tools to support learning and that this context for learning can be effective for younger learners (Papert, 1980, 1993). Papert and colleagues' work on Constructionism laid the groundwork for what is now called Computational Thinking (Wing, 2006). CT is a term used to capture the concepts, practices, and skills one uses in order to effectively solve problems using computational tools, such as developing algorithms, decomposing problems, and debugging solutions (Grover & Pea, 2013; Shute et al., 2017). The last decade has seen a significant amount of research on CT including work looking to integrated CT into other disciplines (e.g. Barr & Stephenson, 2011; Israel & Lash, 2019; Peel et al., 2019; Sengupta et al., 2013; Settle et al., 2012; Weintrop et al., 2016; Wilensky et al., 2014) as well as work seeking to understand how to support younger learners in engaging in CT.

The idea that the concepts and practices associated with CT can be powerful for learning other disciplines has a long history dating back to early work by Papert (1972) on Logo and mathematics and diSessa (1982) and physics. In both cases, programming was used as a means to explore disciplinary concepts. A central premise for this integration is the potentially mutually supportive nature of CT and disciplinary content: that CT provides a way to deepen disciplinary learning while at the same time, disciplinary learning can provide a meaningful context to employ CT concepts and practices (Bih et al., 2020; Sengupta et al., 2013; Weintrop et al., 2016).

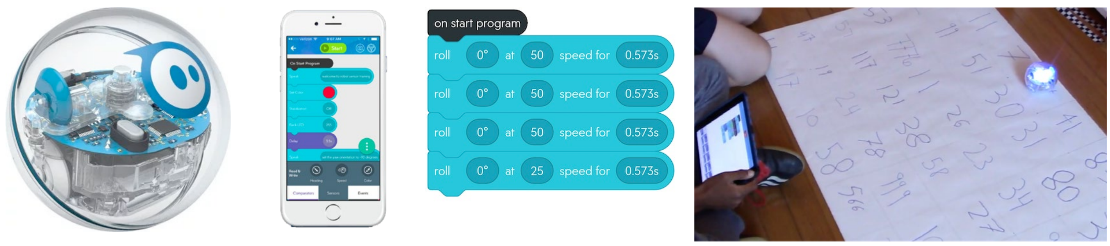
As part of exploring the potential of CT across the curriculum has included investigating what CT might look like with younger learners. Two common approaches for bringing CT into K-5 classrooms are unplugged activities and the use of robotics toolkits. Unplugged activities allow learners to explore and enact CT concepts without using a computer, often having the younger learner act out computational processes such as algorithms or employ computational ideas such as iteration (Brackmann et al., 2017; Curzon et al., 2014; Jagust et al., 2018). Alongside unplugged activities, robots and robotics toolkits have also been used in elementary classrooms to introduce younger learners to CT concepts (Angeli & Valanides, 2020; Bers et al., 2014; Chalmers, 2018).

Embodied cognition

The second body of literature this work draws on is embodied cognition. Cognitive scientists and learning scientists have long explored various aspects of the relationship between thinking and embodiment (Abrahamson & Lindgren, 2014; Wilson, 2002). In mathematics learning research, the role of embodied cognition and its utility as a lens to understand mathematical learning has been well developed (Nunez et al., 1999; Williams-Pierce et al., 2017). In particular, research has identified how gestures can provide mathematical reasoning information not contained in the accompanying speech (Pier et al., 2019), and can mediate abstractions and communication gaps in cases where language verbalization is a challenge (Nathan et al., 2013; Ng, 2016). Attending to gesture in multimodal environments can be particularly productive, as mathematical representations take on a wide variety of forms, and threading through those forms becomes a crucial component of the learning environment (Nathan et al., 2017). This work has led us to consider the potential of bringing an embodied perspective to research on the interactions that occur in technology-enhanced multimodal learning environments (Kirsh, 2013; White & Pea, 2011). Given the overlap between mathematical and computational thinking (Shute et al., 2017), this body of research suggests the generative potential for bringing an embodied lens to understanding CT learning.

Methods and participants

This work was conducted in a fourth-grade mathematics classroom in an urban school district in the Mid-Atlantic region of the United States. The activities reported in this paper are part of a curriculum developed through a Research-Practice Partnership (RPP) (Coburn et al., 2013) with the district. The RPP includes education and technology researchers working alongside elementary mathematics teachers and district-level computer science administrators. To collect this data, we worked closely with a focal fourth-grade teacher, observing her classroom as she taught a CT-enhanced lesson plan that asked learners to use the Sphero robot (Figure 1a) to explore mathematical concepts. The Sphero is a spherical robot that can be programmed on a tablet or smartphone (Figure 1b) using either block-based or text-based commands. In the focal activity for this work, learners wrote block-based programming primarily using the roll command to define the robot's movement (Figure 1c).



(a) (b) (c) (d)

Figure 1. (a)The Sphero robot, (b) programming environment, (c) sample Sphero program, and (d) two students working on their prime number path program.

The lesson that we focus on for this work is entitled *Prime Number Path*. As part of this lesson, students were asked to design a grid on a large sheet of paper that contained prime and composite numbers interspersed and included a "path" from one side to the other composed only of prime numbers (Figure 1d). Students then were tasked with programming the Sphero robot to navigate the prime number path. After completing their activities, teams exchanged their grids with other teams and then find and program the prime number mazes designed by their peers.

This work took place in a racially diverse (51% White, 17% Latinx, 15% Black, 9% Asian, 8% Mixed Race) school where 19% of the students in the school are designated as English Language Learners. The class included 21 students working in pairs with one Sphero and one iPad per pair. The lessons we observed were taught in the final month of the school year. By that point, students were familiar with the structure of Sphero.Math activities and had experience working with the Sphero robots. For data collection, the teacher selected two pairs of students to serve as focal groups. These groups were asked to work outside of the classroom to decrease ambient noise and ensure non-consenting students were not captured on video.

Data and analysis approach

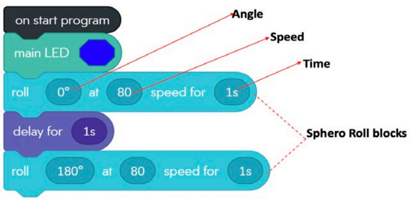
For each focal pair, we set up a stationary tripod to record them working through the activities. Additionally, each student wore a head-mounted camera to provide a student-centric perspective of the activity. This resulted in three video streams for each pair as they worked through the activities. Students were occasionally asked questions by the researchers as they worked to understand their thinking and how they were approaching the assignment. Along with the videos collected, at the end of the activity, the researchers asked the students to describe their experiences with programming the robot and complete the task. The videos were systematically analyzed for CT and mathematics engagement with a particular focus on the ways learners employed embodied practices to communicate and engage with CT. Video clip segments of instances where students engaged in embodied practices were identified and transcribed using interaction analysis methods (Jordan & Henderson, 1995).

Findings

In this section, we present two vignettes of learners showing the ways gesture served as a resource for engaging with and expressing CT ideas. In particular, we present a vignette showing how learners used gesture as a means of expressing iterative logic and the learners' use of their bodies as a resource to problem solve how to express their intentions with the Sphero.

Gesturing iterative logic

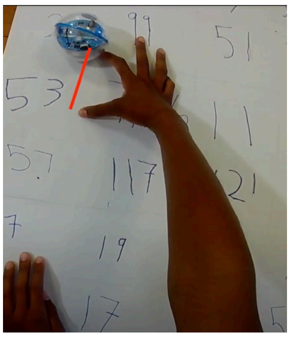
To make the Sphero move, the students have to enter numerical arguments into the field of the `roll` block (Figure 2a) by defining the direction (angle), speed, and duration (in seconds) for the movement. Changing how far the Sphero will roll can be done by modifying the speed input, the duration input, or both. Our first vignette focuses on how one pair of learners navigated this aspect of controlling the Sphero.

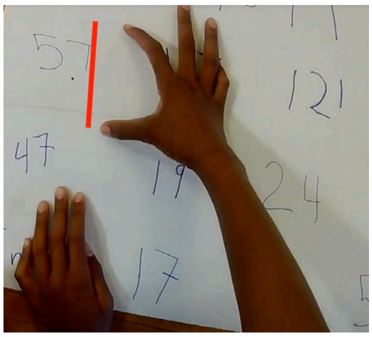


(a) (b)

Figure 2. (a) A Sphero Block program showing direction, speed, and time; (b) the software interface to select time speed and direction.

Early in the activity, the focal participants for this analysis tried to agree on which variable to manipulate to make their Sphero navigate their prime number maze. Student 1 says: *"we need more seconds or speed, like speed"*, and then Student 2 replies, *"no seconds, seconds"*. As the students debate on what adjustments to make on the time, Student 1 says *"do 1 second 'cause you know that's not gonna get you very far from what the next square"*. Student 1 then says, *"maybe try 1.20"*, again, suggesting modifying the duration as a means to change the distance traveled. Instead of changing the duration input, student 2 places her thumb at the place the robot started and her index finger at the location where the Sphero stopped (Figure 3a) and says *"so this is a second"*. In doing so, she has created a measurement of how far the robot travels in one second. She then holds her hand in the fixed position, and moves it from the start location to the square she wants the Sphero to roll to and quietly counts to herself *"two, three"*. In this way, she is using her hand as a unit of measure and maintaining the same hand position between each space separating the numbers as a means to calculate how many times the motion must be repeated to arrive at the desired square.





(a) (b)

Figure 3. Measuring gestures to represent repeated iterations of the time and distance it will take for the Sphero to travel from one number to the next.

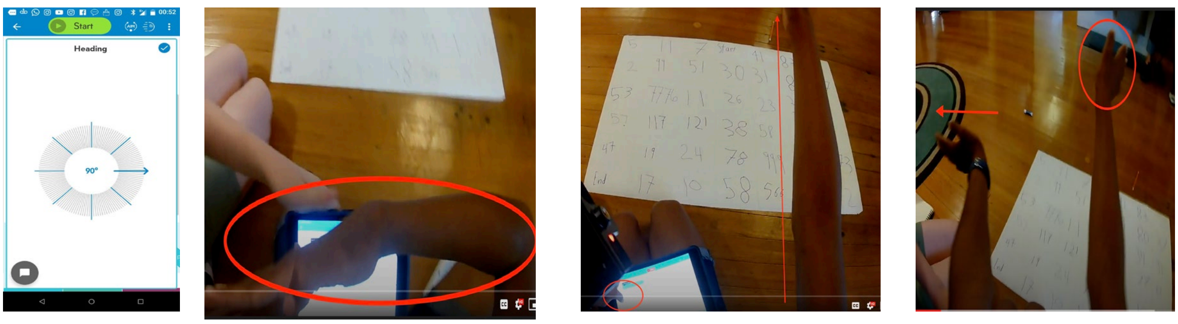
In this vignette, we see gesture accomplishing two goals for the student. First, she uses her hand as a means for defining how far the robot will travel given a set of inputs. More specifically, she uses her hand as a way to translate the virtual command: `roll 0° at 80 speed for 1s` into a specified distance in the physical world and does so in a way that is visible and accessible to her partner. Here, gesture is serving as a cognitive scaffold for concretizing a specific movement command while also serving a communicative role between two partners working to solve a programming challenge. The second role that gesture is providing to support CT is to facilitate the enactment of iterative logic. As a means to inform her algorithm design, she moves her hand, one step at a time, to count the number of times the already-defined roll command should be repeated. In computer programming, iterative logic is an important programming construct frequently used to develop algorithms for computers to execute. In using gesture to quantify distance, the learner is acting out the repeating logic, using her hand and the physical space to scaffold the construction of her program.

This episode shows how this student is embodying her robot's motion as a means to facilitate developing a successful algorithm for her robot navigating the prime number path. Notably, the student never verbalizes this repeating logic or vocalizes her thought process. Instead, gesture is serving as both a way to support her reasoning and communicate computational behaviors. This communicative role is significant for younger learners who may not have the vocabulary to articulate programming concepts or prior experience describing process. Through action the learner demonstrates a central CT concept that had not yet been articulated verbally or symbolically, suggesting gesture served as the initial pathway into engagement with the concept.

Embodiment as a CT problem-solving tool

In the second vignette, we focus on how students work to understand the geometry involved in making the Sphero robot navigate the Prime Number Path (Figure 1d) and the ways in which they translate the physical movement of the robot into a set of commands to control the robot. To enter an angle into the Sphero programming interface, the application presents the user with a 360° protractor with an arrow denoting the selected value (Figure 4a). One challenge of programming physical objects from a virtual interface for young learners is the translation of direction from the physical world onto the 2-dimensions protractor on the interface. This is especially challenging given the orientation of the protractor on the screen is fixed, so when you rotate the tablet, the relationship between direction on the tablet and the real-world changes (i.e. it does not update like the compass on a smartphone). In order to navigate this translation, the learners in our study mapped the coordinate geometric systems of the tools (the angle on the virtual interface and the robot's physical position) onto themselves and used their bodies to ground the meaning of the angles. This kind of sense-making between representations was seen repeatedly as the students navigated this activity. Gesturing was a central grounding and communication resource used by the learners as they translated the geometric angles from virtual to physical contexts of the Sphero.

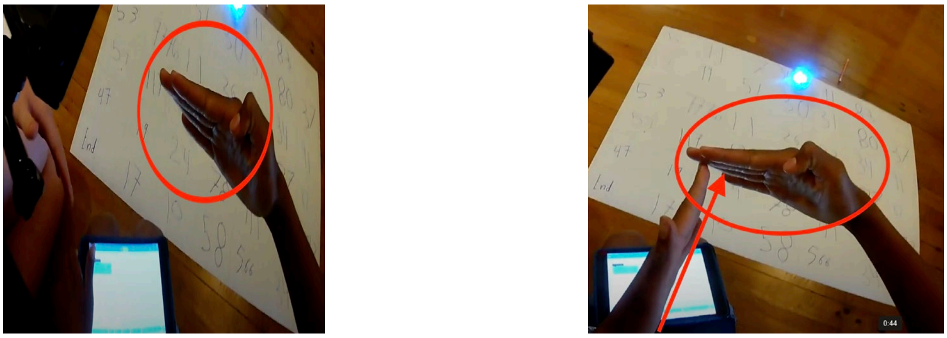
In analyzing the Prime Number Path activity, we can see how embodiment is used by learners to navigate representational contexts and make progress towards computationally expressing their intentions. One such example was seen as the students tried to input the values to define the directional angle through the protractor interface. This episode begins with Student 2 pointing and gazing at the protractor on the iPad (Figure 4a), and then bending her right elbow in front of her for a few seconds without saying a word (Figure 4b). After a few seconds of maintaining her gaze and elbow in that position, she goes ahead and stretches out her right arm in front of her (Figure 4c) and then says *"this is, this way for 90!"* and Student 1 cuts in saying *"so we have to make it go ..."* but Student 2 continues slowly as if in doubt, *"this is this way for 90* [maintaining her arm raised in front of her and gazing into the software protractor] *and we need to make it go... this way"*, gradually raising her left arm to the same level as her right arm, with now both arms raised and stretched parallel in front of her (Figure 4d). She then says *"that means it's going to go… So we need to make it 270"*. This verbal confirmation of what to do next, sheds light on the thought process she was going through in her series of gestures, ultimately helping her figure out what values to input into the program to get the Sphero to roll in the desired direction.



(a) (b) (c) (d)

Figure 4: (a) The Sphero interface for inputting angle and (b-d) a series of sequential images of student reasoning through directions and angles to program her Sphero.

As the group continues to work on writing the program to navigate the maze, they return the Sphero to the starting square to test out their new directions. Before running the program, Student 2 tests her logic again, saying *"so zero* [with her right palm curved in front of her face (Figure 5a)] *so it needs to go this way"* and then curves her left palm to meet up with her right palm at a right angle (Figure 5b), saying *"this is 270!"*. From Student 2's verbalization and interactions with this environment, we know that she is using both arms to represent some of the interactive tools in this environment. Her left hand is representing the robot, while her right hand represents the directional angle the robot will have to make. In this instance, the learner is trying to navigate between the Sphero moving in the physical world and the need to express commands programmatically in the virtual world. To do this, she is grounding both the abstract representation of the angle and the concrete position of the robot through an embodied practice which she maps onto her body. In this way, she uses her body to mediate the transition from the physical, three-dimensional world to the virtual two-dimensional programming interface. As such, her body is serving as a resource to facilitate computational thinking and mediate the act of programming.



(a) (b)

Figure 5: (a) A student reasoning with her body about how to program her Sphero, using her right hand to denote the Sphero's positions (b) and then having her left hand interact with her right as a means to understand what the desired angle should be.

Discussion and conclusion

This paper attends to the ways that learners use their bodies to embody computational ideas, which in turn, helps them make progress on computational problems. In doing so, this work adds to both the CT and embodied cognition literature by showing how embodied resources can be used to express CT concepts while also showing how CT can serve as a productive venue for identifying ways learners engage with new computational ideas that they may not have the verbal or symbolic language to otherwise express. It is common practice in mathematics to embody distances by measuring with parts of our bodies, like our feet or arms, or to use gestures to move across different modalities within a single learning context (e.g., Nathan et al., 2017). In the first vignette, the students embody distance but are using it to represent time as the Sphero's distance is defined by speed and time. They then repeatedly apply that distance as a means of enacting iteration. In the second vignette, embodiment is used as a means of moving between the physical world (i.e. how the Sphero will move), mathematical quantification of the space (i.e. identified the desired angle of travel), and expressing that intention in a computationally meaningful way (i.e. programming the robot to carry out the desired command). This shows how embodiment serves as a resource for learners as they work to solve computational problems.

This research shows how embodiment is a particularly productive resource for young learners who may lack the technical language or representational knowledge to express ideas related to programming and process in other ways. This can be seen in how iteration was embodied in the first vignette. This article argues that gestures and embodiment support students' CT and can ground students' understanding and expression of CT concepts. Further, the fact that the Sphero robot executes programs in the physical world provides a natural invitation for learners to draw on their embodied resources in trying to make sense of CT concepts and employ CT practices, as we saw in the second vignette. In bringing an embodied lens to this work, we begin to see and make sense of the hidden patterns of CT happening in ways that would be missed if we focus solely on verbal utterances or written artifacts. Throughout the Sphero activities, students were able to interact with the learning environment in novel ways that helped deepen their understanding of mathematical and CT concepts. Such embodied practices support the argument that integrating CT practices early on for young learners is a valuable addition to problem-solving skills students need to learn (Wing, 2006; Grover & Pea, 2013).

One implication of this work is identifying the importance and potential for researchers and teachers attending to how students use their bodies as a means to engage with CT. Additionally, it highlights the generativity of robots as a pathway into CT for younger learners. While this generativity is certainly not a new idea (e.g. Papert, 1980), recognizing the same powerful ideas are present with the latest generation of robotics toolkits that are being used in classrooms can serve as an important reminder and help connect earlier work on the topic to contemporary practices.

As computational thinking continues to grow in importance, it is important we support all learners, especially younger learners, in engaging with the concepts and practices. While older learners will have more experience with mathematical and computational representational systems and a larger vocabulary with which to articulate their thinking, younger learners find alternative ways to express and engage with CT. In particular, this work shows how younger learners draw on embodied resources as a means to productively enact CT practices and employ CT concepts. In highlighting the role of embodiment in young learners' CT practices, we shed light on one form of early CT so as to help equip researchers and educators to identify and support the CT that is happening with younger learners and further support the larger goal of bringing CT to all learners.

References

Abrahamson, D., & Lindgren, R. (2014). Embodiment and embodied design. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences (2nd Edition)* (pp. 358–376). Cambridge University Press.

Angeli, C., & Valanides, N. (2020). Developing young children's computational thinking with educational robotics: An interaction effect between gender and scaffolding strategy. *Computers in Human Behavior*, *105*, 105954. https://doi.org/10.1016/j.chb.2019.03.018

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is Involved and what is the role of the computer science education community? *ACM Inroads*, *2*(1), 48–54.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145–157.

Bih, J., Weintrop, D., Walton, M., Elby, A., & Walkoe, J. (2020). Mutually Supportive Mathematics and Computational Thinking in a Fourth-Grade Classroom. *Proceedings of ICLS 2020*, 8.

Brackmann, C. P., Román-González, M., Robles, G., Moreno-León, J., Casali, A., & Barone, D. (2017). Development of Computational Thinking Skills through Unplugged Activities in Primary School. *Proceedings of the 12th Workshop on Primary and Secondary Computing Education*, 65–72. https://doi.org/10.1145/3137065.3137069

Brady, C., Holbert, N., Soylu, F., Novak, M., & Wilensky, U. (2015). Sandboxes for Model-Based Inquiry. *Journal of Science Education and Technology*, *24*(2), 265–286.

Chalmers, C. (2018). Robotics and computational thinking in primary school. *International Journal of Child-Computer Interaction*, *17*, 93–100. https://doi.org/10.1016/j.ijcci.2018.06.005

Coburn, C. E., Penuel, W. R., & Geil, K. E. (2013). *Research-Practice Partnerships: A Strategy for Leveraging Research for Educational Improvement in School Districts*. William T. Grant Foundation.

Curzon, P., McOwan, P. W., Plant, N., & Meagher, L. R. (2014). Introducing teachers to computational thinking using unplugged storytelling. *Proceedings of the 9th Workshop in Primary and Secondary Computing Education on - WiPSCE '14*, 89–92. https://doi.org/10.1145/2670757.2670767

diSessa, A. A. (1982). Unlearning Aristotelian physics: A study of knowledge-based learning. *Cognitive Science*, *6*(1), 37–75.

Dong, Y., Catete, V., Jocius, R., Lytle, N., Barnes, T., Albert, J., Joshi, D., Robinson, R., & Andrews, A. (2019). PRADA: A Practical Model for Integrating Computational Thinking in K-12 Education. *Proceedings of the 50th ACM Technical Symposium on Computer Science Education9*, 906–912.

Franklin, D., Weintrop, D., Palmer, J., Coenraad, M., Cobian, M., Beck, K., Rasmussen, A., Krause, S., White, M., Anaya, M., & Crenshaw, Z. (2020). Scratch Encore: The Design and Pilot of a Culturally-Relevant Intermediate Scratch Curriculum. *Proceedings of the 51st ACM Technical Symposium on Computer Science Education*, 794–800. https://doi.org/10.1145/3328778.3366912

Grover, S., & Pea, R. (2013). Computational Thinking in K-12: A Review of the State of the Field. *Educational Researcher*, *42*(1), 38–43.

Guzdial, M. (2008). Paving the way for computational thinking. *Commun. ACM*, *51*(8), 25–27.

Israel, M., & Lash, T. (2019). From classroom lessons to exploratory learning progressions: Mathematics + computational thinking. *Interactive Learning Environments*, *0*(0), 1–21.

Jagust, T., Krzic, A. S., Gledec, G., Grgic, M., & Bojic, I. (2018). Exploring Different Unplugged Game-like Activities for Teaching Computational Thinking. *2018 IEEE Frontiers in Education Conference*, 1–5.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences*, *4*(1), 39–103.

Kirsh, D. (2013). Embodied cognition and the magical future of interaction design. *ACM Transactions on Computer-Human Interaction (TOCHI)*, *20*(1), 1–30.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction*, *13*(2), 205–226.

Lee, I., Martin, F., & Apone, K. (2014). Integrating computational thinking across the K–8 curriculum. *ACM Inroads*, *5*(4), 64–71.

Nathan, M. J., Srisurichan, R., Walkington, C., Wolfgram, M., Williams, C., & Alibali, M. W. (2013). Building Cohesion Across Representations: A Mechanism for STEM Integration: Cohesion Across Representations. *Journal of Engineering Education*, *102*(1), 77–116. https://doi.org/10.1002/jee.20000

Nathan, M. J., Wolfgram, M., Srisurichan, R., Walkington, C., & Alibali, M. W. (2017). Threading mathematics through symbols, sketches, software, silicon, and wood: Teachers produce and maintain cohesion to support STEM integration. *The Journal of Educational Research*, *110*(3), 272–293.

Ng, O.-L. (2016). The interplay between language, gestures, dragging and diagrams in bilingual learners' mathematical communications. *Educational Studies in Mathematics*, *91*(3), 307–326.

Nunez, R. E., Edwards, L. D., & Filipe Matos, J. (1999). Embodied cognition as grounding for situatedness and context in mathematics education. *Educational Studies in Mathematics*, *39*(1), 45–65.

Papert, S. (1972). Teaching Children to be Mathematicians Versus Teaching About Mathematics. *International Journal of Mathematical Education in Science and Technology*, *3*(3), 249–262.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic books.

Papert, S. (1993). *The children's machine: Rethinking school in the age of the computer*. Basic Books.

Peel, A., Sadler, T. D., & Friedrichsen, P. (2019). Learning natural selection through computational thinking: Unplugged design of algorithmic explanations. *Journal of Research in Science Teaching*, *56*(7), 983–1007. https://doi.org/10.1002/tea.21545

Pier, E. L., Walkington, C., Clinton, V., Boncoddo, R., Williams-Pierce, C., Alibali, M. W., & Nathan, M. J. (2019). Embodied truths: How dynamic gestures and speech contribute to mathematical proof practices. *Contemporary Educational Psychology*, *58*, 44–57.

Sengupta, P., Kinnebrew, J. S., Basu, S., Biswas, G., & Clark, D. (2013). Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education and Information Technologies*, *18*(2), 351–380.

Settle, A., Franke, B., Hansen, R., Spaltro, F., Jurisson, C., Rennert-May, C., & Wildeman, B. (2012). Infusing computational thinking into the middle- and high-school curriculum. *Proceedings of the 17th ACM Annual Conference on Innovation and Technology in Computer Science Education*, 22–27.

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review*, *22*, 142–158. https://doi.org/10.1016/j.edurev.2017.09.003

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

White, T., & Pea, R. (2011). Distributed by design: On the promises and pitfalls of collaborative learning with multiple representations. *Journal of the Learning Sciences*, *20*(3), 489–547.

Wilensky, U., Brady, C. E., & Horn, M. S. (2014). Fostering Computational Literacy in Science Classrooms. *Commun. ACM*, *57*(8), 24–28. https://doi.org/10.1145/2633031

Williams-Pierce, C. C., Pier, E. L., Walkington, C., Boncoddo, R., Clinton, V., Alibali, M. W., & Nathan, M. J. (2017). What we say and how we do: Action, gesture, and language in proving. *Journal for Research in Mathematics Education*, *48*(3), 248–260.

Wilson, M. (2002). Six views of embodied cognition. *Psychonomic Bulletin & Review*, *9*(4), 625–636.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33–35.

Yadav, A., Mayfield, C., Zhou, N., Hambrusch, S., & Korb, J. T. (2014). Computational thinking in elementary and secondary teacher education. *ACM Transactions on Computing Education (TOCE)*, *14*(1), 5.

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Fostering Students' Cue Utilization in a Productive Failure Setting

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Abstract: Productive Failure (PF) with problem solving prior to instruction has been shown to have beneficial effects on learning, at least in STEM domains. It is hypothesized to be fundamental for the effectiveness of PF that learners become aware of their failure during problem solving. Developing this failure awareness seems to be harder for PF students who learn in certain non-STEM domains. To support PF students' development of failure awareness while learning in a non-STEM domain, this quasi-experimental study implemented and tested a cue-utilization activity prior to instruction. Our results show that PF students who experienced the cue-utilization activity still did not more critically evaluate their solution ideas and did not acquire more knowledge about social science research methods than their counterparts in a PF condition without cue-utilization activity. These results are discussed in light of students' epistemological beliefs about social sciences.

Introduction

Over the last decade research on Productive Failure (PF) has been thriving. The PF approach combines two successive learning phases: (1) an initial problem-solving phase and (2) a delayed instruction phase. During the problem-solving phase students are asked to (often collaboratively) generate different solution ideas for a novel and complex problem (e.g. Kapur & Bielaczyc, 2012). Due to this novelty and complexity of the problem, most students struggle or even fail to solve the problem canonically. However, this failure is assumed to prepare students for learning the targeted concepts during subsequent instruction (e.g. Kapur, 2016). For this purpose, the delayed instruction phase should compare and contrast the critical features of students' erroneous solution ideas with the components of the canonical solution (e.g. Loibl & Rummel, 2014a). Many studies have shown beneficial effects of PF on students' acquisition of conceptual knowledge (for reviews see, e.g. Kapur, 2015; Loibl, Roll, & Rummel, 2017). It stands out that most of these studies have focused on investigating student learning in STEM (i.e., science, technology, engineering, and mathematics) domains, especially mathematics (e.g. Kapur, 2012; Loibl & Rummel, 2014a). Only a few studies have examined the effect of problem solving prior to instruction on student learning of domain-general skills (e.g. Matlen & Klahr, 2014; Kant et al., 2017) or in non-STEM-domains (e.g. Glogger-Frey et al., 2015; Nachtigall, Serova, & Rummel, 2020). However, those studies were unable to demonstrate beneficial effects of PF or problem-solving prior to instruction approaches more generally on students' knowledge acquisition.

What PF students in non-STEM or domain-general learning contexts seem to be lacking is a reflective view on their own knowledge. Metacognitive competencies, such as monitoring one's understanding, realizing that one is missing an important piece of information, and identifying that piece of information, are hypothesized to be crucial for successful learning in PF settings (Loibl et al., 2017). For instance, findings by Loibl and Rummel (2014a, 2015) suggest that the PF effect on students' learning in mathematics is linked to PF students' awareness of knowledge gaps and their experience of their competence limitations. PF students' failure awareness is expected to prepare students for successful learning during instruction (Loibl et al., 2017). Specifically, when learners realize their knowledge gaps, their mental model is challenged and they may develop a desire to fill their gaps in order to modify their mental model (e.g., Tawfik, Rong, & Choi, 2015). However, in certain domain-general or non-STEM learning contexts, PF students appear to have difficulties with becoming aware of their knowledge gaps, their competence limitations, or their failure more generally. For instance, Kant, Scheiter, and Oschatz (2017) as well as Matlen and Klahr (2014) hypothesize that the non-effects of problem solving prior to instruction on learning the domain-general CVS (i.e., Control of Variables Strategy) in their studies may be due to the fact that their participants were unable to develop an awareness of their failure prior to instruction. That is, students who design experiments in order to learn the CVS receive no feedback on the quality of their performance through their developed designs, while students who work on mathematical problems (as in typical PF studies) can more easily encounter whether their solutions are correct or not. Moreover, two studies conducted by Nachtigall et al. (2020) demonstrated that PF students – in a non-STEM learning setting – reported significantly higher perceived competence than their counterparts in a Direct Instruction condition although they failed to solve a novel and complex problem during the problem-solving phase. Both studies demonstrated non-effects of PF on student learning of social science research methods, and this non-effect may be caused by PF students' lack of failure awareness prior to instruction (Nachtigall et al., 2020).

Against this background, supporting PF students' monitoring of their own understanding and their accurate judgements of their competence during the initial problem-solving phase appears necessary in order to promote the effectiveness of PF for learning in non-STEM-domains. One reason for students' difficulties with regard to accurately monitoring their learning and assessing their competence may be related to their use of inappropriate cues. According to the cue-utilization framework, "participants do not monitor directly the strength of the memory trace of the [study] item in question [in order to assess their learning and knowing], but use a variety of cues that are generally predictive of subsequent memory performance." (Koriat, 1997, p. 350). However, these cues differ with regard to their predictive accuracy of students' actual learning, and students tend to use pervasive cues, such as time on task or perceived difficulty of learning materials (e.g., de Bruin, Dunlosky, & Cavalcanti, 2017). For instance, if the learning material is easy to process, students often tend to judge their learning or their performance based on their perceived difficulty of the learning materials and not on their actual achievement (de Bruin & van Merriënboer, 2017). In order to accurately monitor their own knowledge, learners need to use diagnostic cues (de Bruin et al., 2017). But, learners are often unable to utilize diagnostic cues on their own. It then becomes necessary to provide external support in order to foster learners' accurate self-evaluation (de Bruin et al., 2017).

However, providing PF students with external support, namely with explicit guidance by the instructor during the initial problem-solving phase has been demonstrated to be either less effective (Kapur, 2012) or equally effective (Loibl & Rummel, 2014b) than withholding any guidance for PF students' knowledge acquisition. To foster PF students' utilization of diagnostic cues and, thus, their learning it may be more promising to provide students with implicit feedback on the quality of their generated solutions, such that students can encounter their specific knowledge gaps on their own. One method could be to confront PF students with a worked example prior to instruction. Studying worked examples reduces cognitive load, helps students to focus their attention on the problem state, and may increase learning outcomes, especially of novice learners (Sweller et al., 1998; Kant et al., 2017). When studying a worked example, learners can compare their own performance to the performances of experts that worked on the same content. This comparison could lead learners to monitor their understanding and competencies in a more elaborated way. Newman and DeCaro (2018) as well as Glogger-Frey et al. (2015) found that studying worked examples prior to instruction is indeed more effective for students' learning than trying to solve a problem prior to instruction as in PF. Therefore, it may be promising to implement the beneficial effects of worked examples into a PF setting in order to support students' utilization of diagnostic cues and consequently their learning in non-STEM-domains. More specifically, asking PF students to compare their often erroneous solution ideas to a worked example prior to instruction could help them to use diagnostic cues for assessing their competence and learning. Thereby, PF students may develop an awareness of their knowledge gaps prior to instruction and be better prepared to learn or to fill their gaps during instruction. To test these hypotheses is the goal of the present study.

The present study

The present study aims at investigating whether fostering PF students' utilization of diagnostic cues by having them study a worked example prior to instruction leads to beneficial effects on both students' awareness of their failure and their learning in a non-STEM domain, namely social science research methods. Specifically, we investigate the following two research questions (RQ):

RQ1: Does a cue-utilization activity (i.e., studying a worked example) prior to instruction help PF students to use diagnostic cues for assessing their problem-solving performance such that they become aware of their failure?

RQ2: Does a cue-utilization activity (i.e., studying a worked example) prior to instruction have an impact on PF students' learning of social sciences research methods?

To investigate these research questions, we conducted a quasi-experimental study comparing two conditions: (1) Productive Failure (PF): Students try to solve a problem prior to instruction, and (2) Productive Failure with *cue-utilization activity* (PF_{cue}): Students try to solve a problem and are asked to compare their solution attempts to a worked example prior to instruction. Building on the cue-utilization framework, research on the worked-example effect, and the findings of PF studies indicating that PF students in domain-general or non-STEM settings may not become aware of their failure during problem solving due to the lack of feedback (Kant et al., 2017; Matlen & Klahr, 2014; Nachtigall et al., 2020), we hypothesize that PF_{cue} students report lower perceived competence (Hypothesis 1/H1) and a higher awareness of knowledge gaps (Hypothesis 2/H2) prior to instruction than PF students. Consequently, we further assume that PF_{cue} students outperform PF students on a posttest assessing their knowledge about social science research methods (Hypothesis 3/H3).

Method

Participants

80 10th and 11th graders (Age: $M = 15.76$, $SD = 0.77$; 58% female) from four social and educational science classes of four German secondary schools participated in the present study. We implemented a quasi-experimental design and randomly assigned the classes to the experimental conditions as a whole. Specifically, two classes (n = 42) were assigned to the PF condition and two classes (n = 38) to the PF_{cue} condition.

Experimental design and procedure

The learning topic related to social science research methods, namely the differences between causal versus correlative empirical evidence within the social sciences. To teach students the topic of causal versus correlative evidence, we used the same learning materials (i.e., two problem-solving tasks and an instructional lesson) as in the study conducted by Nachtigall et al. (2020).

Students in both conditions experienced an initial problem-solving phase (learning phase 1), a delayed instruction phase (learning phase 2), and a final practice phase (learning phase 3). During the initial problem-solving phase, students in both conditions had to work in groups of three to four on the same task. The task asked them to think about the possible results that could be derived from a certain study on the relation between teenager’s consumption of video games that displayed aggressive actions and their own aggressive behavior after playing those games. Students received information on the design of the study (namely a longitudinal study with one group) and the following researchers’ hypothesis: ‘Teenagers show more aggressive behavior, because they play more video games that display aggressive actions.’. Specifically, students were asked (a) to think of possible outcomes of the study, (b) to decide which of those possible outcomes was most likely to be found, and (c) to decide whether and explain why one of the possible outcomes could confirm or reject the researcher’s hypothesis. During the delayed instruction phase in both conditions, the same experimenter explained that a longitudinal study with one group (as described in students’ previous task) offers only correlative evidence and why correlative evidence cannot be interpreted as causal. During the final practice phase, students had to work individually on an isomorphic task.

The only difference between the two conditions relates to the cue-utilization activity (learning phase 1.1), implemented in the PF_{cue} condition. After the initial problem-solving phase, PF_{cue} students were asked to collaboratively compare their solutions generated in the group to a worked example and to write down the respective similarities and differences. The worked example included the information of the instructional lesson.

After each learning phase, we administered questionnaires (three questionnaires in the PF condition and four questionnaires in the PF_{cue} condition) to assess our control and process variables. At the end of the experiment, a posttest assessed students’ knowledge about the targeted learning concept. Table 1 shows the experimental procedure in both conditions.

Table 1: Overview of the experimental design

Learning phase	**Test phase**	**PF condition**	**PF_{cue} condition**
	1	Questionnaire 1	
1		Collaborative problem solving	
	2	Questionnaire 2	
1.1			Cue-utilization activity
	2.1		Questionnaire 2.1
		Break	
2		Instruction	
3		Individual problem solving (practice phase)	
	3	Questionnaire 3	
		Break	
	4	Posttest	

Measures

As previous PF studies (e.g. Kapur, 2014, Nachtigall et al., 2020) demonstrated that *students' grades* affect their learning outcome, the first questionnaire measured students' grades as a control variable by asking them to indicate their grades in three different subject areas (i.e. social/educational sciences, German language, and mathematics).

The questionnaires administered after the learning phases 2, 2.1 (only in PF_{cue}), and 3 assessed students' *perceived competence* and their *knowledge gaps*. For assessing students' perceived competence, we used the short scale of intrinsic motivation developed by Wilde, Bätz, Kovaleva, and Urhahne (2009). The questionnaire includes the following three items on perceived competence: (1) I am satisfied with my performance during this learning phase; (2) I was skilled in the activities during this learning phase; (3) I think I was pretty good at the activities during this learning phase. The internal consistency of the subscale for perceived competence was satisfactory (after learning phase 1: Cronbach's $\alpha = .81$, after learning phase 2.1: Cronbach's $\alpha = .88$, after learning phase 3: Cronbach's $\alpha = .83$). For measuring students' knowledge gaps, we used five items (e.g. "I lack knowledge required to solve this problem") adapted from Loibl and Rummel (2014a) and Glogger-Frey et al. (2015). The internal consistency of these items was again satisfactory (after learning phase 1: Cronbach's $\alpha = .76$, after learning phase 2.1: Cronbach's $\alpha = .82$, after learning phase 3: Cronbach's $\alpha = .77$). All items for assessing students' perceived competence and their knowledge gaps rated from 1 (*strongly disagree)* to 5 (*strongly agree*).

A posttest with eight items assessed students' ability to reproduce, apply, and transfer the contents of the instructional lesson by asking them to individually solve familiar as well as unfamiliar problems. The total score of the posttest ranged from 0 to 21. Two raters coded 100% of the dataset and reached a high agreement ($ICC_{absolute} = .95$; 95%-CI [.92, .97]). Disagreements were resolved through discussion, such that we were enabled to use one dataset for further analyses.

Results

Prior analyses

Before testing our hypotheses, we investigated whether PF and PF_{cue} students differed with regard to their reported grades. We conducted a MANOVA with condition as factor and the three grades as dependent variables. There were no significant differences between the two conditions in the three reported grades (educational/social sciences: $M_{PF} = 2.04$, $SD_{PF} = 0.70$, $M_{PF+CUE} = 2.18$, $SD_{PF+CUE} = 0.95$, $F(1, 74) = 0.49$, $p = .49$, $\eta p^2 = .007$; German language: $M_{PF} = 2.33$, $SD_{PF} = 0.72$, $M_{PF+CUE} = 2.59$, $SD_{PF+CUE} = 0.74$, $F(1, 74) = 2.28$, $p = .14$, $\eta p^2 = .030$; mathematics: $M_{PF} = 2.36$, $SD_{PF} = 1.14$, $M_{PF+CUE} = 2.35$, $SD_{PF+CUE} = 1.04$, $F(1, 74) = 0.00$, $p = .99$, $\eta p^2 = .000$).

Confirmatory analyses

To test H1 (i.e., PF_{cue} students report lower perceived competence than PF students prior to instruction) and H2 (i.e., PF_{cue} students report a higher awareness of knowledge gaps than PF students prior to instruction), we conducted a MANOVA with condition as factor and students' perceived competence and their reported knowledge gaps prior to instruction (i.e., after problem solving in the PF condition and after the cue-utilization activity in the PF_{cue} condition) as dependent variables. The analysis reveals no significant effect of condition neither on perceived competence ($F(1,78) = 1.31$, $p = .26$, $\eta_p^2 = .017$, 90% CI [.000; .089]) nor on reported knowledge gaps ($F(1,78) = 1.08$, $p = .30$, $\eta_p^2 = .014$, 90% CI [.000; .083]). Hence, against our hypotheses, students' perceived competence and their reported knowledge gaps do not differ significantly between the two conditions (see Table 2 for descriptive statistics).

Table 2: Descriptive statistics for students' perceived competence and knowledge gaps prior to instruction

	PF ($n = 42$)	**PF_{cue}** ($n = 38$)
	M (SD)	***M (SD)***
Perceived competence	3.57 (0.59)	3.39 (0.85)
Knowledge gaps	2.41 (0.66)	2.58 (0.80)

To test H3 (i.e., PF_{cue} students reach a higher learning outcome than PF students), we conducted an ANCOVA with condition as factor, posttest performance as dependent variable, and an average score of student grades as covariate (due to significant correlations with students' posttest performance). Against our H3, the ANCOVA reveals no effect of condition ($F(1,78) = 0.33$, $p = .57$, $\eta_p^2 = .004$, 90% CI [.000; .057]). Thus, PF_{cue}

students (M = 8.29, SD = 3.49) did not outperform PF students (M = 8.79, SD = 3.34) on a posttest assessing for knowledge about correlative versus causal evidence.

Exploratory analyses

As none of our hypotheses could be confirmed, the question arises why the cue-utilization activity did not have any impact on students' awareness of their knowledge limitations. To investigate this question, we conducted further exploratory analyses.

We first took a closer look at the development of PF_{cue} students' perceived competence and their reported knowledge gaps across the problem-solving phase, the cue-utilization activity, and the instruction and practice phase. We expected that the cue-utilization activity would help students to become aware of their failure and their knowledge limitations. Thus, the cue-utilization activity should lead to a decline of students' perceived competence and an increase of their awareness of knowledge gaps. After the explanation of the canonical solution during instruction and after practicing, students' perceived competence should increase again, and their reported knowledge gaps should decrease. To investigate these assumptions, we conducted two repeated-measures ANOVAs with the three times of measurement of perceived competence or reported knowledge gaps as within-subjects-factor. For PF_{cue} students' perceived competence, the analysis reveals a small but not significant effect of time of measurement ($F(1.66,61.82) = 2.11$, $p = .14$, $\eta_p^2 = .05$). For PF_{cue} students' reported knowledge gaps, the repeated-measures ANOVA reveals again a small but non-significant effect of time of measurement ($F(1.46,54.09) = 1.29$, $p = .28$, $\eta_p^2 = .03$). Thus, neither PF_{cue} students' perceived competence nor their reported knowledge gaps did differ significantly between the three times of measurement (see Table 3 for descriptive statistics).

Table 3: Descriptive statistics for PF_{cue} students' development of perceived competence and knowledge gaps

		M (SD)
Perceived competence	after problem solving	3.46 (0.91)
	after the cue-utilization activity	3.39 (0.85)
	after instruction and practice	3.66 (0.56)
Knowledge gaps	after problem solving	2.45 (0.87)
	after the cue-utilization activity	2.58 (0.80)
	after instruction and practice	2.33 (0.71)

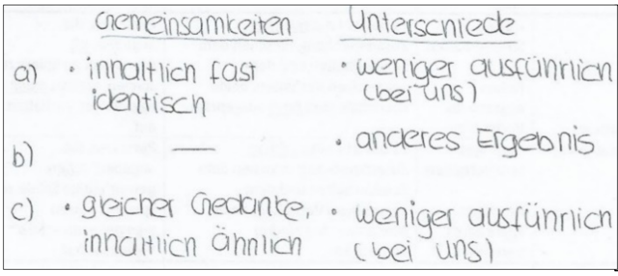
Further, we analyzed how PF_{cue} students used the worked example during the cue-utilization activity. We compared each solution that students had generated in their groups to the worked example in order to analyze how many differences the students could have found between their own solution and the canonical solution presented in the worked example. Afterwards, we examined how many differences PF_{cue} students actually identified. The results (see Table 4) demonstrate that on average PF_{cue} students were only able to find 25% of their mistakes by comparing their own solution with the solution presented in the worked example.

Table 4: PF_{cue} students' actual mistakes versus identified mistakes

PF_{cue} student group	**Number of actual mistakes** *during problem solving*	**Number of identified mistakes** *during cue-utilization activity*
1	7	3 (43%)
2	4	2 (50%)
3	3	0
4	4	1 (25%)
5	5	2 (40%)
6	4	0
7	3	0
8	4	2 (50%)
9	4	1 (25%)
10	5	0
11	5	1 (20%)
12	4	2 (50%)

The fact that PF_{cue} students had difficulties to identify the differences between their own solution and the canonical solution presented in the worked example is further supported by qualitative analyses of students' work during the cue-utilization activity. These analyses reveal that seven out of the twelve student groups stated that their solution and the worked example were similar. Four out of twelve groups simply describe their own solution as less detailed than the worked example (see Figure 1 for an example). Another recurring pattern in the cue-utilization activity is that some students discuss the study described in the problem-solving task and the potential findings of this study. Specifically, five out of twelve groups thought about circumstances and factors (e.g. age or gender) that may have an impact on whether children show aggressive behavior after playing video games with violent content. Hence, instead of comparing their own solution with the worked example, these groups continued their work of the problem-solving phase. Two groups even just stated their opinions about playing video games with violent content and did not compare their solution to the worked example during the cue-utilization activity.

The analysis of students' work during the cue-utilization activity also showed that students' comparisons between their own solutions and the worked example were often incomplete or not very detailed, which is also illustrated by the example in Figure 1.



	Similarities	Differences
a)	nearly similar content	less detailed (ours)
b)	-	different outcome
c)	same thought, nearly similar content	less detailed (ours)

Figure 1. Example of students' results of the cue-utilization activity (left figure: original solution in German; right figure: English translation).

Discussion

Previous research on Productive Failure (PF) suggests that students' awareness of their failure and knowledge limitations could be a crucial mechanism underlying the effectiveness of PF for student learning (Loibl & Rummel, 2014a; Loibl et al., 2017; Nachtigall et al., 2020). However, students often tend to overestimate their own competence (Kruger & Dunning, 1999) and to use inappropriate cues for monitoring and evaluating their learning (e.g. de Bruin et al., 2017). The same seemingly applies to PF students in certain non-STEM or domain-general learning settings (cf., Nachtigall et al., 2020; Kant et al., 2017; Matlen & Klahr, 2013). To support PF students in recognizing their knowledge limitations while learning social science research methods, we implemented a cue-utilization activity after the problem-solving phase and prior to the instruction phase. Our cue-utilization activity aimed at fostering students' use of diagnostic cues by asking them to compare their self-generated (and often erroneous) solution to a canonical solution presented in a worked example. We hypothesized that this activity would help students to become aware of their knowledge limitations and thus that students in a PF setting with cue-utilization activity would report lower perceived competence (H1) and higher knowledge gaps (H2) prior to instruction than students in a PF condition without cue-utilization activity. As students' awareness of their knowledge limitations is hypothesized to underlie the effectiveness of PF, we further expected that PF_{cue} students would outperform PF students on a knowledge test (H3). However, our findings support neither of these hypotheses.

As our exploratory analyses suggest, a reason for our unexpected findings may relate to students' rather low performance during the cue-utilization activity. Specifically, students had difficulties to identify the differences between their own solution and the canonical solution presented in the worked example. Thus, students in our PF_{cue} condition were either unwilling or unable to critically evaluate their own solutions and to become aware of their previous failure in producing the canonical solution to the problem-solving task. Our exploratory analyses with respect to the development of PF_{cue} students' perceived competence and reported knowledge gaps further suggests that our cue-utilization activity indeed led to a small decline of perceived competence and a small increase of reported knowledge gaps, but only descriptively. Thus, asking students to compare their own and often erroneous solution ideas with a worked example prior to instruction may have potential for fostering students' failure awareness, but probably depends on students' critical and careful evaluation of their own solutions. The lack of students' critique towards their own solutions could relate to students' epistemological beliefs about the social sciences. Pauly (2012) describes that students often associate research within the humanities and social sciences with expressions of individual opinions, feelings, and thoughts and not with systemic investigations of phenomena as in the natural sciences. Thus, the students in our study may have seen no need to critically and systematically evaluate the quality of their solutions. Instead, they might have perceived their solutions as well as the solution presented in the worked example as expressions of individual opinions and thoughts which cannot be systematically evaluated. Another reason could relate to the so-called IKEA effect (Norton et al., 2012). Norton and colleagues (2012) showed in four studies that their participants valued self-made products higher than pre-assembled products. Hence, it is likely that PF_{cue} students in our study ascribed a higher value to their self-generated solutions than to the canonical solution presented in the worked example, whereby they did not reflect accurately on differences between their own solution and the worked example. Further research is needed in order to investigate whether students' epistemological beliefs and/or students' appreciation of their self-generated solutions is related to their low performance during the cue-utilization activity. For this purpose, it might be interesting to conduct post-hoc interviews with the students.

However, as PF_{cue} students did not develop a higher awareness of their knowledge limitations prior to instruction than students in the PF condition without cue-utilization activity, it is not surprising that PF_{cue} students did not outperform PF students on a knowledge test. Instead, this finding is in line with the assumption that students' awareness of their knowledge limitations prior to instruction may be a relevant mechanism underlying the effectiveness of PF. Nevertheless, further research is required in order to both test effective ways for fostering PF students' awareness of their knowledge limitations in a non-STEM learning setting and investigate the role of students' failure awareness prior to instruction for the effectiveness of PF.

Limitations

We conducted our study with real students and real courses which increases the external validity of our investigation and is in line with the *in vivo* experimentation paradigm of the LearnLab at Carnegie Mellon University in Pittsburgh (Koedinger, Aleven, Roll, & Baker, 2009). However, due to the random assignment of whole classes to the experimental conditions, prior differences between PF and PF_{cue} students cannot be excluded.

A further limitation relates to the non-effects of our experimental manipulation. Non-effects revealed by null hypothesis significance tests, such as the F-test, are difficult to interpret. Those tests examine whether a null hypothesis can be rejected and not whether a null hypothesis can be accepted (which is contrary to our hypotheses but suggested by our findings). To address this difficulty, we followed the suggestions by Aberson (2002) and calculated the confidence intervals of the effect sizes (which are reported in the results section above).

One could also see it as a limitation of our study that PF_{cue} students were asked to collaborate while studying the worked example and comparing it to their own solution idea. As PF_{cue} students generated their solution idea in small groups during the initial problem-solving phase – which is in line with one of the PF design principles described by Kapur and Bielaczyc (2012) – we also asked them to collaboratively compare their joint solution idea to the worked example during the cue-utilization activity. However, findings by Retnowati, Ayres, and Sweller (2017) demonstrated that studying a worked example individually leads to higher learning gains than studying it collaboratively. Further research is required to investigate whether this effect also transfers to our cue-utilization activity.

References

Aberson, C. (2002). Interpreting null results: Improving presentation and conclusions with confidence intervals. *Journal of Articles in Support of the Null Hypothesis, 1*(3), 36-42.

Chi, M. T. H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *The Journal of the Learning Sciences*, *6*(3), 271-315.

de Bruin, A. B. H., Dunlosky, J., & Cavalcanti, R. B. (2017). Monitoring and regulation of learning in medical education: the need for predictive cues. *Medical Education*, *51*, 575-584.

de Bruin, A. B. H., & van Merriënboer, J. J. G. (2017). Bridging cognitive load and self-regulated learning research: A complementary approach to contemporary issues in educational research. *Learning and Instruction*, *51*, 1-9.

Glogger-Frey, I., Fleischer, C., Grüny, L., Kappich, J., & Renkl, A. (2015). Inventing a solution and studying a worked solution prepare differently for learning from direct instruction. *Learning and Instruction*, *39*, 72-87.

Kant, J. M., Scheiter, K., & Oschatz, K. (2017). How to sequence video modeling examples and inquiry tasks to foster scientific reasoning. *Learning and Instruction*, *52*, 46-58.

Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science*, *40*(4), 651-672.

Kapur, M. (2015) Learning from productive failure. *Learning: Research and Practice*, *1*(1), 51-65.

Kapur, M. (2016). Examining productive failure, productive success, unproductive failure, and unproductive success in learning. *Educational Psychologist*, *51*(2), 289-299.
Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *The Journal of the Learning Sciences*, *21*(1), 45-83.
Koedinger, K. R., Aleven, V., Roll, I., & Baker, R. (2009). In vivo experiments on whether supporting metacognition in intelligent tutoring systems yields robust learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of metacognition in education*. (pp. 383–412). New York: Routledge.
Koriat, A. (1997). Monitoring one's own knowledge during study: A cue-utilization approach to judgements of learning. *Journal of Experimental Psychology: General*, *126*(4), 349-370.
Kruger, J., & Dunning, D. (1999). Unskilled and unaware of it: How difficulties in recognizing one's own incompetence lead to inflated self-assessments. *Journal of personality and social psychology*, *77*(6), 1121-1134.
Loibl, K., Roll, I., & Rummel, N. (2017). Towards a theory of when and how problem solving followed by instruction supports learning. *Educational Psychology Review*, *29*, 693-715.
Loibl, K., & Rummel, N. (2014a). Knowing what you don't know makes failure productive. *Learning and Instruction*, *34*, 74-85.
Loibl, K., & Rummel, N. (2014b). The impact of guidance during problem solving prior to instruction on students' inventions and learning outcomes. *Instructional Science*, *42*(3), 305-326.
Loibl, K., & Rummel, N. (2015). Productive Failure as strategy against the double curse of incompetence. *Learning: Research and Practice*, *1*(2), 113-121.
Matlen, B. J., & Klahr, D. (2013). Sequential effects of high and low instructional guidance on children's acquisition of experimentation skills: Is it all in the timing?. *Instructional Science*, *41*(3), 621-634.
Nachtigall, V., Serova, K., & Rummel, N. (2020). When failure fails to be productive: probing the effectiveness of productive failure for learning beyond STEM domains. *Instructional Science*, *48*(6), 651-697.
Newman, P. M., & DeCaro, M. S. (2018). How much support is optimal during exploratory learning? In *Proceedings of the 40th annual conference of the cognitive science society*. Madison, WI: Cognitive Science Society.
Norton, M. I., Mochon, D., & Ariely, D. (2012). The IKEA effect: When labor leads to love. *Journal of Consumer Psychology*, *22*, 453-460.
Pauly, Y. (2012). Was sind und zu welchem Zweck brauchen wir geisteswissenschaftliche Schülerlabore? [What are and for what purpose do we need out-of-school labs on humanities and social sciences]. In *Handbuch Wissenschaftskommunikation* (pp. 205-210). Wiesbaden: VS Verlag für Sozialwissenschaften.
Retnowati, E., Ayres, P., & Sweller, J. (2017). Can collaborative learning improve the effectiveness of worked examples in learning mathematics?. *Journal of educational psychology*, *109*(5), 666-679.
Sweller, J., van Merriënboer, J. J. G., & Paas, F. G. W.C. (1998). Cognitive architecture and instructional design. *Educational Psychology Review*, *10*(3), 251-296.
Tawfik, A. A., Rong, H., & Choi, I. (2015). Failing to learn: Towards a unified design approach for failure-based learning. *Educational technology research and development*, *63*(6), 975-994.
Wilde, M., Bätz, K., Kovaleva, A., & Urhahne, D. (2009). Überprüfung einer Kurzskala intrinsischer Motivation (KIM) [Testing a short scale of intrinsic motivation]. *Zeitschrift für Didaktik der Naturwissenschaften*, *15,* 31-45.

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Changes in the Media Landscape in the Wake of COVID-19 as a Catalyst for Data Literacy Development thru Life Routines

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Abstract: Do life circumstances introduce opportunities to learn? COVID-19 created a public need for information on the epidemiological developments of this pandemic, resulting in an upsurge in graphical representations in the media. Using a survey, we examine whether, in the wake of COVID-19, people make greater use of data representations, and whether this relates to their confidence in interpreting these representations. We also evaluate their graph interpretation skills. To understand the role of rudimentary education in this process, we report on participants with 12 or less years of education. We found that people mostly increased their use of graphs, and that this explains an increase in their confidence to interpret graphs. People with stronger skills had a higher increase in graph use. People with weaker skills, also increased, rather than avoided, graph use. Life experiences can prompt change and growth, and the media landscape can play a role in this process.

Introduction

Visual representations of data are prevalent in many facets of everyday life (Wise, 2020): in news media (Allen, 2018; Bao, Cao, Xiong, & Tang, 2020), in lifestyle tracking apps (Byrne, O'Grady, Collier, & O'Hare, 2020), in personal health records (Sharit et al., 2014), and others, making proficiency in interpreting such representations key to civic participation. In fact, data literacy is defined as "the desire and ability to constructively engage in society through and about data" (Bhargava et al., 2015). Consequently, there is increasing interest in the learning sciences in understanding the nature of data literacy and how to cultivate data literacy (Wilkerson & Polman, 2020). One of the hallmarks of research in the learning sciences is drawing on research of everyday reasoning and learning in order to reconceptualize formal education (Hoadley, 2018; Kolodner, 2004) so that it creates usable knowledge, and better equips learners to participate more centrally in various contexts of practice (Lave & Wenger, 1991). We follow this tradition by examining how people reason with data representations in the wake of COVID-19.

The COVID-19 pandemic brought income instability and emotional burden, which as recent reports state, also fueled public interest in COVID-19 data (Bowe, Simmons, & Mattern, 2020). Within a few weeks into the year 2020, COVID-19 became a trending topic worldwide. Production and consumption of COVID-19 data was so high and widespread that the term 'infodemic' (Cuan-Baltazar, Muñoz-Perez, Robledo-Vega, Pérez-Zepeda, & Soto-Vega, 2020) was coined to mark and highlight this striking phenomenon. The high public consumption of COVID-19 data in terms of visualizations, open data repositories, simulations and infographics motivates interest in understanding how the public interpret and effectively use the data (Alberda, Alamalhodaei, & Feigenbaum, 2020).

International standardized tests among both children and adults, public surveys, and educational research reports suggest that data literacy and graph interpretation pose a challenge (Assessment, 2013; Bragdon, Pandiscio, & Speer, 2019; Gonzalez, 2018; Highlights of the U.S. PIAAC Results, 2017; Pérez-Echeverría, Postigo, & Marín, 2018). However, other lines of research highlight the discrepancy that can exist between formal school-like assessments and people's competence and performance in everyday contexts (Lave, 1984; Saxe, 2015; Suad Nasir, 2000). Overall, studies of everyday contexts demonstrate that people are more productive in everyday contexts than what might have been predicted based on formal school-like assessments. COVID-19 has created unique circumstances in which we can gain insights into the ways in which diverse people make use of and interpret graphs.

In this paper, we report on a subset of data from a larger study. The larger study examined a cross-sectional national representative sample of people's information behavior prior to and during COVID-19, and examined how people interpret COVID-related graphs. In the present paper, we focus only on the sub-sample who have up to 12 years of formal schooling. Our goal is to use this sub-sample to better understand the role that rudimentary (K-12) education plays in people's use of data literacy in everyday contexts, and in their trajectories of data literacy development.

Background: Graph interpretation skills

Data literacy builds on the literacies of: numerical literacy; information literacy (including critical thinking about sources); scientific literacy; statistical literacy; computational literacy; and digital literacy. (Bhargava, 2019). In this paper, we focus more specifically on graph comprehension.

Despite the increasing importance of graph interpretation skills, many adults have low graph literacy (Galesic & Garcia-Retamero, 2010; Herrmann, Brumby, & Oreszczyn, 2016). Though people vary in their ability to interpret graphs based on the type of graphical representation, with bar graphs yielding higher performance (Dowding et al., 2017). Full competence in reading graphs is not achieved even by college and university graduates (Nayak et al., 2016; Roth, Bowen, & McGinn, 1999). Facets that are involved in graph comprehension are: understanding representational conventions and understanding the content and context related to the data that is represented (Maltese, Harsh, & Svetina, 2015). One way in which stronger skills are distinguished from weaker skills is in the ability to focus on those aspects of a graph that are most pertinent to the questions that people want to answer by interpreting the graph (Okan, Galesic, & Garcia-Retamero, 2016).

Methods

Participants

500 participants were recruited through a stratified random sample from a panel (N=500). Stratification categories were gender, age, religious status (e.g., ultra-orthodox, secular), and geographic region (e.g., northern Israel, greater Tel Aviv area, etc…). Category sample quotas were established to represent the population demographics of Israel. In this paper, we focus on a sub-sample of N=170 participants who reported that they have up to 12 years of formal education.

Instrument

We developed a 21-question survey to elicit self-reports of information behavior, COVID19 attitudes and behaviors, trust in science, as well as questions assessing graph interpretation skills.

The survey included 1 question collecting demographic information; 4 questions about information behavior addressing: what information sources (e.g., WHO, FaceBook) do participants employ and with what frequency – before and during COVID19, and how reliable they consider the sources; what data representations (e.g., graph, table) they encounter, how frequently, and how confident they are in interpreting the various data representations; 1 question asked about the frequency with which participants employ COVID19 health-protective behaviors (e.g., distancing, wearing a mask) (adapted from: Plohl & Musil, 2020); 14 questions presented different types of graphs with related multiple choice questions that required direct lookup of information in the graph (e.g., which age group in a bar-graph is the age group that does not show symptoms), as well as inferencing (e.g., the table shows the smallest number of infected individuals in the 90 and older age group, yet they are considered a high risk group, how can that be explained based on the data in the table?). This set of questions also included some open-ended questions that required participants to apply the information in the graph to decisions such as whether they would pursue international travel or whether schools should re-open. All but one of the 14 graph interpretation questions were set in the context of COVID19 and were similar to graphs that have appeared in news reports on COVID19. The one graph interpretation question that was not set in a COVID19 context was a question that appeared in the PEW Research Center survey (Kennedy & Hefferon, 2019) and was included in this survey as a way to compare responses in this pool of adult Israeli participants with the Pew's pool of adults in the United States. The last question in the survey was a Likert scale assessing trust in science and scientists (adapted from: Nadelson et al., 2014), and COVID19 risk perceptions (adapted from: Plohl & Musil, 2020).

Face validity was established by having four scholars review the survey. The scholars are experts in public health, mathematics education, and visual representations in cognition and learning with extensive experience in developing and validating research instruments. The survey was refined based on their comments. The survey was further refined by having four volunteers with different levels and fields of education complete the survey.

Procedure

After receiving IRB approval, the survey was distributed online in a cross-sectional study. The survey was implemented in Qualtrics (version September, 2020, Qualtrics, Provo, UT). The survey was distributed through iPanel (https://www.ipanel.co.il/en/), one of the largest polling services in Israel, which adheres to the high-quality research code of the European Society for Opinion and Marketing Research (ESOMAR; Bodas & Peleg, 2020). The survey was distributed during September 2020, during the second wave of COVID19 outbreak in Israel, and at the beginning of a second nation-wide lockdown.

In the present paper, we analyzed data only from those participants who reported that they had up to 12 years of formal education (N=170). We computed descriptive statistics (means, standard deviations, frequencies and percentages) to describe participants tendency to use COVID-19 related data and information sources, as well as their degree of frequency and confidence in using different modes of representation. We used t-tests to examine whether there were significant changes in frequency and confidence prior and during COVID-19. To understand the impact of the participants' characteristics, graphs interpretation skills, frequency of graph use on the confidence of using graph representations following COVID-19 outbreak, we conducted hierarchical regression analysis. Preliminary analyses were conducted to ensure that there were no violations of the assumptions of normality, linearity, and homoscedasticity. In addition, interaction effects between high and low graph interpretation skills were evaluated using repeated measures analysis of variance (ANOVAs). Data was analyzed using SPSS (version 25, IBM Corporation, Armonk, NY).

Findings

Descriptive statistics (Table 1) show that this sub-set of participants were fairly evenly distributed between male and female participants, with about half the participants under 30 years of age, and predominantly of average and below average income.

TABLE 1: Socio-demographic characteristics

Variables	***Participants (n=170)***
	M(SD)
Education (years)	11.7 ± 1.2
	N (%)
Age (years)	
18-22 years	45 (26%)
23-29 years	40 (24%)
30-39 years	24 (14%)
40-49 years	17 (10)
50-70 years	45 (26%)
Gender	
Female	82 (48%)
Male	89 (52%)
Income level	
Above average	20 (12%)
Average	45 (26%)
Less than average	106 (62%)

Increase in consulting information sources during COVID-19

Participants' primary sources for COVID-19 information were media and television news, Google search engine, friends and family, WhatsApp messenger and Facebook. Surprisingly, health organization websites such as the WHO and twitter were listed as the venues least used for COVID-19 information. Correspondingly, participants rated the most frequently used sites as more reliable and the least frequently used sites as least reliable. There was a significant increase from before to during COVID-19 in the frequency of use of all information sources (Table 2), with the largest shift in greater use of health organization sites such as the WHO or the Ministry of Health site.

TABLE 2: Information Sources before and during COVID-19 pandemic

	Before COVID-19	During COVID-19	t-test			Before COVID-19	During COVID-19	t-test
Media News and TV	3.9 ± 1.8	4.6 ± 1.7	-6.818***		Physician	2.8 ± 1.2	3.2 ± 1.4	-4.827***
Google search engine	3.7 ± 1.6	4.5 ± 1.4	-7.507***		Workplace	2.7 ± 1.7	3.3 ± 1.9	-5.898***

Friends and family	3.6 ± 1.6	4.2 ± 1.6	-6.472***	Religious leaders	1.9 ± 1.3	2.5 ± 1.7	-6.082***
WhatsApp messenger	3.3 ± 2.2	3.7 ± 2.1	-3.837***	Health Ministry website or HMO	2.5 ± 1.2	3.4 ± 1.5	-8.996***
Facebook	3.3 ± 2.0	3.6 ± 2.0	-3.870***	Scientific and medical journals	2.1 ± 1.4	2.5 ± 1.6	-4.496***
YouTube	3.1 ± 1.9	3.3 ± 1.9	-2.132***	Health related websites (e.g., Infomed, WHO)	1.7 ± 1.2	2.3 ± 1.5	-6.293***
Newspaper	2.9 ± 1.7	3.5 ± 1.8	-6.167***				
Wikipedia	2.9 ± 1.5	3.2 ± 1.6	-3.998***	Twitter	1.6 ± 1.3	1.8 ± 1.5	-2.580***

Data are presented in percentage mean ± SD; *** $p < .001$

Increase in reading graphs and in confidence to interpret graphs

We asked participants how often they used different modes of data representation such as tables, simulations, text and graphs, before and during COVID-19, in addition for each mode of representation we asked them to rank their confidence in interpreting the information in that mode. There was an increase in the frequency of use in all modes of representation, and a significant increase in interpretation confidence in all but text and lectures. Graphs showed the highest change before and during COVID-19 in both frequency and confidence (Figure 1).

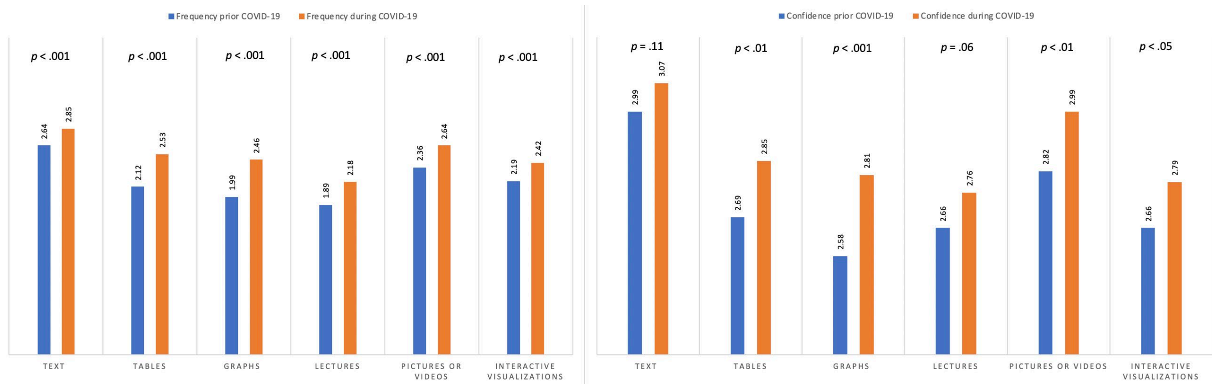

Figure 1. Changes following COVID-19 in frequency and confidence in use of modes of data representation

Graph interpretation skill and its correlates

Graph interpretation questions that involved looking up information in the graph were answered correctly on average by at least half of the respondents. These graphs included both bar graphs and line graphs. One question showed two version of a graph, where the second version includes two additional data points, which have a much higher value than all of the data points in the previous graph. Participants were asked what would happen to the average when these two data points were added to the measurements. 61% of the respondents correctly answered that the average would increase (61±49), demonstrating an understanding of the relationship between individual data points, and represented aggregate information such as average. The most challenging questions for participants, where less than 50% responded correctly, were questions relating to rates of change (36±48), and to changes in numerator or denominator (39±49).

To further understand the impact of participants' characteristics, their graph interpretation skill, frequency of using graphs, on the levels of confidence in using graphs as a result of COVID-19, a hierarchical multiple regression analysis was performed (Table 3). In model 1, contribution of sociodemographic characteristics, only age variable had a significant contribution to the explanation of participants' confidence levels, $F_{(3,\ 162)} = 3.02$, $p < 0.05$, explaining 5% in variance in confidence levels. Incorporation of graphs interpretation skill in and frequency in graph use in model 2 significantly explained additional 37% of the variance in confidence levels, and the entire model 3 explained 42% of the variance in confidence, $F_{(2,\ 160)} = 51.43$, $p < 0.001$.

TABLE 3: Summary of hierarchical regression analysis for variables predicting confidence in using graph representations following COVID-19 outbreak (*N* = 170)

Variable	Model 1	Model 2
	β	*β*
Age	-.19*	-.03
Gender (male)	-.05	.01
Family income level (above average/below average)	.01	.00
Graph interpretation skill		.32***
Frequency in Graph use following COVID-19 outbreak		.48***
R^2	0.05	0.42
F for change in R^2	3.01*	51.43***
ΔR^2	0.05	0.37

*$p < .05$; ***$p < .001$.

In order to better understand the role of graph interpretation skills in the use of graphs during COVID-19, we split the sample based on their total score on the graph interpretation questions, using the median as the splitting point. We conducted a repeated measures ANOVA with time as the within subjects factor using the measures of frequency of graph and of confidence in the ability to interpret graphs, graph skill was the between subjects factor. There were significant differences within each group in both measures across time, and there were significant differences between groups at both time points (Figure 2). There was a significant interaction between time and skill level for frequency $F(1,168)=4.141$, $p<.05$, but not for confidence ($F(1,168)=0.25$, p=.62). There was a significant difference in the rate of change (slope) between the lower graph skill group (0.34) and the high skill group (0.6), $t(84)=2.2$ p=.029.

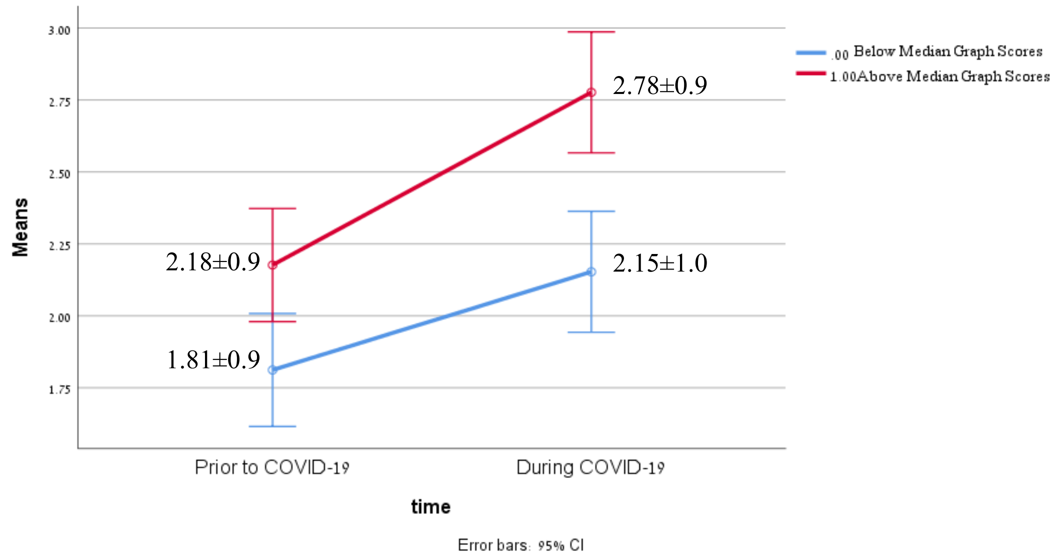

Figure 2. Rate of Change of Frequency of Viewing Graphs Prior to and During COVID-19

Discussion

Our goal in this paper is to connect to research in the learning sciences that considers productive activity in real-world contexts as the prism through which we should understand learning and design in education. Research from this tradition has exposed that performance on highly formalized, decontextualized and abstract assessments can obscure how well people might perform, in context, in response to real-world demands (Lave, 1984; Saxe, 2015; Suad Nasir, 2000). In the present study, we capitalized on the unique circumstances of the COVID-19 pandemic to gain insight into the ways in which the public might interpret and use data representations in a period in which such representations are prevalent in the media, and in which attending to this information carries strong purchase for the course of people's lives. In this paper, we also focus on participants who have up to 12 years of education as a way of reflecting the role of rudimentary education in preparing people for civic participation.

We found that information behavior changed in the wake of COVID-19, and that our participants reported the greatest change in their consumption or use of graphs over other modes of representation. In this discussion, we do not focus on assessing participants' ability to interpret COVID-19-related graphs per se. Instead, we examine what this study teaches us about how information behavior, skills and beliefs interact and influence how we might realize the opportunities to learn that everyday life experiences offer. Our survey includes graph interpretation questions, and our findings reflect prior research (e.g., Galesic & Garcia-Retamero, 2010; Herrmann et al., 2016): at least 50% of the 170 participants were able to correctly respond to most questions. As noted, we will discuss how this knowledge is related to other factors, and how this might affect propensity for change.

As might be expected, proficiency was correlated with confidence in one's ability to interpret graphs. Participants along the full range of proficiency and confidence levels reported statistically significant increases in graph consumption during the pandemic, and in confidence in their ability to interpret graphs. For those with lower confidence in their ability, this is a somewhat surprising result, because people who doubt themselves might tend to avoid graphs. Given the relationship that we found between consuming graphs and feeling confident about interpreting graphs, the fact that even low-confidence participants increased their graph consumption during the pandemic, carries important implications for propensity for change.

Our findings suggest that changes in graph consumption explain confidence, so that increased use of graphs is associated with higher levels of confidence. This finding can advance our understanding of reasoning and change in everyday contexts. Conceivably, experience and practice should lead to increased confidence in one's ability. This is more likely if these experiences are successful. However, in routine life experiences, rather than intentional learning environments, people may not be able to discern whether they were successful, because they may not receive feedback on their performance. In the present context of COVID-19, the media landscape includes a higher number of data representations that are key to understanding and navigating life during the pandemic, and there is increased use or consumption of these graphs, but people do not receive any clear indication as to how well they are interpreting these graphs. Despite this ambiguity, our findings suggest that increased use of graphs led to increased confidence.

However, the process and relationship between use and confidence is complex. When we consider differences between higher and lower performers on the graph interpretation questions, within our sample of individuals with up to 12 years of education, we find that there are significant differences between these groups in terms of graph use and confidence, before and during COVID-19. Moreover, in terms of graph use, the changes during COVID-19 are higher for the higher performing group, but there are no significant differences in the rate of change in confidence between the two groups. We see that prior proficiency with graph interpretation leads to greater changes in using graphs when life circumstances call for consuming this type of information, creating an advantage for those with prior higher proficiency. However, confidence in graph interpretation operates differently, and follows similar patterns of change regardless of prior proficiency. These similarities in rates of change in confidence might be a function of the general lack of feedback on success in everyday contexts, as discussed above.

We would also like to consider some of the limitations of our study and analysis. First, while our goal is to understand how people reason within the media landscape of everyday life, we did not observe people in situ. In order to mitigate this issue, we designed our graph analyses questions to reflect the types of representations that have appeared in the media, and raised questions that reflected some of the public discourse during the COVID-19 pandemic. Another concern might be that people may have reported higher ratings for the COVID-19 period than for the preceding period out of social desirability considerations, sensing that this is the pattern of responses for which the study aims. However, if responses were biased in this way, we would expect this same pattern of bias across all responses, but we found different patterns for different modes of representation, including a decrease in consumption of tables. Similarly, ratings may have been higher for graphs over other modes of representation, given that the survey included graph-interpretation questions. However, the graph interpretation questions appeared only after a sequence of Likert-scale questions concerning information behavior, which we believe reduces the risk of such bias. Finally, we did not have a way to obtain a measure of participants' graph interpretation skills prior to the COVID-19 outbreak, and therefore, cannot ascertain whether people improved their graph interpretation skills. Uncovering how patterns of everyday media use affect learning is an important goal for future research.

Conclusion

The main implications of our research are: (1) that lower graph interpretation ability does not necessarily imply low or no consumption of graphs as part of information behavior; and (2) that people can undergo change and growth as part of life experiences and as a function of the media landscape. However, existing knowledge and skills can affect propensity for change, and therefore we cannot simply rely on people's ability to learn what they need to learn as needs arise over the course of the life span. This study motivates future research into how we can understand and design informal learning in the community.

References

Alberda, A., Alamalhodaei, A., & Feigenbaum, A. (2020). COVID-19 Data Literacy is for Everyone. . Retrieved from Retrieved November 3, 2020, from Nightingale: The Journal of the Data Visualization Society website: https://medium.com/nightingale/covid-19-data-literacy-is-for-everyone-46120b58cec9

Allen, W. L. (2018). Visual brokerage: Communicating data and research through visualisation. *Public Understanding of Science, 27*(8), 906-922. doi:10.1177/0963662518756853

Assessment, T. (2013). International Association for the Evaluation of Educational Achievement (IEA). In.

Bao, H., Cao, B., Xiong, Y., & Tang, W. (2020). Digital Media's Role in the COVID-19 Pandemic. *JMIR mHealth uHealth, 8*(9), e20156. doi:10.2196/20156

Bhargava, R. (2019). Data Literacy. In R. Hobbs & P. Mihailidis (Eds.), *The International Encyclopedia of Media Literacy* (pp. 1-5). Hoboken, NJ: Wiley.

Bhargava, R., Deahl, E., Letouzé, E., Noonan, A., Sangokoya, D., & Shoup, N. (2015). *Beyond data literacy: reinventing community engagement and empowerment in the age of data*. Retrieved from Cambridge, MA:

Bodas, M., & Peleg, K. (2020). Self-Isolation Compliance In The COVID-19 Era Influenced By Compensation: Findings From A Recent Survey In Israel. *Health Affairs, 39*(6), 936-941. doi:10.1377/hlthaff.2020.00382

Bowe, E., Simmons, E., & Mattern, S. (2020). Learning from lines: Critical COVID data visualizations and the quarantine quotidian. Big Data & Society, 7(2), 2053951720939236. doi:10.1177/2053951720939236

Bragdon, D., Pandiscio, E., & Speer, N. (2019). University students' graph interpretation and comprehension abilities. *Investigations in Mathematics Learning, 11*(4), 275-290. doi:10.1080/19477503.2018.1480862

Byrne, C. A., O'Grady, M., Collier, R., & O'Hare, G. M. (2020). An Evaluation of Graphical Formats for the Summary of Activities of Daily Living (ADLs). *Healthcare, 8*(3), 194.

Cuan-Baltazar, J. Y., Muñoz-Perez, M. J., Robledo-Vega, C., Pérez-Zepeda, M. F., & Soto-Vega, E. (2020). Misinformation of COVID-19 on the Internet: Infodemiology Study. *JMIR Public Health Surveill, 6*(2), e18444. doi:10.2196/18444

Dowding, D., Merrill, J. A., Onorato, N., Barrón, Y., Rosati, R. J., & Russell, D. (2017). The impact of home care nurses' numeracy and graph literacy on comprehension of visual display information: implications for dashboard design. *Journal of the American Medical Informatics Association, 25*(2), 175-182. doi:10.1093/jamia/ocx042

Galesic, M., & Garcia-Retamero, R. (2010). Graph Literacy: A Cross-Cultural Comparison. *Medical Decision Making, 31*(3), 444-457. doi:10.1177/0272989X10373805

Gonzalez, L. S. (2018). *Aspects of a Literacy of Infographics: Results from an Empirical-Qualitative Study.* UC Santa Barbara,

Herrmann, M. R., Brumby, D. P., & Oreszczyn, T. (2016). *How much electricity do you use at home? An investigation into householders' literacy for comprehending domestic electricity data.* Paper presented at the Behave 2016: 4th European Conference on Behaviour and Energy Efficiency.

Highlights of the U.S. PIAAC Results. (2017). *Web Report (NCES 2020-777).* Retrieved from U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics: https://nces.ed.gov/surveys/piaac/current_results.asp.

Hoadley, C. (2018). A short history of the learning sciences. In *International Handbook of the Learning Sciences* (pp. 11-23).

Kennedy, B., & Hefferon, M. (2019). What Americans Know about Science: Science Knowledge Levels Remain Strongly Tied to Education; Republicans and Democrats Are about Equally Knowledgeable. *Pew Research Center.*

Kolodner, J. L. (2004). The learning sciences: Past, present, future. *Educational Technology, 44*(3), 34-40.

Lave, J. (1984). The values of quantification*. *The Sociological Review, 32*, 88-111. doi:10.1111/j.1467-954X.1984.tb00108.x

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. New York, NY: Cambridge University Press.

Maltese, A. V., Harsh, J. A., & Svetina, D. (2015). Data Visualization Literacy: Investigating Data Interpretation Along the Novice-Expert Continuum. *Journal of College Science Teaching, 45*(1), 84-90. Retrieved from www.jstor.org/stable/43631889

Nadelson, L., Jorcyk, C., Yang, D., Jarratt Smith, M., Matson, S., Cornell, K., & Husting, V. (2014). I Just Don't Trust Them: The Development and Validation of an Assessment Instrument to Measure Trust in Science and Scientists. *School Science and Mathematics, 114*(2), 76-86. doi:10.1111/ssm.12051

Nayak, J. G., Hartzler, A. L., Macleod, L. C., Izard, J. P., Dalkin, B. M., & Gore, J. L. (2016). Relevance of graph literacy in the development of patient-centered communication tools. *Patient Education and Counseling, 99*(3), 448-454. doi:https://doi.org/10.1016/j.pec.2015.09.009

Okan, Y., Galesic, M., & Garcia-Retamero, R. (2016). How People with Low and High Graph Literacy Process Health Graphs: Evidence from Eye-tracking. *Journal of Behavioral Decision Making, 29*(2-3), 271-294. doi:10.1002/bdm.1891

Pérez-Echeverría, M. d. P., Postigo, Y., & Marín, C. (2018). Understanding of graphs in social science undergraduate students: selection and interpretation of graphs. *Irish Educational Studies, 37*(1), 89-111. doi:10.1080/03323315.2018.1440248

Plohl, N., & Musil, B. (2020). Modeling compliance with COVID-19 prevention guidelines: the critical role of trust in science. *Psychology, Health & Medicine*, 1-12. doi:10.1080/13548506.2020.1772988

Roth, W. M., Bowen, G. M., & McGinn, M. K. (1999). Differences in graph-related practices between high school biology textbooks and scientific ecology journals. *Journal of Research in Science Teaching, 36*(9), 977-1019. Retrieved from <Go to ISI>://000083281500003

Saxe, G. B. (2015). Studying culture-cognition relations in collective practices of daily life: a research framework / El estudio de las relaciones cultura-cognición en las prácticas colectivas cotidianas: un modelo de investigación. *Journal for the Study of Education and Development, 38*(3), 473-508. doi:10.1080/02103702.2015.1054669

Sharit, J., Lisigurski, M., Andrade, A. D., Karanam, C., Nazi, K. M., Lewis, J. R., & Ruiz, J. G. (2014). The roles of health literacy, numeracy, and graph literacy on the usability of the VA's personal health record by veterans. *J. Usability Studies, 9*(4), 173–193.

Suad Nasir, N. i. (2000). 'Points ain't everything': Emergent goals and average and precent understandings in the play of basketball among African American students. *Anthropology and Education Quarterly, 31*(3), 283-305.

Wilkerson, M. H., & Polman, J. L. (2020). Situating Data Science: Exploring How Relationships to Data Shape Learning. *Journal of the Learning Sciences, 29*(1), 1-10. doi:10.1080/10508406.2019.1705664

Wise, A. F. (2020). Educating Data Scientists and Data Literate Citizens for a New Generation of Data. *Journal of the Learning Sciences, 29*(1), 165-181. doi:10.1080/10508406.2019.1705678

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Capturing Learners' Interactions with Multimedia Science Content Over Time during Game-based Learning

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Abstract: Learners demonstrate difficulties effectively deploying self-regulated learning (SRL) strategies while using game-based learning environments (GBLEs). Features designed to scaffold and support learners' SRL with GBLEs may limit autonomy and impact their performance. However, the effectiveness of limiting autonomy as individual learners engage in SRL over time (i.e., throughout a 90-minute learning session) has been largely unexplored. Therefore, this study examines how learners' prior knowledge and varying levels of autonomy (i.e., full versus partial) moderate the relationship between fixation durations over time on different information representations (i.e., books and research articles, conversations, posters) that are either considered relevant or irrelevant to the pre-test. Undergraduate students (N=82) learned with Crystal Island, a microbiology GBLE. Results identified interaction effects between (1) fixation durations and representations on learning gains and (2) text relevance, type of representation, and relative game time as well as a moderating effect of autonomy.
Keywords: Game-based Learning, Autonomy, Multimedia, Self-regulation, Eye Tracking

Autonomy and SRL during game-based learning

Game-based learning environments (GBLEs) incorporate tasks and game elements while allowing learners full autonomy (i.e., complete control over actions; Bandura, 2001) to enhance learning, motivation, and cognitive engagement (Plass, Homer, Mayer, & Kinzer, 2020; Taub, Sawyer, Smith, Rowe, Azevedo, & Lester, 2020). Because of the open-ended nature of GBLEs, learners must engage in self-regulated learning (SRL) to monitor and adapt their learning strategies to meet goals (Winne & Azevedo, in press). However, as learners typically lack the SRL skills needed to successfully interact with GBLEs (Josephsen, 2017), GBLEs embed scaffolds (e.g., guidance through restricted autonomy) to support learners' use of SRL processes and strategies (Josephsen, 2017).

GBLEs must balance the level of autonomy afforded to learners to simultaneously increase motivation through full autonomy and scaffold learning by restricting autonomy (Dever & Azevedo, 2019; Dever, Azevedo, Cloude, & Wiedbusch, 2020). For example, Crystal Island, a microbiology GBLE, limits autonomy by dictating the order in which learners interact with game elements (e.g., informational text) and forcing learners to engage with all information. However, regardless of the level of autonomy, learners must use SRL strategies to select relevant information from the text, organize the information into a mental model, and integrate their mental models with prior knowledge. As such, it is important to consider how limited autonomy moderates learners' interactions with GBLE elements by capturing process-oriented data as learners monitor and regulate learning processes. This study focuses on how learners' gaze fixations on different information representations (i.e., large paragraphs of text, conversations, posters) within Crystal Island contribute to learning gains, change over time, and are related to representation relevance, learners' autonomy, and prior knowledge.

Capturing SRL via eye-tracking methodology

Eye-tracking methodologies are utilized to capture learners' cognition and SRL strategy use (Azevedo, Taub, & Mudrick, 2018; Catrysse, Gijbels, Donche, De Maeyer, Lesterhuis, & Van den Bossche, 2018; Mayer, 2019). Fixation durations, which are defined as relatively still gaze for at least 250ms, and saccades are regularly used (see Cloude, Dever, Wiedbusch, & Azevedo, 2020) to quantify learners' underlying cognitive processes (e.g., reading; Bolzer, Strijbos, & Fischer, 2015; Catrysse et al., 2018l Cutumisu, Turgeon, Saiyera, Chuong, González Esparaza, MacDonald, & Kokhan, 2019). For example, time fixating on in-game texts indicates when learners are monitoring their understanding of text and capture the total time learners need to process information. These gaze behaviors further indicate learners' ability to accurately and efficiently apply SRL strategies. For example, learners fixating on irrelevant text for a long period of time may indicate the learner has not made an appropriate or efficient content evaluation (i.e., inaccurate metacognitive monitoring). Yet, accurately identifying relevant from irrelevant information is influenced by the multimedia material where accuracy increases when information is represented by multiple modalities (e.g., text and picture versus solely text; Azevedo & Dever, in press; Butcher, 2014; Mayer, 2019, in press). Within this paper, we use eye-tracking data to explore this relationship between information representations and SRL.

Previous research with Crystal Island

Recent studies in Crystal Island utilize eye-tracking data to understand learners' in-game behaviors, deployment of SRL processes, and learning gains (Syal & Nietfeld, 2020; Taub, Mudrick, Azevedo, Millar, Rowe, & Lester, 2017). Dever et al. (2020) compared log-file with eye-tracking data and examined how learners interact with relevant versus irrelevant text in Crystal Island. Their findings suggest that learners' eye-tracking data provides a better indication of how learners interact with information throughout a GBLE compared to log files. Cloude et al. (2020) found moderating relationships between fixations and information gathering actions within Crystal Island where learners with less prior knowledge had a positive relationship between interactions and fixation durations. Taub et al. (2017) used eye-tracking data to examine learners' use of SRL processes where results found that eye-tracking data was essential to capturing the quality of learners' processing through fixation durations. While these studies used eye-tracking data to provide evidence on learners' in-game behaviors and SRL processes associated with heightened knowledge acquisition, they do not address these relationships over time. This current study uses eye-tracking data to assess learning gains in relation to autonomy, prior knowledge, and text representations over time within Crystal Island to examine how these constructs influence learners' SRL strategies while interacting with multimedia materials in a GBLE.

Theoretical frameworks

To examine the relationship between learners' SRL processes, specifically content evaluation, and the cognitive processes required to select and comprehend multimedia material, both Mayer's (2019, in press) CTML and Winne's (2018) COPES models are used to ground this study. CTML is centered around three cognitive processes: (1) selecting relevant visual and auditory information; (2) organizing the selected visual and auditory information into mental models; and (3) integrating mental models together with prior knowledge to construct a cohesive representation of information (Mayer, 2019). These processes are assumed to be linearly structured, limited by learners' cognitive resources, and elicited by learners' active processing of multimedia.

COPES details learners' conditions, operations, evaluations, and standards as they engage in SRL throughout learning (Winne, 2018). Within this paper we examine the conditions, operations, and products that influence learners' interactions with different representations of information. Conditions refer to the types of resources and constraints that are available to a learner through internal (e.g., prior knowledge) or external/environmental (e.g., limited versus full autonomy) factors (Winne, 2018). Conditions can significantly influence learners' deployment of SRL strategies during learning. For example, Taub, Azevedo, Bouchet, and Khosravifar (2014) found that learners with high prior knowledge had a greater number of and duration on SRL strategies than learners with low prior knowledge. Operations are the internal cognitive processes that a learner continuously deploys while learning with a GBLE which, when combined with conditions, results in products, or the new understanding of the content based on information presented in the GBLE (i.e., learning gains).

Current study

Limited research has examined how learners' interactions with information representations change over time as a result of prior knowledge, autonomy, and learners' SRL abilities. The goal of this study is to add to this area by examining learners' fixation durations on relevant versus irrelevant types of representations over time and how learners' prior knowledge and autonomy throughout the environment are related to this interaction by examining three research questions. The first research question focuses on learners' products: To what extent does the proportion of time learners spend on different representations influence learning gains? Supported by CTML, we propose that the greater amount of time learners spent reading information from non-player character (NPC) dialog and posters relative to their total time in game and accounting for the type of representation will increase learning gains. The second research question focuses on learners' operations: How does relative game time, relevance of the text to the pre-test, type of representation, and their interactions account for the variation of fixation durations within and between learners? We propose that (1) the variation in fixation durations within and between learners will be increasingly accounted for as we add these variables within our model, and (2) as relative game time increases, fixation durations across all types of relevant representations will increase at a greater rate than fixation durations on all types of irrelevant representations. The third research question focuses on learners' conditions: How does autonomy and prior knowledge moderate the effects between relative game time, relevance of the text to the pre-test, type of representation, and learners' fixation duration? Supported by previous literature (Dever et al., 2020; Sawyer, Rowe, Azevedo, & Lester, 2018; Taub et al., 2014), we propose that learners with high prior knowledge and limited autonomy will have greater fixation durations on relevant representations over time than learners with lower prior knowledge and full autonomy.

Methods

Participants
Undergraduates (N = 139) from a large North American public university were randomly assigned to either the full, partial, or no agency conditions that varied in the autonomy afforded (see Crystal Island). Only 82 participants ($Range_{age}$: 18-26, M_{age} = 20.1, SD_{age} = 1.69; 68.3% female), split between full (n = 47) and partial (n = 35) agency conditions, were included in our analyses. Participants were removed if they had missing data and measurement errors in eye-tracking calibration (n = 25) or belonged to the no agency condition (n = 32).

Crystal Island: A GBLE for microbiology
Crystal Island, a GBLE set on a remote island, aims to cultivate learners' SRL and scientific reasoning skills by introducing microbiology content through a problem-solving scenario. Learners must identify an unknown disease infecting island residents by reading informational content (e.g., books, research articles, dialogue with NPCs, posters), completing concept matrices corresponding to informational content, filling out a diagnosis worksheet, and scanning food items. Agency conditions were embedded within Crystal Island. Full agency did not restrict participants' interactions with the environment, generalizable to the majority of GBLEs. Partial agency consisted of a predetermined path (i.e., "Golden Path") that restricted the participants' choice of actions to provide learners support and optimize their learning outcomes. No agency required learners to watch a playthrough of Crystal Island. Learners in this condition could not directly interact with any video (e.g., pause, rewind) or game features.

Experimental procedure
At the start of the experimental session, participants signed an informed consent and were calibrated to the eye tracker. Participants then completed a demographic questionnaire, a microbiology content knowledge pre-test, and several self-report measures. Following pre-task measures, participants started the learning session. As participants interacted with Crystal Island, eye-tracking data were collected. Once a correct diagnosis was identified and submitted, participants completed post-task measures including a microbiology post-test similar to the pre-test and self-reports. Participants were then thanked and compensated, receiving $10 an hour (up to $30).

Apparatus
Gaze behavior data were captured using an SMI RED250 eye tracker with 9-point calibration at a sampling rate of 250 samples per second (s). The SMI eye tracker captured fixation durations, saccades, and regressions on pre-identified areas of interest (AOIs) which are boundaries that contain the object on which the participants fixate.

Coding and scoring

Reading
Reading duration and instances were operationalized as learners' fixation duration (i.e., relatively stable eye movements for at least 250ms) on different types of representations using AOIs overlaid on top of each representation. Types of information representations refer to NPCs (informative text, uninformative visual), books and research articles (informative text, no visual), and posters (informative and uninformative text and visual). Books and research articles are combined as both representations contain large paragraphs of text.

Learning gains
Normalized change scores (Marx & Cummings, 2007) are used to identify learning gains, or the differences between pre- and post-test scores, while controlling for the prior knowledge of each participant.

Relevance of representations
Individual representations were evaluated for relevance to the pre-test where if a representation contained information addressed in the pre-test, the representation was classified as relevant (see Table 1). If the representation did not hold any information addressed in the pre-test, the representation was labeled as irrelevant. This classification is based on priming literature (see McNamara, 2005) assuming that participants will identify information as more instructionally relevant based off of the pre-test domain-related questions and is needed for the post-test.

Table 1: Relevance of representations

Representation	Total #	# Relevant Representations
Books & Research Articles	21	12
NPC Dialog	9	3
Posters	10	4

Relative game time

As each participant varied in their total game duration, relative game time was calculated by dividing the time in game participants fixated on content by the participants' total game duration, scaling instances from 0 to 1 so that all participants could be compared. This measure was found to first look at a continuous scaling of time to normalize all participants' time in game, which ranged from 39.7 to 135.8 minutes.

Model building and estimation

Our model examines how fixation duration, the outcome variable, was related to several observation- and individual-level variables (see Table 2). Several leveraging outliers ($N = 72$), i.e., data that falls approximately 1.5 interquartile ranges below or above the first and third quartile of data respectively, from the observations were removed from analyses. Fixation duration values were transformed through natural logs to normalize the data (skew and kurtosis < |2|) and reduce heteroscedasticity. As such, geometric means for fixation durations are interpreted within results. Two-level multilevel linear growth models analyzed our hierarchically structured data with observations (i.e., level one, $N = 4274$) nested within individual learners (i.e., level two, $N = 82$) where each learner had approximately 52 observations (Range: 25-75). Observation-level variables included relative game as a latent time variable with a random slope in all growth models. To interpret model intercepts, relative game time values were forced to zero to exemplify learners' first interactions with representations as learners cannot fixate on a representation when they first enter the game. Pre-test relevancy (irrelevant versus relevant) and type of representation (i.e., NPC, books and research articles, posters) were added as fixed effect observation-level variables. Individual-level variables included pre-test scores and conditions.

Table 2: Definitions of variables included in the models.

Level	Variable	Definition	Effects
Observation-Level (Level 1)	Relative Game Time	Proportion of time learners initiate an action.	Random
	Representation	Book or Research Article, NPC, Poster	Fixed
	Relevance	Representation contains information related to a question on the pre-test (1). Representation does not contain information related to a question on the pre-test (0).	Fixed
Individual-Level (Level 2)	Condition	Full Autonomy (1); Restricted Autonomy (0).	Fixed
	Prior Knowledge	Raw scores on the domain knowledge pre-test quiz.	Fixed

Five models were calculated using maximum likelihood estimation within R (R Core Team, 2019) utilizing packages 'lme4' (Bates, Maechler, Bolker, & Walker, 2015), 'jtools' (Long, 2020), and 'emmeans'

(Lenth, 2020) for model building and analysis. The unconditional means model was estimated first. Based on this model, the intraclass correlation coefficient was 0.05, suggesting that about 5% of the variation in fixation duration on representations within Crystal Island is between learners and about 95% is within learners. There was a statistically significant variation between learners (t(82.64) = 75.14, $p < .01$). Thus, it is reasonable to proceed with multilevel linear growth models. The next four models were built with: (1) an unconditional growth model; (2) level one predictors and their interactions; (3) predictors from (2) and level two predictors; and (4) predictors from (3) and cross-level interactions. Tests of model fit were calculated using maximum likelihood estimates.

Model 4: $Y_{ti} = \pi_{0i} + \pi_{1i}(RelativeGameTime) + \pi_{2i}(TypeofRepresentation) + \pi_{2i}(PretestRelevance)$
$+\pi_{3i}(RelativeGameTime^{*}TypeofRepresentation$
$+ \pi_{4i}(RelativeGameTime^{*}PretestRelevance)$
$+ \pi_{5i}(RelativeGameTime^{*}TypeofRepresentation^{*}PretestRelevance) + e_{ti}$

$\pi_0 = \beta_{00} + r_0$
$\pi_1 = \beta_{10}$
$\pi_2 = \beta_{20}$
$\pi_3 = \beta_{00} + \beta_{01}(Condition) + \beta_{02}(PriorKnowledge)$
$\pi_4 = \beta_{10}$
$\pi_5 = \beta_{20}$

Results

Research question 1: To what extent does the proportion of time learners spend on different representations influence learning gains?

A multiple linear regression was run and, while the overall model was not significant ($p > .05$), there was a significant interaction effect for proportion of time fixating on NPCs (t(485) = 8.99, $p < .05$) where as proportion of time on NPCs increased by one unit, normalized change scores increased by 0.48 points. As the proportion of time fixating on books and research articles increased by one unit, normalized change scores increased by approximately 1.28 points compared to the proportion of time fixating on NPCs (t(485) = 2.81, $p < .01$). Proportion of time on posters did not significantly relate to learning gains. In sum, the proportion of time spent on NPCs as well as books and research articles were positively related to normalized change scores.

Research question 2: How does relative game time, relevance of the text to the pretest, type of representation, and their interactions account for the variation of fixation durations within and between learners?

To answer this question, we utilize Models 1 and 2. Model 1, the unconditional growth model, includes time as a level-1 predictor of learners fixation duration. The average fixation duration at participants' initial interaction with text is approximately 31.19s (SE = 0.06) and decreases by approximately 67% (i.e., 20.81s; SE = 0.11) for every unit increase in relative game time. This model (BIC = 14379, D = 14329) is significantly better in terms of fit than the unconditional means model (BIC = 14582, D = 14557) wherein adding time, the model explains approximately 11% of individual-level variance in fixation duration ($\chi 2(3)$ = 227.41, $p < .01$). Model 2 (BIC = 12623, D = 12506) examined the extent to which level 1 variables contribute to variation in learners' fixation durations. This model is a significantly better fit than the unconditional growth model ($\chi 2(8)$ = 1822.8, $p < .01$). Holding all other variables constant, the average fixation duration is 104.58s (SE = 1.08, t(301.39) = 60.69, $p < .01$). There was a main effect for relative game time where, holding all variables constant, fixation durations decreased 89% (i.e., 93.08s) for every unit increase in relative game time (SE = 16.15; t(653.86) = -13.36, $p < .01$). There was a main effect where, when text was relevant, fixation durations were greater than those on irrelevant text by approximately 25.9% (i.e., 27.04s; SE = 1.96; t(4186.66) = 3.37, $p < .01$). There were significant differences between the type of representation and their effect on fixation durations. In comparison to book and research article observations and holding all other variables constant, fixation durations are lower on both NPCs and posters by approximately 85.6% (i.e., 89.55s; SE = 6.49; t(4200.02) = -26.8, $p < .01$) and 91.5% (i.e., 95.65s; SE = 9.01; t(4210.62) = -28.31, $p < .01$) respectively.

Holding all variables constant, there were significant two-way interactions between relative game time, NPCs (t(4211.68) = 11.85, $p < .01$), and posters (t(4209.54) = 8.86, $p < .01$) compared to book and research articles. Books and research articles (by 92.6% or 96.89s; SE = 14.45; see Figure 1) decreased at a greater rate over time than posters (by 44.4% or 46.43s; SE = 7.68). NPCs did not have a significant decrease in fixation durations over time. There was a significant interaction effect for pre-test relevancy and relative game time where fixation durations on relevant text were lower over time than fixation durations on irrelevant text by approximately

56.4% (i.e., 58.98s; SE = 11.63; $t(4182.43) = -4.65$, $p < .01$). When examining a three-way interaction and controlling for all observation-level variables, fixation durations on relevant posters (SE = 9.75; $t(4180.03) = 2.65$, $p < .05$) and NPCs (SE = 40.01; $t(4176.82) = 6.70$, $p < .01$) increased over time by 53.7% (i.e., 56.19s) and 206% (i.e., 215.94s) respectively compared to fixations on books and research articles. As relative game time increased, fixations decreased on relevant books and research articles by 95.1% (i.e., 99.50s; SE = 17.85) and posters by 54.3% (i.e., 56.83s; SE = 10.73). Over time, fixation durations decreased on irrelevant books and research articles by 88.9% (i.e., 92.95s; SE = 16.67) and posters by 32.3% (i.e., 33.78s; SE = 6.46).

In sum, fixation durations generally decreased at a greater rate over time for representations that were relevant to the pre-test than irrelevant. However, there were only significant interaction effects on fixation durations between books and research articles (regardless of relevancy to the pre-test) and posters relevant to the pre-test where fixation durations decreased over time.

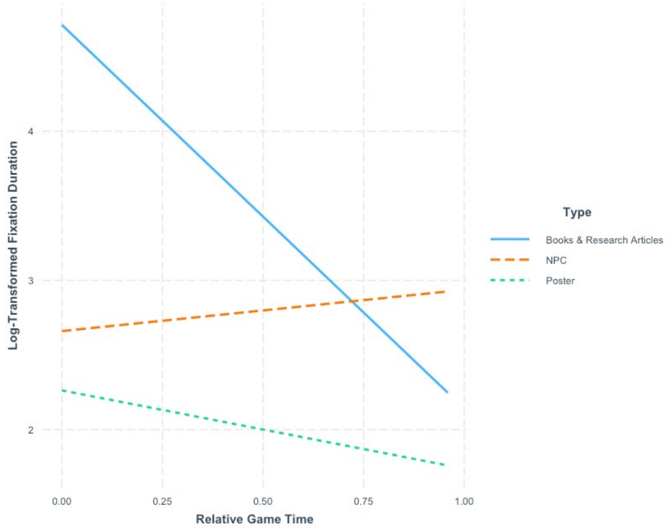

Figure 1. Interaction between relative game time, fixation durations, and type of representation.

Research question 3: How does autonomy and prior knowledge moderate the effects between relative game time, relevance of the text to the pre-test, type of representation, and learners' fixation duration?

Preliminary analysis on condition and learning gains using a t-test confirmed participants with partial agency ($M = 0.45$, $SD = 0.27$) had significantly greater learning gains than participants within the full agency condition ($M = 0.32$, $SD = 0.26$; $t(71.6) = 2.18$; $p < .05$). Because of this significant preliminary finding, Model 3 (BIC = 12640, $D = 12506$) added prior knowledge and condition as variables but these variables were not significant ($ps > .01$). Model 4 (BIC = 12608, $D = 12466$) examined the moderating effects of condition on the relationship between the type of representation and fixation duration. This model was a significantly better fit than Model 2 ($\chi 2(3) = 40.43$, $p < .01$), explaining approximately 44% of individual-level variance in fixation duration. Prior knowledge was initially included but removed due to non-significance. While there was no moderating effect ($ps > .01$) of condition on the relationship between NPCs and fixation durations over time, there was a three-way cross-level interaction effect where learners who were in the full agency condition had greater fixation durations on books and research articles over time compared to learners in the partial agency condition ($t(169.3) = 3.89$, $p < .01$). For every unit increase in relative game time, fixation durations on books and research articles increased by 97.4% (i.e., 101.84s; SE = 18.87) for learners with full autonomy than those with partial autonomy. For every unit increase in relative game time, fixation durations on posters decreased by 30.2% (i.e., 31.62s; SE = 5.86) for learners with full autonomy compared to those with partial autonomy. In sum, learners with more control during gameplay had increasingly greater fixation durations on books and research articles over time and lower fixation durations on posters compared to learners with restricted control, regardless of prior knowledge.

Discussion and future directions

The goal of this paper was to examine how learners' fixation durations on relevant and irrelevant types of representations changed over time and how prior knowledge and autonomy moderated this relationship. The first research question examined how learners' products were related to the proportion of time fixating on different types of representations. Results partially support our hypothesis where the proportion of time fixating on NPCs and books and research articles were positively related to learning gains, but there was no relationship between posters and learning gains. This is not in complete alignment with CTML (Mayer, 2019, in press) where NPCs have text, pictures, and audio, and posters have both text and pictures, but books and research articles only contain large blocks of text. Findings may be attributed to the breadth of knowledge contained within books and research articles where posters do not explain relationships between terms or constructs related to microbiology.

Results for the second research question did not confirm our hypothesis where, as relative game time increased, fixation durations tended to decrease. Interestingly, results showed an interaction between text and relevancy where fixation durations tended to decrease at a greater rate over time for posters and books and research articles that were relevant than texts that were irrelevant. This may be due to the presence of other instructional activities within Crystal Island such as completing concept matrices, filling out the worksheet, and scanning items (Azevedo et al., 2018). However, this result emphasizes learners' inability to consistently and accurately use SRL strategies, such as content evaluations, throughout the game (Taub et al., 2020).

The third research question examined how findings in research question two are affected by autonomy. Results did not support our hypothesis and contradicted prior works where learners with full autonomy had increasingly greater fixation durations on books and research articles over time and lower fixation durations on posters compared to learners with limited autonomy, regardless of prior knowledge (McCardle & Hadwin, 2015; Winne, 2018). Previous work has emphasized the relationship between autonomy and learning gains (Dever et al., 2020). Traditionally, limited autonomy is associated with greater learning gains (Dever & Azevedo, 2019; Dever et al., 2020; Sawyer et al., 2018). Between the first and third research question results, learners with full autonomy had greater fixation durations on books and research articles over time which is further associated with greater learning gains. When accounting for preliminary findings on autonomy and learning gains in the third research question, results from this study suggest that learners with full autonomy were not able to employ efficient or accurate SRL strategies while reading books and research articles whereas learners supported in their actions throughout gameplay had significantly less time interacting with information, but efficiently employed SRL strategies to achieve greater learning gains.

Findings from this current study partially validate the relationship between COPES and CTML where we find that learners' conditions and operations are directly related to their products, especially as we explore the role of different types of representations of information within GBLEs. This study serves as a baseline for future studies to further examine the relationship between COPES, autonomy, and information representations over time within GBLEs. Future studies should incorporate searching, monitoring, assembling, rehearsing, and translating processes into the COPES and CTML model over time within GBLEs to better understand how SRL strategies are used by learners over time (Azevedo & Dever, in press). From the results, we identify the need for adaptive GBLEs depending on learners' eye-tracking behaviors as they read information over time and between different types of representations, especially as we see mixed results compared to previous studies about the role of autonomy as a scaffold for acquiring information. Using adaptive GBLEs from learners' gaze behaviors has the potential to better support learners in navigating the environment, selecting relevant instructional text, and integrating this information to increase learning outcomes while supporting self-regulated learning.

References

Azevedo, R., & Dever, D. A. (in press). Multimedia learning and metacognitive strategies. In R. E. Mayer & L. Fiorella (Eds.) Cambridge handbook of multimedia learning (3rd ed.). Cambridge, MA: Cambridge University Press.

Azevedo, R., Taub, M., & Mudrick, N. V. (2018). Understanding and reasoning about real-time cognitive, affective, and metacognitive processes to foster self-regulation with advanced learning technologies. In D. H. Schunk & J. A. Greene (Eds.), Handbook on self- regulation of learning and performance (2nd ed.) (pp. 254-270). New York, NY: Routledge.

Bandura, A. (2001). Social cognitive theory: An agentic perspective. Annual Review of Psychology, 52, 1-26.

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting linear mixed-effects models using lme4. Journal of Statistical Software, 67, 1-48. doi:10.18637/jss.v067.i01.

Bolzer, M., Strijbos, J., & Fischer, F. (2015). Inferring mindful cognitive- processing of peer-feedback via eye-tracking: Role of feedback-characteristics, fixation-durations and transitions. Journal of Computer Assisted Learning, 31, 422–434.

Butcher, K. (2014). The multimedia principle. In R. E. Mayer (Ed.), The Cambridge handbook of multimedia learning (2nd ed., pp. 174-205). Cambridge, MA: Cambridge University Press.

Catrysse, L., Gijbels, D., Donche, V., De Maeyer, S., Lesterhuis, M., & Van den Bossche, P. (2018). How are learning strategies reflected in the eyes? Combining results from self-reports and eye-tracking. British Journal of Educational Psychology, 88, 118-137.

Cloude, E. B., Dever, D. A., Wiedbusch, M. D., & Azevedo, R. (2020). Quantifying scientific thinking using multichannel data with Crystal Island: Implications for individualized game-learning analytics. Frontiers in Education. doi: 10.3389/feduc.2020.572546
Computing, Vienna, Austria.
Cutumisu, M., Turgeon, K.-L., Saiyera, T., Chuong, S., González Esparza, L. M., MacDonald, R., & Kokhan, V. (2019). Eye tracking the feedback assigned to undergraduate students in a digital assessment game. Frontiers in Psychology. https://doi.org/10.3389/fpsyg.2019.01931
Dever, D. A., & Azevedo, R. (2019). Autonomy and types of informational text presentations in game-based learning environments. In S. Isotani, E. Millán, A. Ogan, P. Hastings, B. McLaren, & R. Luckin (Eds.), AIED'19: Proceedings of the 20th International Conference on Artificial Intelligence in Education (pp. 110-120). Amsterdam, The Netherlands: Springer.
Dever, D. A., Azevedo, R., Cloude, E. B., & Wiedbusch, M. (2020). The impact of autonomy and types of informational text presentations in game-based environments on learning: Converging multi-channel processes data and learning outcomes. International Journal of Artificial Intelligence in Education, 30, 581-615.
Josephsen, J. M. (2017). A qualitative analysis of metacognition in simulation. Journal of Nursing Education, 56, 675-678.
Lenth, R. (2020). Emmeans: Estimated marginal means, aka least-squares means. R package version 1.5.1.
Long, J. A. (2020). Jtools: Analysis and presentation of social scientific data. R package version 2.1.0.
Marx, J. D., & Cummings, K. (2007). Normalized change. American Journal of Physics, 75, 87-91.
Mayer, R. E. (2019). Computer games in education. Annual Review of Psychology, 70, 531-549.
Mayer, R. E. (Ed.) (in press). Cambridge handbook of multimedia learning (3rd ed.). Cambridge, MA: Cambridge University Press.
McCardle, L., & Hadwin, A. F. (2015). Using multiple, contextualized data sources to measure learners' perceptions of their self-regulated learning. Metacognition and Learning. doi:10.1007/s11409-014-9132.
McNamara, T. P. (2005). Semantic priming: Perspectives from memory and word recognition. New York, NY: Psychology Press.
Plass, Y. L., Homer, B. D., Mayer, R. E., & Kinzer, C. K. (2020). Theoretical foundations of game-based and playful learning. In J. L. Plass, R. E. Mayer, & B. D. Homer (Eds.), Handbook of game-based learning (pp. 3-24). Cambridge: The MIT Press.
R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical
Sawyer, R., Rowe, J., Azevedo, R., & Lester, J. (2018, July 15-18). Filtered time series analyses of student problem-solving behaviors in game-based learning [Paper presentation]. 11th International Conference on Educational Data Mining, Buffalo, NY, United States.
Syal, S., & Nietfeld, J. L. (2020). The impact of trace data and motivational self-reports in a game-based learning environment. Computers & Education, 157, 1-12. https://doi.org/10.1016/j.compedu.2020.103978
Taub, M., Azevedo, R., Bouchet, F., & Khosravifar, B. (2014). Can the use of cognitive and metacognitive self-regulated learning strategies be predicted by learners' levels of prior knowledge in hypermedia-learning environments? Computers in Human Behavior, 39, 356-367.
Taub, M., Mudrick, N. V., Azevedo, R., Millar, G. C., Rowe, J., & Lester, J. (2017). Using multi-channel data with multi-level modeling to assess in-game performance during gameplay with Crystal Island. Computers in Human Behavior, 76, 641–655. http://dx.doi.org/10.1016/j.chb.2017.01.038
Taub, M., Sawyer, R., Smith, A., Rowe, J., Azevedo, R., & Lester, J. (2020). The agency effect: The impact of student agency on learning, emotions, and problem-solving behaviors in a game-based learning environment. Computers & Education, 147. https://doi.org/10.1016/j.compedu.2019.103781
Winne, P. H. (2018). Theorizing and researching levels of processing in self-regulated learning. British Journal of Educational Psychology, 88, 9-20.
Winne, P. H., & Azevedo, R. (in press). Metacognition. In K. Sawyer (Ed.), Cambridge handbook of the learning sciences (3rd ed.) Cambridge, MA: Cambridge University Press.

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Students' Justifications for Epistemic Criteria for Good Scientific Models

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Abstract: Scientists use epistemic criteria to evaluate products of scientific inquiry, such as models. Engaging students with epistemic considerations as part of scientific practice is a growing focus of science education. Recent research has shown that students are able to identify and describe criteria for good scientific models. However, we know little about how students reason about and justify why specific criteria are important and which criteria are more important. In this study we explore these questions using data from interviews with 5th grade students. Interviews were conducted after a five-week model-based inquiry intervention and focused on students' reasoning about a set of criteria for good models developed by the class. Our findings illustrate the array of justifications provided regarding the importance of different criteria in their own right and relative to other criteria. We discuss implications for supporting students' use and evaluation of epistemic criteria in scientific practice.

Introduction

Recent reforms in the US have emphasized engagement with the practices of science and engineering as central to scientific literacy (NGSS Lead States, 2013). Competent engagement in practices involves both "doing" the practice and understanding what it means to do the practice (e.g., constructing models or explanations) (Barzilai & Chinn, 2018). Epistemic competence includes engaging in reliable cognitive processes to achieve epistemic aims that meet valued epistemic criteria (Barzilai & Chinn, 2018). These epistemic criteria are, "…the standards scientists use to evaluate the validity and accuracy of scientific products such as models, arguments, and evidence" (Pluta et al., 2011, p. 1). Examples of epistemic criteria for good scientific models or explanations include: models or explanations should fit the evidence, be conceptually coherent, fit with other established theories, and be parsimonious (Kuhn, 1977; Longino, 2002). These criteria become the guidelines for how to create, refine, and evaluate models. For example, models that fit with evidence have greater validity than models that are unsupported. Scientific communities have developed epistemic criteria that are shared and justified in terms of why they are important. Scientists may prioritize some criteria over others in pursuit of an aim. For example, a model's fit with evidence may be viewed as more critical than how parsimonious it is. Prioritization of epistemic criteria changes over time and may vary by discipline or even area of research. In general, however, criteria use is a core aspect of scientific practice across disciplines (Longino, 2002).

In this study we focus specifically on the practice of scientific modeling and the use of epistemic criteria to evaluate models. Giere (2004) defined models as, "…idealizations that scientists use to represent aspects of the world for specified purposes" (p. 742). Examples include the Copernican and Ptolemaic models of the solar system and Bohr's plum-pudding model of atoms (Frigg et al., 2020). Models are useful because they enable scientists to explain and predict natural phenomena. The process of building, testing, and refining models occurs within a community of practice in which scientists critique each other's ideas. Oreskes (2019) argued that through community argumentation, justification, and critique scientists can revise and build better epistemic products. As noted above, a key piece of the social construction of knowledge is deploying the criteria developed and accepted by the scientific community to critique and evaluate the epistemic products created by its members.

Given the centrality of epistemic criteria in scientific practice, we have argued that it is important to engage students in the development and use of epistemic criteria in science learning (Pluta et al., 2011). Developing, using, and justifying epistemic criteria provides two core benefits. First, it helps students develop a better understanding of scientific knowledge production and how scientists evaluate epistemic products (models, arguments, evidence) and decide between competing claims/models. Such understandings are crucial for a scientific literacy that espouses an informed trust in science. Second, similarly to how they function in the scientific community, epistemic criteria can be used by communities of learners to evaluate their own epistemic products. In this sense criteria can function as scaffolds to guide the production and evaluation of models. Given these arguments for the benefit of epistemic criteria use, the obvious question is whether students are able to productively engage with the development and use of such criteria.

Research suggests that students can do this. Pluta et al., (2011) found that seventh graders were able to generate a wide variety of epistemic criteria for good models and that the criteria align with those proposed by scientists. Av-Shalom et al., (2018) found that seventh graders grew in their ability to recognize and use fit with evidence as an epistemic criterion, which is a central criterion in modeling. However, research that investigates younger students' epistemic considerations when evaluating claims and evidence is sparse (Sandoval et al., 2014), and much of the current research has focused on students' description and use of shared criteria (e.g., Ryu & Sandoval, 2012). We know little about how students justify why these criteria matter, which criteria matter in different situations, and whether some matter more than others. When students talk about such justifications of criteria, they are engaged in *meta-epistemic discourse*, which involves explicit discussions about these criteria and the reasons why they matter (Chinn et al., 2020). Our study therefore focused on the kinds of justifications students provided for why specific criteria are important, and how multiple criteria relate to each other and are prioritized as a set (i.e., ordering within the set). Our research questions were as follows:

1. What criteria do fifth grade students develop for model quality?
2. How do students prioritize criteria?
3. What justifications do students give for why individual criteria are important?
4. What justifications do students provide for reasoning about criteria sets and order within a set?

Method

Context and participants

The study was conducted in a fifth-grade classroom during a five-week model-based inquiry unit with 50 students. During the unit, students reviewed evidence in the form of reports and simulations to develop a model that explained why fish were dying in a local pond (a eutrophication phenomenon). Students made models in a new modeling software called MEME (Model and Evidence Mapping Environment) that enabled them to create components and link them with arrows (mechanisms) to provide a causal account. Students could link evidence (the reports and simulations) to the various elements of the model.

The unit began with an activity in which students developed a shared class list of criteria for good models. To develop the class criteria list, students reviewed a series of model pairs, determining which model in each pair they believed to be the better model and why. Based on these evaluations, students individually made a list of the most important criteria for good models and ranked the order of importance. Through a class discussion the teachers drew on students' suggestions for criteria to develop a class list of five shared and agreed-upon criteria for good models. The class criteria list was revised once throughout the unit. Thus, students had opportunities to use the criteria as they developed and revised their models as well as when they critiqued peer models.

The unit was taught in a public charter school in the Northeast of the United States. The school performs above average on standardized state tests on Mathematics, Language Arts and Science. The demographics of the school were 60% White, 22% Asian, 9% African American, 7% Latinx, and 2% other; 5% of students were eligible for free and reduced lunch.

Data collection and analysis

The data for this study are from interviews that were conucted at the end of the intervention. Sixteen students were interviewed in dyads. The interview consisted of a series of questions to assess students' conceptions of criteria for good models, including criteria importance, order, and justifications. In the interview, students were briefly shown their class's final criteria list and then were given the individual criteria and asked to order the criteria from most to least important. As students were ordering the criteria list, they had the option to add any additional criteria they felt were not covered by the class list. Students were then asked to provide justifications by explaining why they chose the order that they did, beginning from the most important and working their way down to the least important. They were also asked if any criterion was way less or way more important than the others or if they were all similar in importance.

The interviews were videotaped, audio recorded, and later transcribed. The transcripts were then reviewed to identify instances in which students provided reasons about why criteria are important, or why one criterion was more important than another. Through constant comparison (Glaser, 1965), these statements were categorized based on the kinds of justifications they presented. We discuss these categories in the next section.

Results

Research Question 1: What criteria do fifth grade students develop for model quality?

As noted above, students generated a criteria list early in the intervention and then revised it later. The final list is shown in Figure 1.

1. Be organized, clear, and explain what is happening
2. Include relevant evidence
3. Include evidence to support both components and mechanisms
4. Include thorough explanations of the evidence (should completely explain what the evidence shows or why it is relevant
5. Not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)

Fig 1. Class Criteria List

It is important to note that while there are five criteria in the final list, some of them include multiple ideas that arguably could have been separated into separate criterion. For example, the criteria "*be organized, clear, and explain what is happening"* includes three separate ideas or propositions: be organized, be clear, and explain what is happening. This proved to be important for our analyses because during the interviews students sometimes referred to one, two, or all of the propositions within a criterion, and dyads differed in how they treated criteria in this sense. For example, some dyads referred to particular criteria as a whole (e.g., "*be organized, clear and explain what is happening"* treated as a single criterion), whereas other dyads referred to only one proposition within the criterion (e.g., "*be organized* or *explain what is happening"*). There was also redundancy, as some ideas appeared in multiple criteria. For example, the notion of evidence appeared, in some form, in four out of the five criteria: evidence needs to be relevant (2), it needs to support both components and mechanisms (3), it should be thoroughly explained (4), and there should not be extra evidence (5).

In a prior study of individual seventh graders' development of lists of criteria, Pluta et al., (2011) classified students' criteria into five broad categories: (a) criteria that articulated the goals of models, such as explanation; (b) criteria related to evidence fit, such as quality and quantity of support; (c) criteria that specified constituent parts that needed to be present, such as diagrams; (d) criteria related to communicating the model clearly, such as being clear and organized; and (e) criteria related to other epistemic features such as accuracy. The criteria in the 5th grade class list in this study fall into four of the five categories: (a) goals of models (explain what is happening); (b) evidential criteria (include evidence to support both components and mechanisms); (c) criteria that specified constituent parts that needed to be present (not have extra or irrelevant components, mechanisms, or evidence); and (d) communicative elements (be organized and clear). There were no criteria related to the fifth category, epistemic features, from Pluta et al., (2011).

Research Question 2: How do students prioritize criteria?

In the interviews, students were asked to prioritize criteria from most to least important. Table 1 shows the class criteria list and how many dyads placed each criterion in the first to fifth location on the list. In our analysis, the placement of criteria was given a point value: A criterion in first place was awarded five points, a criterion in second place was awarded four points, and so on. These points were added to yield a "total points" score (shown in the final column) to give a sense of overall criteria prioritization among the dyads.

Table 1: Ranking of criteria and corresponding point value

Criteria	**1st**	**2nd**	**3rd**	**4th**	**5th**	**Total Points**
Include evidence to support both components and mechanisms	3	2	2	1	0	**31**
Be organized, clear, and explain what is happening	3	1	2	2	0	**29**
Include thorough explanations of the evidence (should completely explain what the evidence shows or why it is relevant)	1	2	2	1	2	**23**
Include relevant evidence	0	3	2	0	3	**21**
Not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)	1	0	0	3	4	**15**

Criteria prioritization reveals a few general trends. The criteria "*be organized, clear and explain what is happening*" and "*include evidence to support both components and mechanisms*" were ranked the highest. The criterion "*not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)*" was ranked lowest. The criterion "*include thorough explanations of the evidence (should completely explain what the evidence shows or why it is relevant)*" and "*include relevant evidence*" varied in placement across dyads with the largest spread throughout. However, these trends were weak as there was variation in placement across dyads. More information is given in the next section about why this variation may have occurred, as we analyze the justifications students gave for why each criterion was important.

Research Question 3: What justifications do students give for why individual criteria are important?

Students gave a variety of reasons for why each criterion was important. Table 2 shows the class criteria and the justifications students gave for why each criterion is important. The frequency counts are given after each justification type. For example, three dyads said that the first criterion ("*include evidence to support both components and mechanisms*") is important because it makes the model believable. The frequency counts vary because in some cases students gave only one reason in support of a criterion, whereas in other cases they gave several reasons (this varied across criteria and dyads). Also, sometimes one student spoke for the dyad, whereas at other times both students spoke and either gave different justifications or elaborated upon each other's ideas. Elaborations of the same justification by both students within a dyad were counted as one instance. Elaborations that focused on a different aspect of a criterion or a different justification were counted as two separate responses. This resulted in an unequal number of justifications per criterion.

Table 2: Justifications for why individual criteria are important

Criteria	Justification Types (Frequency counts)
Include evidence to support both components and mechanisms	• Evidence makes the model believable, true or correct (3) • Evidence shows why something is happening, or it shows the thinking behind the model (2) • Evidence should support all components and mechanisms; all parts of the model (2)
Be organized, clear, and explain what is happening	• When a model is clear and organized it is understandable or readable (5) • The model will show what it's supposed to show (1) • People will be able to think how you think (1)
Include relevant evidence	• Relevant evidence means the parts of the model, idea and purpose are understandable (2) • Relevant evidence explains the model (1) • Without relevant evidence, no one will believe you (1)
Include thorough explanations of the evidence (should completely explain what the evidence shows or why it is relevant)	• Explaining the evidence is needed so people know what the model is showing, the main idea, why something happens (4) • Explanations show how the evidence supports the model (3) • Without explanations and evidence there is no model (1) • Evidence makes the model true- evidence proves the point (1)
Not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)	• Have to have real information (1) • Focus on what we need first; not having everything you need is worse than having everything you need plus extras (1) • Extra/irrelevant pieces aren't good- makes the model unfocused and off topic (1)

The reasons students gave for the importance of each criteria were varied. Due to space constraints, the justifications for two criteria will be more fully discussed here. The first criterion ("*include evidence to support both components and mechanisms*") was selected because it was the highest ranked and because evidence fit is a centrally important epistemic consideration. Students valued evidence because they viewed it as making the model accurate. Students referred to accuracy through the terms, "believable," "true," or "correct." Students also valued evidence because they viewed it as showing why something is happening. This implies that students understood the role of evidence in making the model valid, accurate, and complete. Finally, students specified that evidence must support all parts of the model, not only one piece. This shows that students understood that models are not a unitary entity but have constituents that all need to be supported individually. Their justifications for this criterion show that students valued fit with evidence in general because it confers accuracy and validity, as well as in more nuanced ways—in terms of the need to specifically support each and every part of the model.

We discuss the second criterion ("*be organized, clear, and explain what is happening"*) because out of all the justification types, the idea of understandability was stated most frequently and was applied to justify this criterion. Five dyads explained that this criterion was important because a model that was clear and organized would be understandable. Students also said that this criterion was important because if a model is clear and organized, then it will achieve its purpose (show what it is supposed to show), and the audience will be able to follow your reasoning (think how you think). This shows an awareness of the communicative role of model representations and the importance of clearly representing one's ideas. These justifications also point to students' understanding that models have an epistemic purpose or aim that they need to achieve.

We wish to note that students cited understandability as a justification for four out of five criteria, which shows it was not only a popular justification for the criterion "*be organized, clear and explain what is happening"*; it was a popular justification for criteria in general. Students said that models that are organized and clear, include relevant evidence, show how evidence supports the model, and have fewer (and only needed) parts, will be understandable. Although the justification of understandability was given for different reasons, the frequency of this justification type shows that students privileged understandability as an important justification for criteria for good models but also used this justification in different ways (i.e., had different notions of what understanbilty means in relation to models).

Another interesting pattern was the variation in justifications students gave for why evidence is important. (These justifications spanned the four criteria that mentioned evidence.) Out of the 29 total justifications given, 20 pertained to evidence. Some dyads argued that evidence is important because it makes the model accurate (i.e., evidence makes the model true, correct, or believable). This supports the previous point that students are relating evidentiary support to model accuracy. Some dyads related evidence to understandability claiming that relevant evidence means that parts of the model (i.e., components and mechanisms) are understandable, whereas other dyads reasoned that relevant evidence makes the idea or purpose of the model understandable. Finally, some dyads thought that without evidence and explanations, there would be no model. These results show that students understood the importance of evidence in multiple distinct ways.

Research Question 4: What justifications do students provide for reasoning about criteria sets and order within a set?

Students also reasoned about criteria as a set and the order within the set. Students discussed criteria as a set by giving reasons for why certain criteria were more important than others by discussing criteria in relation to each other. This section extends the prior results by focusing on connections across and between criteria.

Table 2: Justifications about criteria sets and order within a set

Justification	**Example**
Encompass other criteria. A criterion is more important because it encompasses others.	This is first because it includes all the other criteria mixed into one.
Specificity. A criterion is more important because it is more specific.	These two are about the same but this one [irrelevant pieces] is more specific...
Essential to the model. A criterion is more important because it is essential to even having a model.	Without explanations and evidence there is no model.
Redundancy. A criterion is less important than others because it is redundant.	One is opposite of the other so they're kind of saying the same thing.
Already known. A criterion is less important because it is already known.	We put this one last because this is something you already know.

The first justification, encompass other criteria, was used to explain why one criterion was more important because it encompassed others. This is shown in the following excerpt from a transcript of Ivy and Arya explaining why they chose their first criterion "*be organized, clear, and explain what's happening*". Note that throughout this section, the descriptions in brackets clarify what the speaker was referring to:

Ivy: Umm, so we chose the order because like, because like you first want to make sure it's organized and clear 'cause like... if you... if that was like the last thing you would do, then um... you would like... then it wouldn't be that clear because then maybe like organizing clearly first is like the uh the hard thing to do, so you want to get it done first. Yeah.

Arya: To add on to what she said, if you have a model that's really messy, if somebody's trying to get a conclusion out of it, they're not going to be able to understand what's happening because they're going to get confused, and it's like more important for people to understand your model and for you to explain it thoroughly as if they don't know like what's happening.

Ivy: Yeah, and like these [all criteria apart from the first one] would just be extra checking, organized and clear.

Ivy and Arya explained that the first criterion ("*be organized, clear, and explain what's happening"*) is the most important because the model needs to be understandable. If the model is messy it will be confusing, and the reader will not understand what is happening. Therefore, the dyad concluded, all other criteria are basically encompassed by (or subordinate to) this first criterion.

Other dyads referred to the idea of some criteria being encompassed by others, but in a slightly different way, by claiming that one criterion was entailed by another. For example, Geona and Deborah argued that the fifth criterion ("*not have extra or irrelevant components, mechanisms, or evidence [all should help answer the question]"*) implies that relevant components and evidence are included and therefore entails the third criterion ("*include relevant evidence"*).

Deborah: It ["*not have extra or irrelevant components, mechanisms, or evidence (all help answer the question*)"] included already like relevant evidence.

Geona: Yeah like "*extra and irrelevant components*" it shouldn't have that so that means it should include relevant evidence.

The second justification privileged specificity; that is, more specific criteria are better. This rationale was given by John and Miguel for why the criterion "*not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)"* was ranked higher than the criterion "*include relevant evidence."*

John: "*Not have extra or irrelevant components, mechanisms, or evidence."* I still think it's the same as this "*include relevant evidence"*. It's just saying don't have extra irrelevant evidence so it's basically the same. Don't have uh, have relevant evidence and then mechanism and components, that's a little more detailed than this one so we put this one ahead.

John and Miguel reasoned that these two criteria are basically the same, but the prior criterion was more specific and detailed and was therefore ranked higher.

The third justification type was that some criteria are important because what they specify is essential to models and modeling. This was shown in the justifications given by two dyads. The first dyad, Geona and Deborah, stated that the criterion "*include thorough explanations of the evidence (should completely explain what the evidence shows or why it is relevant)"* was the most important because if a model doesn't have explanations and evidence, then there is no model:

Deborah: Umm because here the most important thing for a model is that it shows ummm it needs to show explanations cause without like explanations and evidence there's basically no model.

The students perceived explanations and evidence as being so integral to the model that it is not possible for a model to exist without them.

Another dyad, Patrick and Grant, explained that the criterion "*be organized, clear, and explain what is happening"* is the most important because if it is not organized the audience will not be able to read and understand it, rendering it pointless:

Patrick: Because organize, clear, and explain what is happening is the most important because if it's not organized then other people won't be able to read it so basically there's no point in doing it if it's not organized or clear.

This implies that clearly communicating ideas through the model is of paramount importance. If the audience are not able to read the model, the ideas within it will not be communicated or understood, therefore the purpose for making the model has not been attained.

The fourth justification type ranked some criteria lower because they were deemed redundant. By redundant, we mean that other criteria were more important and covered the most important standards for good models. Therefore, the criteria that are classified as redundant are a part of the set, but they are not as significant as others. For example, Laila and Olympia explained that the criterion "*include relevant evidence*" is the least important because a lot of the other criteria already show that evidence is important:

Laila:	Umm... we put this one last because we already have a lot of these that show that evidence is really important to have in a model and that it needs to answer the question so that it makes sense. So, including relevant evidence is sort of just like… including relevant evidence means that you need to include good and pretty good evidence, but I think these are more important because you need to have mechanisms and components and umm... you need to make sure your evidence connects with the question and you have to be organized and clear and explain what's happening.

Laila explained why the criterion "*include relevant evidence*" is the least important and showed why she placed other criteria higher. In her explanation, she explicitly listed all other criteria and says they were more important because models need to have components and mechanisms, make sure evidence connects to the question, be organized and clear, and explain what is happening. Laila felt that this criterion is least important because it has already been said in these other, more important criteria.

The fifth and last justification category ranked some criteria as specifying aspects of models students already knew and therefore the criterion was deemed less important. For example, the dyad James and Ethan said that the criterion "*not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)*" was least important because they already knew not to do this:

James:	And this one is pretty much commonsense.
Ethan:	Yeah.
James:	If something doesn't go with your model, then-
Ethan:	Don't put it there.
James:	Yeah, don't put it there.

James and Ethan reasoned that the criterion "*not have extra or irrelevant components, mechanisms, or evidence (all should help answer the question)*" is "commonsense" and "something you already know." As a result, the criterion was given less priority and was placed at the bottom of the list.

Discussion

Epistemic criteria are central elements of scientific practices, including the practice of modeling. Scientists evaluate models in accordance with epistemic criteria, such as fit with evidence and explanatory power. If we are to engage students similarly with epistemic criteria that they develop and are accountable to in the context of a learning community, we need to better understand how students understand these criteria, their importance, and their relative priority in relation to other criteria. Towards that end, we analyzed fifth grade students' justifications of why specific criteria are important and their reasons for rank ordering them. Our analyses show that students were able to develop a class criteria list to guide model creation and revision. Students were also able to evaluate criteria by prioritizing and reasonably justifying why criteria were important. Further, students were able to provide reasonable justifications about criteria as a set and criteria in relation to each other. Some of these justifications included important aspects of criteria lists, such as specificity, redundancy, essential elements, and being encompassed and entailed by others.

Our findings extend previous research, which showed that seventh graders could develop appropriate epistemic criteria for model goodness, by demonstrating that younger students share this competence, and further, that they can prioritize criteria. More significantly, our findings demonstrate that fifth graders have meta-epistemic competence. By this we mean that they are able to reason about and justify epistemic criteria for scientific models. First, students are able to describe the criteria of good scientific models. This is valuable because it means that students are aware of their thinking and are able to articulate ideas about epistemic criteria. This may seem trivial, but such discussions are rare in classrooms, and it is not simple to articulate meta-reasons for complex epistemic considerations (Chinn et al., 2020). Second, students are able to engage in a more sophisticated level of meta-epistemic discourse by evaluating criteria of good scientific models. This was shown by the students' justifications, which reveal that students understand why criteria are valuable. This is a novel finding.

Meta-epistemic competence is an important aspect of scientific practice, and we have demonstrated that elementary school students, as young as fifth graders, exhibit this competence. This is an impressive capacity that instruction can build on. Not only can students describe very reasonable criteria; they can also articulate why their criteria are important in ways that are sensible and compelling. Instruction can attend to these student competencies by engaging students in developing and applying criteria lists to models, and engaging students in meta-epistemic discussions of why these criteria matter, to whom, and under what conditions. In some cases, people differ in the criteria they value and this can lead to deep epistemic disagreement (Chinn et al., 2020). Resolving such disagreement entails reflecting on the criteria the different parties espouse and why. Discussions of this sort, about the relative merits of different criteria, are important yet rare in schools. If we want students to build competence in noticing differences in criteria use, and in arguing about their utility and value, we need to engage them in these kinds of discussions early and often. Our study has shown that even fifth grade students are capable, at least to some extent, of justifying criteria and reasoning about their relative merits.

References

Abd-El-Khalick, F., Bell, R. L., & Lederman, N. G. (1998). The nature of science and instructional practice: Making the unnatural natural. *Science Education*, *82*(4), 417-436.

Av-Shalom, N. A. Y., El-Moslimany, H., Duncan, R. G., & Chinn, C. A., (2018). Changes in students' use of epistemic criteria in model evaluation. In J. Kay & R. Luckin (Eds.), *Rethinking learning in the digital age: Making the learning sciences count, 13th International Conference of the Learning Sciences (ICLS) 2018 Volume 2* (pp. 768-775). International Society of the Learning Sciences.

Barzilai, S., & Zohar, A. (2016). Epistemic (meta) cognition: Ways of thinking about knowledge and knowing. In J. A. Greene, W. A. Sandoval, & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 409-424). Routledge.

Chinn, C. A., Barzilai, S., & Duncan, R. G. (2020). Disagreeing about how to know: The instructional value of explorations into knowing. *Educational Psychologist*, *55*(3), 167-180.

Frigg, R., & Hartmann, S. (2020). *Models in science. The Stanford encyclopedia of philosophy*. https://plato.stanford.edu/entries/models-science/

Giere, R. N. (2004). How models are used to represent reality. *Philosophy of Science, 71*, 742–752.

Glaser, B. G. (1965). The constant comparative method of qualitative analysis. *Social Problems*, *12*(4), 436-445.

Kuhn, T. S. (1977). *The essential tension: Selected studies in scientific tradition and change*. University of Chicago Press.

Laugksch, R. C. (2000). Scientific literacy: A conceptual overview. *Science Education*, *84*(1), 71-94.

Longino, H. E. (2002). *The fate of knowledge*. Princeton University Press.

Oreskes, N. (2019). *Why trust science?*. Princeton University Press.

Pluta, W. J., Chinn, C. A., Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching, 48(5), 486-511.*

NGSS Lead States. (2013). *Read the Standards. Next Generation Science Standards: For States, By States.* https://www.nextgenscience.org/search-standards

Ryu, S., & Sandoval, W. A. (2012). Improvements to elementary children's epistemic understanding from sustained argumentation. *Science Education*, *96*(3), 488-526.

Sandoval, W. A., Sodian, B., Koerber, S., & Wong, J. (2014) Developing children's early competencies to engage with science, *Educational Psychologist, 49* (2), 139-152.

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Are Community Relevant PBL Supports enough to Promote Epistemic Agency? Exploring Variation in Epistemic Pedagogical Practices in Science Classrooms

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Abstract: Promoting epistemic agency using problem-based learning (PBL) in science curricula allows students to co-construct scientific knowledge and practices. However, researchers have revealed that teachers struggle to distribute epistemic authority inside classrooms. We use exploratory case studies of two biology teachers' adaptation of PBL units to explore the variation in pedagogical practices that influenced students' epistemic positioning. We analyzed classroom observation notes, teachers' interviews, and teachers' daily reflection notes to identify different instructional approaches. The findings suggest that teachers perceive the opportunities to activate epistemic agency within the same PBL curricula differently. Their pedagogical choices to leverage these opportunities depend on teachers' perception of the more important learning objectives and the structural limitations and affordances provided by the context of the classroom.

Introduction

There is growing interest to promote epistemic agency in science education (Haverly, Calabrese Barton, Schwarz, & Braaten, 2020; Miller, Manz, Russ, Stroupe, & Berland, 2018; Stroupe, Caballero, & White, 2018). Epistemic agency is the ability for students to engage as co-constructors of knowledge in science classrooms (Miller et al., 2018). When engaging as epistemic agents, students display ownership of the knowledge-building process and share the cognitive authority of directing science inquiry with teachers within classrooms (Hardy et al., 2018; Miller et al., 2018; Stroupe et al., 2018). Classrooms that engage students as epistemic agents, empower students to shape the knowledge production practices (Stroupe et al., 2018), thereby, transitioning students from "receiver of facts" to "doers of science" (Miller et al., 2018). Pedagogical practices that engage students as epistemic agents allow students to co-construct science storylines with their teachers and disrupt hierarchies of power in science education (Calabrese Barton & Tan, 2009; Hand, 2012; Rosebery, Warren & Tucker-Raymond, 2015). Epistemic positioning of students also propels a shift in instructional practices from those that engage students in mimicking "correct" canonical science information to adopting strategies that empower students to develop their own ideas (Hardy et al., 2018; Miller et al., 2018; Stroupe et al., 2018). This helps fulfill the larger need of engaging students in disciplinary practices as advocated by the Next Generation Science Standards (NGSS) (NRC, 2012).

However, despite the known advantages of student's epistemic positioning in science classrooms, current classroom practices and learning experiences often fail to promote epistemic agency (Miller et al., 2018; Brown, 2017). Most schools, especially within formal environments, struggle to engage students as epistemic agents (Eriksson & Lindberg, 2016). Supporting student's epistemic agency within science classrooms is a challenge for teachers because of the tensions that arise from maintaining authoritative control over the content while attempting to create authentic opportunities for students to engage with and construct knowledge that is meaningful to them (Braaten & Sheth, 2017; Windschitl, 2002). Teaching science using epistemic teaching practices disrupts traditional power structures within a class (Bang, Brown, Calabrese Barton, Rosebery, & Warren, 2017; Haverly et al., 2020). This kind of teaching requires different pedagogical strategies, to leverage students' ideas for an active knowledge production process within classrooms (Brown, 2017; Miller et al., 2018; Schwartz et al., 2018).

A few potential paths have been suggested to modify teacher instruction for students to act with epistemic agency in science classrooms (Stroupe et al., 2018). One of these paths include teachers adapting science curricula to intentionally allow their students more say over how the community engages in knowledge construction work using problem-based learning (PBL) (Miller et al., 2018; Stroup et al., 2018). PBL provides one avenue for repositioning learners as epistemic agents as it allows for collective responsibility of knowledge building through sharing of students' individual science stories (Stroupe et al., 2018; van Es, Hand, & Mercrado, 2017). It also provides multiple opportunities to shift the epistemic authority from the teacher, wherein power and authority traditionally lie, to the students (Miller et al., 2018; Stroupe, 2014). However, early studies have shown that teachers tend to identify these opportunities differently (Haverly et al., 2020). They often struggle with interpreting and leveraging pedagogical opportunities to engage students as epistemic agents (Barnhart & van Es, 2015; Jacobs, Lamb, & Philipp, 2010). Hence, there is a need to understand how teachers vary in interpreting pedagogical opportunities to position students as epistemic agents within the design of the PBL units (Haverly et al., 2020; Stroupe et al., 2018). Furthermore, there is a need to explore the factors that influence these decisions (Stroupe et al., 2018) in adapting PBL supports to formal science classrooms. To design professional development (PD) supports that scaffold teacher's epistemic instructional practices, we need to understand how teachers vary in their degree of engaging students as epistemic agents within the implementation of PBL units (Miller et al., 2018; Stroupe et al., 2018). In this paper, we explore how two science teachers improvise PBL units on the topic of bioinformatics that had students explore a problem relevant to their community, collect and analyze data from their neighborhood to make inferences about the topic, and propose interventions. We look closely at select movements where the teachers differed in providing opportunities for students to engage as epistemic agents. In this paper, we ask the following research questions: 1) How do teachers' pedagogical practices vary in engaging students as epistemic agents during the implementation of the PBL unit? and 2) What factors influence these decisions?

Conceptual framework

Over the years, researchers have found that students engage with epistemic agency when they contribute to the knowledge-building process while engaging in science practices such as argumentation and experimentation as opposed to replicating the practices modeled by the teacher (Haverly et al., 2020; Zimmerman & Weible, 2018). Also, recent science education studies have found that the learning environment for supporting epistemic agency should be contextualized in a way that values students' ideas as resources in producing useful knowledge in the curriculum (Stroupe, 2014; Stroupe et al., 2018). Miller et al., (2018) detail four opportunities to unpack epistemic agency within the NGSS and argue for these to be specified in the design of the lesson. These are; 1) opportunities to solicit and build on student knowledge as a resource for learning; 2) opportunities for students to build knowledge; 3) opportunities for students to build a knowledge product that is useful to them; and 4) opportunities to change structures that constrain and support action. We use this conceptualization to identify opportunities that existed within the bioinformatics PBL unit. Table 1 shows the definition of each of these pedagogical opportunities and provides examples of how these were incorporated into our PBL unit.

An important characteristic of science curricula that relates to epistemic practices in classrooms is the emphasis on student authority over what counts as knowledge within an activity (Erikson & Lindberg, 2016; Haverly et al., 2020). This kind of teaching requires teachers to notice students' "individual student histories" inside and outside of class (van Es et al., 2017, p. 266). Haverly et al. (2020) explains that teachers make space for students to co-construct knowledge when opportunities for meaningful student discourse and interactions are coupled with visible shifts in epistemic authority from teachers to students. Stroup et al. (2014) recommend an ambitious instructional model, where the cognitive authority of knowledge inside a science classroom is constantly negotiated by both students and teachers. In classrooms characterized by ambitious instruction, teachers give cognitive authority to students by involving students' inputs in framing an argument and evaluating the efficiency of methods employed by the teacher. In contrast, in a classroom setting where cognitive authority is not distributed, the teacher guides students to discover elements of knowledge that the teacher has decided as important. Similarly, Haverly (2020) conceptualizes science teaching across three degrees of distribution of epistemic authorities; (a) co-constructed practices where the teacher and students share epistemic authority, (b) teacher-constructed practices where the teacher maintains epistemic authority, or (c) student-constructed practices where epistemic authority shifts entirely to students.

Teachers make pedagogical decisions to intentionally share (i.e., co-construct) the epistemic authority with students using multiple instructional strategies such as, using "wait time" for students to reflect on their mistake before immediately fixing it with teacher instruction (Haverly et al., 2020) or using collaborative scaffolds that create opportunities for students to critically analyze responses of their peers (González-Howard & McNeill, 2020; Haverly et al., 2020). Another strategy is to use teacher prompts that elicit contradictory responses from students so that they can deliberate about the complexities of the topic among themselves (Haverly et al., 2020; Miller et al., 2014; Stroupe, 2014). Conversely, in classrooms that model teacher-centered pedagogical practices, the visible evidence of shared epistemic authority is minimal. Here, students may be invited to pedagogically share their experiences during the knowledge building process, however, these exchanges do not translate to sharing of epistemic authority as teachers reign control of the class by directly correcting students' mistakes and by using teacher-centered scaffolding such as modeling for students to enact the steps shown by the teacher (Schoerning, Hand, Shelley, & Therrien, 2015; Erikson & Lindberg, 2016). Evidence of student-constructed pedagogical practices, where the epistemic authority completely shifts to students, is limited within existing literature in formal science classrooms (Haverly et al., 2020; Stroupe, 2014). We us this conceptualization to analyze the variation in pedagogical practices adopted by the science teachers in implementing the PBL units.

Methodology

This study is part of a larger NSF-funded project on teacher PD that aimed at integrating scientific research on the topic of bioinformatics in high school science classrooms. In this paper, we conduct qualitative case studies of two science teachers who used different pedagogical approaches to implement the PBL curricula support distributed in PD.

Participants

We worked with two biology teachers, one female, and one male, who taught in different urban public schools in the Northeastern United States. Both teachers were volunteers. The first teacher, Sam, had 15 years of teaching experience, taught ninth-grade biology in a school where students were identified as 39% White, 29% Asian, 16% Black, 5% Hispanic, and 11% other. The second teacher Linda had two years of teaching experience, taught ninth-grade biology in a school where students were identified as 54% Black, 24% Hispanic, 12% Asian, 7% White, and 4% others. All students in both schools were eligible for free or reduced-price lunch (an indicator of income level in the United States). On the state standardized test, students scored 93% and 33% proficient or advanced in biology respectively from both schools.

Context

The bioinformatics PBL unit was anchored in a scientific inquiry to explore the issue of high asthma rates within urban communities. Students were provided with sensors and phones to measure air quality in different locations of their community and analyzed data patterns using Google Sheets and Microsoft Excel. Based on an analysis of collected data, students were asked to propose an intervention to address the air quality issue in their neighborhood. Table 1 provides an overview of the PBL activities and illustrates its alignment with Miller et al. (2018)'s epistemic opportunities. Teachers were given the agency to adapt these PBL units to align better with their individual teaching goals.

Table 1: Definition of Miller et al. (2018)'s epistemic agency opportunities and alignment with the PBL unit

Epistemic Opportunities	Definition	Examples of PBL Activities
Building on student knowledge as resources	Instructional approaches where students' community and culturally based intellectual resources are used for knowledge building.	- Anchoring the study of bioinformatics in the issue of asthma and air quality - a problem highly relevant in the city especially among students of color (Bryant-Stephens et al., 2012). - Group reflection of asthma cases within family and community.
Building knowledge	Instructional practices that position students to engage in the practices of scientists instead of typical roles as passive recipients of information.	- Students work with large online data sets to identify patterns and make inferences about air quality across years. - Students use mobile air quality sensors to collect and analyze data from areas around schools. Then they design proposals to analyze data around their neighborhood.
Building knowledge product that is useful to the student	Instructional practices that provide opportunities to engage in authentic problems in nature that are part of their experience, rather than trying to learn a fact or idea.	- Students identify areas of relevance in their neighborhood using the air quality sensor and app. Then, they draw conclusions about the air quality and its effects on one's community and propose interventions.
Changing structures that constrain and support action	Instructional practices that position students as change agents in the local and global structures that constrain and support tangible action.	- Students present and defend their intervention proposals.

Data source and analysis

We analyzed three data sources: Classroom observation notes; teachers' post-implementation interviews; and teachers' PD daily reflection notes. The classroom observation notes were used to identify the different instructional strategies employed by teachers in implementing the PBL unit. The post-implementation interviews and teacher reflection notes were used to understand the factors that influenced teachers' decision-making process with regard to engaging in practices that positioned students with epistemic authority. We used an exploratory case study methodology (Yin, 2017) to provide qualitatively rich descriptions of instructional practices and classroom implementations that enacted epistemic agency. The classroom observations were organized to group instances that were reflective of Miller's epistemic opportunities built into the curriculum. The data was then deductively coded to identify instances of teacher-constructed strategies, co-constructed strategies, and student-constructed strategies (Haverly et al., 2020). We did not find any instances of student-constructed pedagogical practices. The transcribed data sources were analyzed and triangulated qualitatively to identify themes that could be attributed to the decision and activation of epistemic agency. All analyses were discussed by the research team to validate the themes. Table 2 describes the coding scheme with examples from the data.

Table 2: Coding scheme and examples from the observation notes

Epistemic Opportunities	Instructional Variations in Positioning Students with Epistemic Authority
Anchoring bioinformatics in student's experiences with asthma.	**Teacher constructed strategies:** Class starts with a "do now" question (Do you know anyone who has asthma? What do you know about asthma?). Here, students are asked to agree or disagree with the statement and write down an explanation. The teacher shows a video on asthma giving students a few minutes to revise their statement if their viewpoint has changed and then, introduces the PBL scenario. **Co-constructed strategies:** The teacher elicits student dialogue about family instances of asthma and allows students to engage in conversations about ways in which it affects family health and routine. The teacher creates "affect" around the topic before introducing the line of inquiry of the PBL unit.
Students use mobile air quality sensors and Google Sheets to collect and analyze data from areas around schools.	**Teacher constructed strategies:** Students are asked to make a copy of the data and analyze them by calculating mean, median, and mode. The teacher breaks down these steps and demonstrates them one by one while waiting for students to follow the steps. **Co-constructed strategies:** Students start by looking at the data they collected and write down what they think. Sam explained the units for the particles. Then, showed two *t*-test videos and asked students how the t-test was going to be helpful for their project. Then, students try mean, median, mode, and t-test on the Car-Barn sites data in groups. For the students who completed getting a *t*-test value, they were guided to do a *t*-test with their indoor data. The teacher reminds students that they are researchers to encourage them to work with each other to resolve emerging questions.
Students identify areas of relevance in their neighborhood using the air quality sensor and app. Then, they draw conclusions about the air quality and its effects on one's community and propose interventions.	**Teacher constructed strategies:** Teacher explains the assessment criteria (informal rubric - Full sentences, check grammar; Two sentences for each question; 30 points in total). Teacher provides a sample data chart table on the writing board. Then, the teacher provided a template for how to do data comparison and describe data in sentences. She also explains what data students could compare with examples of Carbon Monoxide and Particulate Matter 2.5. **Co-constructed strategies:** Students analyzed data and discussed ways to help solve the problem of rising asthma rates in Philadelphia. Sam provided a Google Document template for writing the project report, at the same time he

	allowed students to make one of their own. Sam walked around each group to check how students are going to analyze data for their final report. Class ended with sharing what students observed so far and what were some things that students might have done differently with their data collection.

Result

The findings are organized into themes that illustrate how the two teachers differed in their implementation of the PBL activities, particularly in their distribution of cognitive authority within the PBL activity, and to explain the rationale behind these differences. In the next section, we explain how the two teachers differed in the instructional practices employed for the same PBL units.

Variation in teacher instructional practices: Teacher-centered versus distributed epistemic authority

Among the two teachers. Sam adapted the PBL in ways that allowed students to co-construct the science inquiry process by engaging in epistemic pedagogical practices. However, Linda struggled with sharing the cognitive authority of directing science inquiry with the students and instead relied heavily on teacher-centered strategies.

In the classroom that used co-constructed practices, Sam created multiple opportunities for students to take ownership of their science inquiry process. For example, Sam provided students with choices in selecting the context of data collection, setting investigation questions, framing final reports, and presenting their community solutions to the whole class. Throughout the implementation, Sam consistently referred to students' epistemic authority while encouraging student ownership. He also directed students to use their peers as resources when they ran into issues with the use of mobile sensors, and data analysis resources. He used collaborative scaffolding immensely during the data collection and analysis portion of the PBL. For instance, in the lesson where students engaged with online data sets to build inferences about the air quality data over different years. Sam had students freely explore the website and discover various elements of the site and share their observations with the whole class. He also gave students the freedom to choose the years they wanted to compare to infer varying data patterns. During the discussion, he asked students to critique the analysis each group presented. Throughout the activity, Sam kept reminding students of their agentic positioning by telling them that they were researchers of the project and hence should drive their own conclusions. Moreover, when students ran into issues with setting up mobile sensors for data collection and navigating the Google Sheets for recording and analyzing indoor collected data, Sam referred students to direct their questions to peers who showed proficiency for navigating these tools. In his interview, when referring to using collaborative scaffolds, he mentioned,

> I think the part where kids learned from each other went really well. The couple days where I spent going over stuff with Excel, they really taught each other most stuff and how to get through that quicker than if I did it your typical way, where I do the activity with an example and they model it as a whole class. They as a group were good at collaborating with each other. I prompted them to talk to one another when they were stuck. So, I think that part of it actually was one of maybe more the success stories.

Linda, however, struggled with distributing cognitive authority while adapting the PBL to meet the requirements of her class. Linda’s implementation employed teacher-centered practices where students were either enacting practices modeled to them or were engaging in discussions to get to an answer Linda had decided as the correct one. The classroom observations highlighted Linda's reliance on teacher-centered scaffolds to guide student learning during instances where the PBL lessons created opportunities for students to build knowledge. In implementing the same lesson referenced in Sam's class, Linda modeled the usage of the website that hosted the data sets in a step-by-step manner and had students enact the steps. She also asked students to compare data patterns of specific years. There was a limited choice given to students in selecting the years. As a result, there was limited variation among student responses as all students examined patterns of the same year. Also, when questions were raised about the nature of data or Google Sheets usage in the indoor data collection lesson, students directed their questions to Linda, and they were addressed through verbal exchanges between the teacher and the students. Linda emphasized the use of teacher’s scaffolds used in her lessons, in her post-implementation interview,

> My students don't know a lot of the basics in using Microsoft software, or Excel, or any Google applications. So, there was a lot of fundamental knowledge that I had to scaffold for all of the students. There are a couple here and there who just will shut down once they've struggled so much with trying to use Excel, or copy and paste data, or find the averages. So, it is better to guide all students to one or similar kinds of answers, otherwise, it gets confusing.

In Sam's adaptation of the PBL, he made pedagogical choices to engage students as epistemic agents by giving students more agency over tools, context, framing of results, and by giving students space to discuss and critique ideas. He leveraged collaborative scaffolds to guide the class towards the larger goals of the PBL. However, Linda's adaption of the PBL included less student choice and more teacher-centered scaffolds. While Linda provided space for children to share their experiences, these exchanges did not result in sharing epistemic authority with students as all students continued to refer to Linda to correct their interpretations or their science inquiry instead of referring to their peers or oneself as having the authority to direct one's learning.

Rationale for different instructional choices: Navigating around versus adhering to structural limitations

In co-constructed classrooms, Sam prioritized student engagement with content over canonical knowledge. Sam created opportunities for students to engage as epistemic agents while navigating around normative practices of formal classrooms such as limited instructional time and meeting grade-level learning standard requirements. This is because he felt students' engagement with the content mattered more than their ability to recall terms and definitions. When reflecting on the choice of design assignments, Sam stated in his interview,

> Yes, I felt a sense of urgency that I'm going to be behind with the other content that I need to teach in biology and I also don't know if students can actually remember the definitions but the fact that it was an inquiry activity and they got to choose what they were looking at was more important. Early in the unit when we were going over what asthma was, I was getting some real specific questions from students. They were telling me, "Well, this is what happens when my brother has asthma," or "This is what happens when I have an asthma attack." This project was very personal for my students, and it was unique to them.

Similarly, when reflecting on the effectiveness of the PBL implementation, Sam commented,

> I think they got a sense of some parts of the curriculum like the power of information or data, but I am not sure how well they will be able to define bioinformatics for instance. I also think different students hooked on to different parts, that is why I gave them a choice on the format of the final report as well. I think each student has distinct interpretations of the task.

The analysis of co-constructed pedagogical choices shows how Sam navigated through the structural barriers of formal classrooms by choosing to prioritize student engagement over content recall. However, these reflections reveal that Sam made choices about the tradeoffs that resulted from the use of epistemic practices in the classroom such as non-uniform understanding of the content, non-alignment of learning goals with standardized testing requirements, and extending the time allotted to the unit. These tradeoffs were not explicitly addressed in the PBL design. However, in the teacher-constructed classroom, Linda struggled with providing student agency with assessment and activities as she prioritized science content knowledge over engaging with students' individual or lived experiences. She felt her class would benefit more from a stronger focus on content knowledge as it prepared students better for their standardized testing requirements. She said,

> My head was very invested in reaching the goals for each benchmark, which are tests we have to take throughout the year to make sure students are learning the knowledge that's relevant for the Keystones. There's kind of the other side of it with educational research and project-based learning. Principals like those buzz words. They like to see that their students are active and doing things in the community, but at the same time, principals like for their Keystone scores to be high. While I can engage in dialogue with students, I need to ensure they all have the correct understanding of the terms.

While Sam was successful in navigating around normative structures of formal classrooms to engage students as epistemic agents with the PBL, Linda adhered to the structural demands of formal classrooms limiting students' epistemic agency. The PBL was not successful in helping Linda navigate around the tensions inherent to formal classroom instruction. This decision to navigate around or adhere to normative expectations may have been influenced by teachers' prior experience with science teaching or the urgency of standardized testing in the particular grade. Linda, when compared to Sam, was a novice science teacher with 2 years of experience as opposed to Sam who had 15 years of experience teaching science. Linda also implemented this unit in the 9th-grade science, where students were scheduled to take the state science exam in the same year. This was not the case for Sam as he taught in a magnet school that allowed his students leeway in participating in the science exam. These contextual factors may have given differential opportunities for making curricular choices.

Discussion

This paper contributes to the emerging literature on the use of contextual relevant PBL and its efficiency in supporting teachers' use of epistemic practices in science classrooms (González-Howard & McNeill, 2020; Ko & Krist, 2019; Stroupe et al., 2018). Our findings advance the existing understanding of how teachers adapt PBL supports differently to meet their classroom needs and in doing so enhance or compromise students' agentic positioning within science classrooms. Our analysis aligns with findings of other "sense-making" studies which showed that teachers predict and leverage epistemic opportunities within a curriculum differently (Haverly et al., 2020; Rosebury et al., 2015). Sam perceived the PBL topic of asthma to be of personal relevance to his students and hence identified opportunities within the curriculum to share the cognitive authority with his students and leveraged them. On the other hand, Linda perceived the PBL curriculum as a medium to prepare students for their state science exams through enactments of science inquiry practices. These varied perceptions of the PBL influenced the pedagogical choices of epistemic positioning of students, during the implementation.

Both teachers did not engage in student-constructed pedagogy where students participate in equitable sense-making practices. Sam did not cede epistemic authority entirely to his students, rather, he steered his student's conversations and interactions towards the broader learning goals of the PBL. However, he did position his students as people whose opinions and interpretations were worthy of being challenged by their peers, instead of positioning only his guidance and input as the voice of value which is a movement towards shifting cognitive authority and advancing students epistemic agency (González-Howard & McNeill, 2020; Haverly et al., 2020; Miller et al., 2014; Stroupe, 2014). Linda was successful in making room for her students to share their experiences but was not able to share the epistemic authority with her students as she often corrected students directly and asked students to enact the behavior, she was modeling. This reinforces the existing power dynamics of teachers being the owner of cognitive authority and limiting opportunities for students to engage as epistemic agents (Haverly et al., 2020; Miller et al., 2014).

Our paper highlights the tensions between the inherent free nature of open-ended PBL and the normative practices that drive teacher instruction in formal classrooms, which aligns with tensions hypothesized by Miller et al. (2014) and raised by Stroupe (2014). To support epistemic pedagogical practices in formal science classrooms, PD developers should explicitly address structural limitations and provide supports that illustrate or model how epistemic authority can be co-constructed within these limitations to encourage teachers to shift away from teacher-centered scaffolds while adopting PBL curricula to their classrooms.

References

Bang, M., Brown, B. A., Calabrese Barton, A., Rosebery, A. S., & Warren, B. (2017). Toward more equitable learning in science. In C. Schwarz, C. Passmore, & B. J. Reiser (Eds.), *Helping students make sense of the world using next generation science and engineering practices (pp. 33-58).* Arlington, VA: National Science Teachers Association.

Barnhart, T., & van Es, E. (2015). Studying teacher noticing: Examining the relationship among pre-service science teachers' ability to attend, analyze and respond to student thinking. *Teaching and Teacher Education*, *45*, 83-93.

Basu, S. J., Calabrese Barton, A., Clairmont, N., & Locke, D. (2009). Developing a framework for critical science agency through case study in a conceptual physics context. *Cultural Studies of Science Education, 4*(2), 345–371.

Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of research in science teaching*, *49*(1), 68-94.

Braaten, M., & Sheth, M. (2017). Tensions teaching science for equity: Lessons learned from the case of Ms. Dawson. *Science Education*, *101*(1), 134-164.

Brown, J. C. (2017). A metasynthesis of the complementarity of culturally responsive and inquiry-based science education in K-12 settings: Implications for advancing equitable science teaching and learning. *Journal of Research in Science Teaching, 54*(9), 1143-1173.

Bryant-Stephens, T., West, C., Dirl, C., Banks, T., Briggs, V., & Rosenthal, M. (2012). Asthma prevalence in Philadelphia: description of two community-based methodologies to assess asthma prevalence in an inner-city population. *Journal of Asthma*, *49*(6), 581-585.

Erikson, I., & Lindberg, V. (2016). Enriching 'learning activity' with 'epistemic practices'–enhancing students' epistemic agency and authority. *Nordic Journal of Studies in Educational Policy*, *2016*(1), 32432.

González-Howard, M., & McNeill, K. L. (2020). Acting with epistemic agency: Characterizing student critique during argumentation discussions. *Science Education*, *104*(6), 953-982.

Hardy, L., Dixon, C. & Hsi, S. (2020). From data collectors to data producers: Shifting students' relationship to data. *Journal of the Learning Sciences, 2*9(1), 104-126.

Haverly, C., Calabrese Barton, A., Schwarz, C. V., & Braaten, M. (2020). "Making Space": How novice teachers create opportunities for equitable sense-making in elementary science. *Journal of Teacher Education*, *71*(1), 63-79.

Jacobs, V. R., Lamb, L. L., & Philipp, R. A. (2010). Professional noticing of children's mathematical thinking. *Journal for research in mathematics education*, 169-202.

Ko, M. L. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education, 103(*4), 979–1010

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053–1075.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Rosebery, A. S., Warren, B., & Tucker-Raymond, E. (2015). Developing interpretive power in science teaching. Journal of Research in Science Teaching, 53(10), 1571-1600. doi:10.1002/ tea.21267

Savery, J. R. (2015). Overview of problem-based learning: Definitions and distinctions. *Essential readings in problem-based learning: Exploring and extending the legacy of Howard S. Barrows*, *9*, 5-15.

Schoerning, E., Hand, B., Shelley, M., & Therrien, W. (2015). Language, access, and power in the elementary science classroom. Science Education, *99*(2), 238-259.

Schwarz, C., Braaten, M., Haverly, C., Calabrese Barton, A., & de los Santos, E. (2018, March). *Noticing and responding moments as windows for disciplinary and equitable sense-making.* Paper presented at the *Annual International Conference of the National Association of Research in Science Teaching*, Atlanta, GA.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487-516.

Stroupe, D., Caballero, M. D., & White, P. (2018). Fostering students' epistemic agency through the co-configuration of moth research. *Science Education, 102*(6), 1176-1200.

van Es, E. A., Hand, V., & Mercado, J. (2017). Making visible the relationship between teachers' noticing for equity and equitable teaching practice. In *Teacher noticing: Bridging and broadening perspectives, contexts, and frameworks* (pp. 251-270). Springer, Cham.

Hand, V. (2012). Seeing culture and power in mathematical learning: Toward a model of equitable instruction. Educational Studies in Mathematics, 80(1/2), 233-247.

Windschitl, M. (2002). Framing constructivism in practice as the negotiation of dilemmas: An analysis of the conceptual, pedagogical, cultural, and political challenges facing teachers. *Review of educational research*, *72*(2), 131-175.

Yin, R. K. (2017). *Case study research and applications: Design and methods*. Sage publications, Thousand Oaks, CA.

Zimmerman, H. T., & Weible, J. L. (2018). Epistemic agency in an environmental sciences watershed investigation fostered by digital photography. *International Journal of Science Education*, *40*(8), 894-918.

Spreading GIS-Infused Instruction: A Cross-Case Comparison of Two Instructional Approaches

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Abstract: This work is part of an ongoing partnership that seeks to create a sustainable infrastructure to support GIS-infused instruction in a large urban school district. In this paper, we report an illustrative cross-case comparison of two teachers' approaches to infusing GIS in their courses. The goal of this analysis is to examine how GIS-infused instruction is adapted in different contexts and to consider the affordances of divergent approaches. Findings illustrate the relationships among organizational context, individual and collective context, particularly teacher identity, and instructional practice in the work of spreading GIS-infused instruction. We also discuss key lessons learned in our partnership thus far and implications for district-level partnerships focused on spread and scale.

Issue addressed and potential significance

Spatial reasoning is an important part of the practices of many disciplines from STEM to the social sciences. However, spatial reasoning is rarely explicitly taught in the K-12 classroom (NRC, 2006) and efforts to design curricula that support the development of spatial reasoning skills have been limited. Given that spatial thinking improves with training and experience these efforts could be extremely beneficial for young learners (e.g., Uttal, Miller, & Newcombe, 2013).

Recent research and standards emphasize the value of Geographic Information Systems (GIS) as a tool for enhancing K-12 students' spatial reasoning (e.g., Jant et al., 2020; NGSS, 2013; NRC, 2006). GIS has been suggested as a tool to support spatial reasoning skills because it enables users to create rich data visualizations and reason about spatial patterns and relationships among different types of data (Bednarz et al., 2008; Bodzin, 2011). Prior work suggests GIS is effective as a learning tool in multiple contexts (e.g., Edelson, Smith, & Brown, 2008). For example, GIS-infused instruction led to better understanding of concepts in energy, climate change, and social science compared to typical instruction in those areas (e.g., Edelson et al. 2008; Lee & Bednarz, 2009). Given the potential value of GIS, a critical next step is to develop effective approaches for incorporating GIS into classroom instruction.

The current work is part of an ongoing partnership that builds on the Geospatial Semester (GSS), a year-long high school course focused on developing geospatial problem-solving skills using GIS and applying those skills to local problems chosen by students (Kolvoord, Keranen, & Rittenhouse, 2019). The goal is to understand whether and how the GSS can be adapted to meet the needs of Chicago Public Schools (CPS), a large, urban school district teaching a variety of content areas and to create a sustainable infrastructure to support GIS-infused instruction in CPS. Given the widespread, career-relevant applications of geospatial technologies, we focus in particular on the CPS Career and Technical Education (CTE) program, which serves groups currently underrepresented in STEM careers, with the goal of building career-relevant GIS skills in the pathways students are already pursuing.

Our work is informed by Coburn et al.'s (2013) conceptual framework of spread and scale (see Figure 1). Spread is defined as the process by which tools, ideas, practices, or programs move to a greater number of people or organizations through both top-down and bottom-up means (p. 3). Coburn et al. consider who spreads, what spreads, strategies to foster spread, and the contexts that influence spread. They also discuss the various levels at which contexts influence spread: individual and collective, organizational, environmental, and policy. In this project, we focus primarily on the individual and collective level, which involves teacher identity, knowledge, and skills, and the organizational level, which includes support from administration and colleagues and availability of technology. Within these contexts, capacity building and participation are key spread strategies. Coburn et al. use the term scale to refer to the intended outcome of spread and note that scale can be defined in several distinct ways, including adoption, replication, adaptation, and reinvention. In the current work, we define scale as adaptation. Adaptation privileges modifications that incorporate contextual perspectives and needs over strict fidelity and seeks to engender widespread use (Coburn et al., 2013). Modifications can be either appropriate in that they reflect the key ideas, practices, or principles or inappropriate, often referred to as "lethal mutations" (e.g. Tatar et al., 2008). Design principles provide the means to guide appropriate adaptations (James et al., 2020).

In this paper, we report a cross-case comparison that illustrates two teachers' approaches to infusing GIS in their courses. The challenge we take up in this paper is to examine how GIS-infused instruction is adapted in different organizational and individual and collective contexts and to understand the affordances of divergent approaches, given contextual differences and local goals for adaptations.

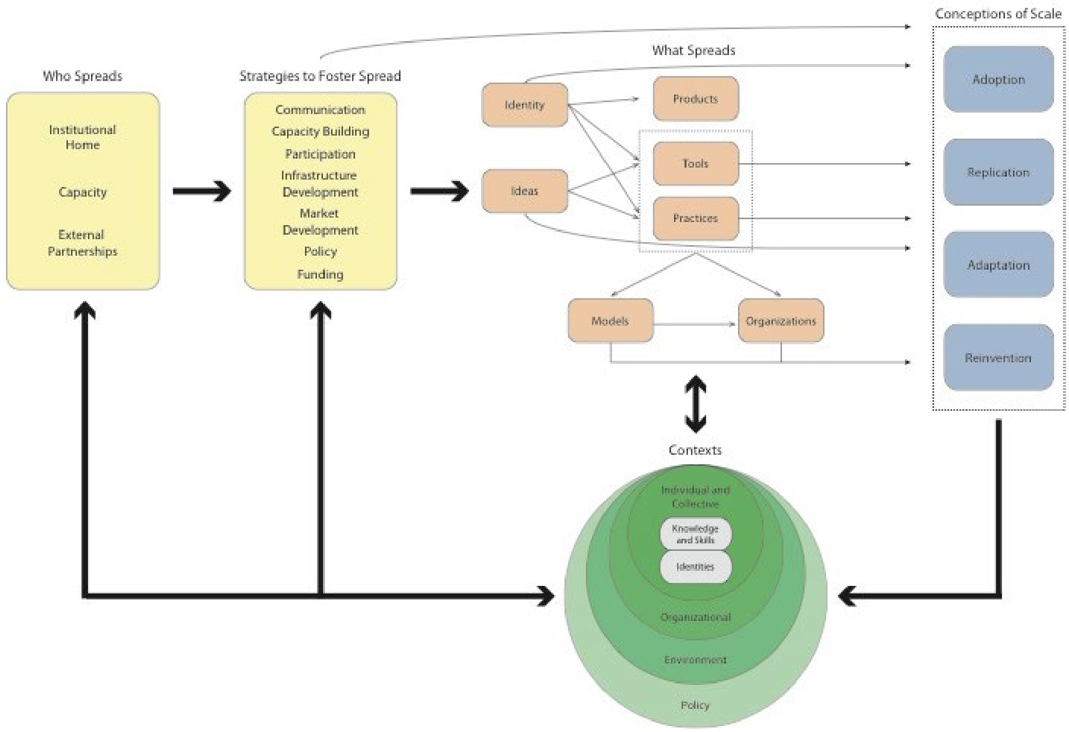

Figure 1. Coburn et al.'s (2013) spread and scale framework.

Methodological approach

Research context

At the outset of the project, we established an ongoing partnership with the CPS CTE office. During Spring 2018, the researchers met with the entire CTE team, including office leadership as well as representatives from the career pathway clusters, such as cluster managers, curriculum specialists, and implementation specialists. We took a top-down approach to recruitment at the organizational level by partnering with the CTE office to identify pathways and courses that could benefit from the infusion of GIS. We initially sought to adapt and implement the original GSS model, which involves an entire year-long GIS course focused on extended student-driven inquiry projects. The partners determined that the CTE capstone course, a year-long, project-based course taken by all seniors in the CTE program, would be a natural fit for this model. Six CTE pathways were initially identified as targets for the year-long GIS course: Pre-Engineering, Entrepreneurship, Agricultural Sciences, Health Science, Construction and Architecture, and Law and Public Safety. Managers of each of these CTE pathways then invited teachers to participate.

In the early stages of the project, it became clear that additional GIS capacity building was needed to help students build the complex GIS and spatial reasoning skills that would be drawn on in the year-long GIS course. To this end, we began incorporating freshman and sophomore content courses outside of CTE that could support GIS capacity building and facilitate multi-year GIS trajectories at schools. In other words, we shifted from spreading the entire GSS model to spreading relevant tools and practices. To facilitate this shift, we began additionally using a bottom-up strategy to recruit individual teachers based on interest. Teachers in the social sciences and computer science chose to join the project.

Professional development and lesson co-design

Teachers participated in a series of professional development workshops, including a five-day summer workshop and one-day mid-year workshop during the 2018-2019 school year (year one) and a four-day summer workshop during the 2019-2020 school year (year two). During the workshops, GIS technical skills were taught through challenge tasks and skill-building activities. The workshops also incorporated support for lesson planning and implementation, including structured peer feedback routines, small- and large-group discussions of classroom video excerpts (e.g., Sherin & van Es, 2005), and metacognitive reflections on and discussions of teachers' instructional practice. Throughout the workshops, teachers explored how to infuse GIS in ways that align with their context, content, and instructional goals.

Teachers partnered with the researchers and local GIS mentors to develop course maps that lay out a year-long sequence of GIS-infused lessons and pinpoint which units those lessons align with in their course. They then co-designed lesson plans and classroom materials for each of the lessons in their course map and implemented those GIS-infused lessons in their courses.

Case study context

As teachers carried out the work of designing and implementing GIS-infused lessons, we noticed differences in organizational as well as individual and collective contexts, particularly teacher identity relative to GIS-infused instruction. The current study focuses on two different school contexts where contrasting teacher identities emerged: Jackson High School and Addison High School (all names are pseudonyms). Jackson is a high-ranked selective enrollment school located in the center of the city. The racial and ethnic makeup of the school's roughly 1900 students is 40% White, 29% Hispanic, 14% Asian, and 11% Black. At Jackson, there was no organizational-level GIS initiative. Teacher recruitment was done through the social sciences department based on teacher interest. A total of three teachers from Jackson, each of whom taught a different area of social science, initially participated in the project. Thus, each GIS-infused course at Jackson was a standalone course. At Jackson, the teachers viewed themselves primarily as content teachers and, thus, framed GIS as an instructional tool to convey disciplinary content.

Addison High School is a wall-to-wall CTE magnet school located on the periphery of the city. The approximately 820 students are 48% Black, 32% White, and 18% Hispanic. At Addison, there was organizational-level interest in developing multi-year GIS trajectories and infusing GIS into all of the CTE pathways at this school. Indeed, the principal was already aware of GIS and saw the value of integrating GIS school-wide. He mandated that all CTE teachers and several sophomore-level teachers that could support capacity building courses attend the year one professional development workshops, which were also hosted by the school. Initially, seven teachers, including five CTE teachers and two sophomore-level teachers, participated in the project. At Addison, the teachers identified as both GIS technology instructors and content teachers. Thus, they viewed the development of GIS skills and content understandings as equivalent instructional priorities.

To facilitate a cross-case comparison, we selected a course that was common across the two schools: AP Human Geography. We focused on the AP Human Geography teacher from each school with the goal of comparing their approaches to GIS-infused instruction, given noted differences in the organizational and individual and collective contexts. The two teachers, Mr. Bradley and Mr. Mitchell, each co-designed and implemented a different GIS-infused AP Human Geography course. Both teachers implemented their GIS-infused lessons in all sections of their 10th grade AP Human Geography course during years one and two. Mr. Bradley, who is a teacher at Jackson High School (selective school), implemented seven lessons during year one and four lessons during year two. All lessons were a single class period in length. Mr. Mitchell, who teaches at Addison High School (CTE school), implemented five lessons during year one and six lessons during year two. Lessons ranged from three to seven class periods in length.

Data sources

Consistent with design-based research, we used micro-ethnographic methods to observe and document lesson implementation, focusing on teaching and learning processes. Data from the classroom observations include field notes, video, and classroom artifacts, such as lesson materials and student work. At the end of year one, we conducted hour-long, semi-structured interviews with each teacher with the goal of understanding their rationale for and reflections on their design and implementation process. The classroom observation field notes, videos, and artifacts and teacher interview videos constitute the data sources for this paper.

Analytic approach

The classroom observation field notes, videos, artifacts, and interview data were compiled chronologically into case files for each teacher. The researchers engaged in repeated readings and re-readings and thematic summarization of the case files. Analytic memos were written to describe patterns and themes in the data, focusing on each teachers' approach to GIS-infused lesson design and implementation.

To more closely examine differences in teachers' instructional practices, we selected one lesson implemented by each teacher in the middle of year one. These focal lessons were selected because they illustrate the contrasts noted during earlier analysis and are representative of each teachers' instructional approach. The focal lessons were further analyzed through research team debriefing. During the debriefing session, we reviewed an observation summary, which included a description of each lesson and a focal theme, relevant artifacts from the classroom observation data, and a set of guiding questions to structure the discussion around the theme. The research team then analyzed the data with the goal of understanding the affordances of each approach and generating new insights.

Finally, the cases were compared to identify distinctive characteristics of each teachers' approach. The findings presented here are of the two case studies and cross-case comparison.

Findings

The two cases discussed here illustrate variations in the teachers' approaches to GIS-infused content instruction. Table 1 provides an overview of the key differences between the two cases with respect to context, lesson design, learning goals, role of GIS, and timing.

Table 1: Case study teachers

Case	Context	Lesson Design	Learning Goals	Role of GIS	Timing
Mr. Bradley	Selective school, standalone course, content teacher identity	Focused, content-specific lessons	Content-relevant spatial reasoning	Extremely user friendly, minimize interaction with technology	Focus on efficiency, balance with AP content coverage
Mr. Mitchell	CTE school, organizational-level GIS initiative, GIS instructor and content teacher identity	Topical but open-ended lessons, focus on student-driven inquiry	Investigate topics of interest, GIS skill building	GIS as tool for inquiry, productive struggle to figure out GIS skills	Open-ended, space for exploration

Case #1: Mr. Bradley

The focal lesson was the fourth GIS-infused lesson in Mr. Bradley's course. He provided a set of three pre-made maps that contained the information and afforded the content-relevant spatial sense-making he wanted students to engage in. The three maps contained information about 1) world religions, 2) climate, and 3) elevation. To structure students' interaction with the maps, he provided a series of questions that moved from data gathering to analysis and interpretation, particularly noticing and understanding the targeted spatial patterns. In this lesson, students were asked to determine how geographic factors contributed to the spread of a list of religions, focusing on the contrast between universalized religions (e.g., Christianity, Islam) and ethnic religions (e.g., Hinduism, Igbo). Students toggled between the maps to qualitatively analyze the information, focusing on identifying corresponding areas of the maps and understanding relevant spatial patterns. Students worked independently or in pairs to answer the questions based on the information in the maps and then shared their insights and questions with the class. In the excerpt below, the world religions map is projected on the screen and zoomed in on the area surrounding the Himalayas. The teacher poses one of the questions from the activity and the class discusses the spatial relationships between geography and the spread of religion in the region.

Teacher:	Why didn't Buddhism go south and why didn't Hinduism go north? What's blocking the diffusion of the religions here, Charlie?
Student 1:	The Himalayas.
Teacher:	What...are those?
Student 1:	Mountains.
Teacher:	Mountains! The tallest mountain range in the world and they kind of extend this way [gestures east along the Himalayas on the map] That's why these areas have maintained their traditional beliefs because, again, the mountains

	and very tropical areas and very difficult to get through so these areas never were really touched by Buddhism. Instead, Buddhists went around using the ocean and thus they reached over here. Why on earth then would these Buddhists be so different than the ones from the north, Maria?
Student 2:	There's no interaction between them so they each established different religions.
Teacher:	My budding Geographers, you're so close to blossoming. It's beautiful. Right! Look! You have mountains, high elevation...the only way you can reach these areas is through traders going through the ocean, right? So thus, these areas have maintained and then you see a whole different version of Buddhism because there's less interaction.

As the transcript illustrates, this lesson enabled students to make key insights into the spatial patterns and relationships underlying the spread of world religions. Indeed, this GIS-infused activity meaningfully enhanced their understanding of the content while allowing them to build spatial reasoning skills through GIS. As briefly mentioned in the transcript, Mr. Bradley framed GIS as a tool for thinking like geographers, emphasizing that maps are an important source of information in geography and, while they can draw inferences about patterns from this data, there are multiple valid interpretations and a need to corroborate the information with other sources. This rooted the activity in disciplinary practices and connected it to the other work that students were doing in this course.

As reflected in the focal lesson, Mr. Bradley's GIS-infused lessons commonly engaged students in using GIS to analyze content-relevant spatial patterns. These lessons were strongly connected to the content and thoughtfully integrated into units where there were important spatial relationships, such as global patterns, underlying the geography content. In discussing his goal for using GIS in his course, he emphasized building spatial reasoning skills and enhancing students' content understandings through analyzing spatial patterns:

> Teaching human geography, I understand the value of having that spatial awareness and understanding, like, how two things might be related to each other if they're happening in the same spot. I'm trying to get kids, you know...my students, curious about those types of connections to try and figure out why things are the way they are *where* they are. Right? So, we're worried about the location, not just why things are happening.

Importantly, he also indicated that his goal in using GIS in his course was to leverage its affordances for enhancing understanding, rather than building technical skills. This approach to GIS-infused instruction was shaped by the learning goals, content coverage expectations, and time limitations associated with this AP Human Geography course:

> With AP Human Geo there's just not the time to really get kids to kind of work with the software...I just wanted kids to make those connections, it was very basic. I wasn't interested in getting them to learn the software. I was more concerned about learning that spatial awareness skill.

Overall, Mr. Bradley's approach to GIS-infused content instruction focused on efficient, user-friendly lessons. His lessons minimized the time commitment needed and enabled him to balance the GIS work with the content coverage and learning goals of this AP course in a selective enrollment school context. This approach also minimized the GIS technical skills required of both teachers and students, making the lessons usable by GIS novices without extensive training. These lessons reduced the GIS learning curve and successfully avoided "in the moment" technology snafus that can make GIS challenging to use in the classroom. At the same time, these focused, content-driven lessons effectively engaged students in content-relevant spatial reasoning. Indeed, Mr. Bradley's GIS-infused lessons engaged students in reasoning about spatial patterns and relationships in ways that meaningfully enhanced their understanding of the content.

Case #2: Mr. Mitchell

The focal lesson in Mr. Mitchell's AP Human Geography course was the third in the GIS sequence. In this lesson, which took place over four class periods, students independently explored GIS to investigate a historical human migration. The teacher provided a list of possible topics, vetted data sources, and a set of questions to structure and constrain the task, but students were allowed to choose any human migration that interested them. Students were asked to use GIS to create any three maps and a storymap that told the story of that migration. Storymaps are a GIS tool that allows users to embed maps, videos, photos and other media within a narrative to create a dynamic, interactive presentation that interweaves maps with written analysis. Students had three class periods to explore GIS in small groups and create their storymaps. During this time, the teacher modeled key practices and provided support as needed, but the inquiry was almost entirely student-driven. Indeed, students explored GIS to identify and analyze relevant data and worked together to figure out the technical skills they needed to create their maps and storymaps. On the fourth day, students presented their storymaps orally to the class. The storymaps that students created included maps of key locations and routes involved in the migration and analysis of the factors (e.g., political, geographical, historical) that may have contributed. Many students chose to focus on migrations that were personally relevant, such as their own family's migration.

As illustrated in the focal lesson, Mr. Mitchell's approach to GIS-infused instruction was characterized by exploratory, student-driven inquiry around content-relevant topics. He designed tasks that provided scaffolds, such as vetted topics and data sources, but enabled students to independently explore their interests. In this course, students also commonly used GIS to create their own maps and storymaps, which were presented to the class at the end of each lesson. For example, in their storymap about the dust bowl, one group included a primary source photograph as well as an interactive map with early 20th century county population and agricultural land amounts data for the Great Plains states to illustrate key routes and factors involved in the migration (see Figure 2).

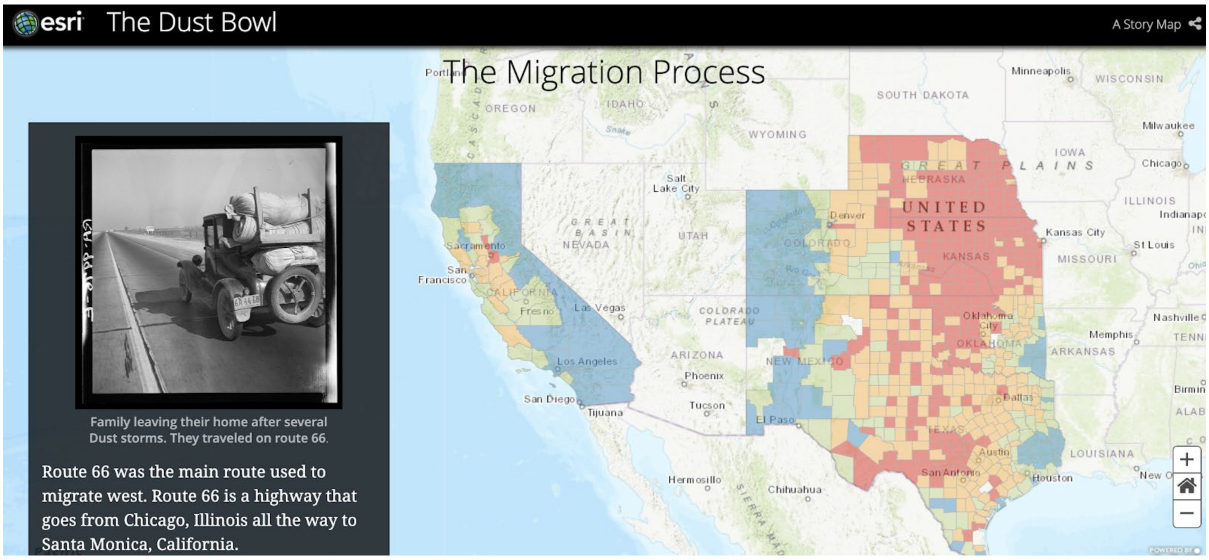

Figure 2. Section of a storymap created by students during the focal lesson.

While creating maps and storymaps introduced additional challenges, it also enriched students' understanding and experience of GIS and enabled them to share and discuss their findings with the community. Indeed, Mr. Mitchell's lessons created space for students to struggle productively and figure out GIS on their own while investigating topics they care about. In discussing his instructional approach, he emphasized the value of exploration and productive struggle for teaching and learning with GIS:

> My teaching style is that they've all got to struggle themselves and they get through that struggle for the most part and they end up doing better. I think it went pretty well, I was really impressed with the stuff they came up with...As we got further and further, I just said ok this is what we're gonna do and then they already had ideas about what layers am I gonna find for that or how am I gonna set this up...it was just them getting the assignment and then them creating and making their own different things.

Indeed, Mr. Mitchell's lesson design motivated and enabled students to do the work of learning GIS. As a result, they developed valuable, real-world GIS-based technical and problem-solving skills:

> What I like about it is after you do [GIS], like we've been doing [GIS] all year, they become little experts...now they actually know more about it than I do...I love seeing that. Giving them something they can actually use in their endeavors forward, regardless of what they actually do.

This exploratory, student-driven approach to GIS-infused instruction, while time-consuming and perhaps challenging to orchestrate, struck an important balance of freedom and structure. Mr. Mitchell's lessons allowed for personalized learning experiences in which students had the space to explore different paths based on their interests and become immersed in that area of the content. As a result, students meaningfully connected with and more deeply understood the content, which also motivated them to develop the GIS technical skills needed to investigate and communicate about their topic of interest. The development of expertise in GIS laid the foundation for application of GIS skills within subsequent CTE pathways.

Conclusions and implications

This cross-case comparison furthered our understanding of the relationships among organizational context, individual and collective context, particularly teacher identity, and instructional practice in the work of spreading GIS-infused instruction. Although they taught the same course, Mr. Bradley and Mr. Mitchell used different approaches to infusing GIS into their instruction. One teacher foregrounded content-relevant spatial reasoning while the other privileged exploratory, student-driven inquiry. Importantly, GIS was also positioned differently in their organizational and individual and collective contexts. Mr. Mitchell's course was part of an organizational-level initiative to develop multi-year GIS trajectories. Specifically, his instructional goal relative to this initiative was to build capacity and prepare students for using GIS in their CTE courses. Thus, he identified as both a GIS instructor and a content teacher and viewed GIS skills and content understandings as equally important in his course. This teacher identity may have shaped his instructional practice, leading to a focus on developing GIS skills through content-relevant, student-driven inquiry projects. In contrast, Mr. Bradley's standalone course was neither supported by earlier GIS capacity building courses nor connected to future courses in which students would apply the GIS skills they had learned. Given this organizational context, he primarily identified as a content teacher. Therefore, only minimal time could be devoted to learning the GIS technology and the focus was instead on building content understandings through the tool. Thus, the organizational and individual and collective contexts in which the GIS-infused instruction occurred may have shaped the specific practices and purposes for using GIS.

This work also underscored the importance of capacity building and adaptation in facilitating spread. With respect to "what spreads", we shifted our focus from the entire GSS model to tools and practices in the early stages of the project. This gave teachers flexibility in the co-design process to tailor their approach to their context and allowed for both of the appropriate adaptations examined in the cross-case comparison. In this way, expanding to incorporate capacity building courses and focusing on adapting tools and practices enabled us to further the spread of GIS-infused instruction in CPS.

In terms of our ongoing district-level partnership, this work also emphasized the value of participation. As is common in large urban districts, department restructuring, teacher turnover, and attrition have occurred. However, in areas where we had a critical mass of team members involved, we have been able to leverage the relationships we had developed and the capacity we had built to continue the partnership in spite of these organizational changes. Indeed, we have found that involving more stakeholders, from individual teachers to department leadership and central office staff, in a partnership leads to greater stickiness and potential for spread. For example, after significant restructuring occurred in the CTE department, we were able to continue our work because the new CTE director was involved in our partnership and planning discussions from the beginning. Additionally, given the success of Mr. Mitchell's and other teachers' capacity building courses at Addison High School, there is ongoing interest from the principal and teachers in expanding the role of GIS at this school.

The next phase of this work will entail revisiting which CTE pathways are the best fit for infusing GIS with the goal of developing both GIS-infused capacity-building and year-long capstone courses for those pathways. We also plan to gradually shift "who spreads" to the teachers and organizational leadership, rather than the researchers. To this end, we will continue to develop our current teachers into teacher-leaders who can train new teachers to implement the courses they've developed with the goal of creating a sustainable infrastructure to support GIS-infused instruction in CPS.

References

Bednarz, S. W., Chalkley, B., Fletcher, S., Hay, I., Heron, E. L., Mohan, A., & Trafford, J. (2008). Community engagement for student learning in geography. *Journal of Geography in Higher Education, 32*(1), 87-100.

Bodzin, A. M. (2011). The implementation of a geospatial information technology (GIT)-supported land use change curriculum with urban middle school learners to promote spatial thinking. *Journal of Research in Science Teaching, 48*(3), 2

Coburn, C. E., Catterson, A. K., Higgs, J., Mertz, K., Morel, R., & Coburn, C. (2013). Spread and scale in the digital age: A memo to the John D. and Catherine T. MacArthur Foundation. *Prepared for a convening at the MacArthur Foundation.*

Edelson, D. C., Smith, D. A., & Brown, M. (2008). Beyond interactive mapping: Bringing data analysis with GIS into the social studies classroom. *Digital geography: Geospatial technologies in the social studies classroom*, 77-98.

James, K., McGee, S., Uttal, D., & Kolvoord, B. (2020). Design-based research in GIS-infused disciplinary courses: Toward a design framework. In Gresalfi, M. and Horn, I. S. (Eds.). *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 2* (pp. 1111-1117). Nashville, Tennessee: International Society of the Learning Sciences.

Jant, E., Uttal, D., Kolvoord, B., James, K., & Msall, C. (2020). Defining and measuring the influences of GIS-based instruction on students' STEM-relevant reasoning. *Journal of Geography, 119*(1), 22-31.

Kolvoord, B., Keranen, K. & Rittenhouse, P. (2019). The Geospatial Semester: Concurrent Enrollment in Geospatial Technologies. *Journal of Geography*, 18 (1), pp. 3-10.

Lee, J., & Bednarz, R. (2009). Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education, 33*(2), 183-198.

NGSS Lead States (2013). *Next generation science standards: For states, by states.* Washington, DC: The National Academies Press.

National Research Council. (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academies Press.

Sherin, M., & van Es, E. (2005). Using video to support teachers' ability to notice classroom interactions. *Journal of technology and teacher education, 13*(3), 475-491.

Tatar, D., Roschelle, J., Knudsen, J., Shechtman, N., Kaput, J., & Hopkins, B. (2008). Scaling up innovative technology-based mathematics. *The Journal of the Learning Sciences, 17*(2), 248-286.

Uttal, D. H., Miller, D. I., & Newcombe, N. S. (2013). Exploring and enhancing spatial thinking: Links to achievement in science, technology, engineering, and mathematics? *Current Directions in Psychological Science, 22*(5), 367-373.

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Children and Parents Using Coordinated Multimodal Meaning Making During a Robot Coding Activity

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Abstract: Codable robots are now popular toys for families to play with at home. However, during play with codable robots, children may confront novel mathematical and spatial concepts that are central to achieving their coding goals. This work focuses on how parents use multiple modalities in representations with their children to elucidate and make meaning about these concepts. We present three episodes from a corpus of video recordings of parents and children completing a playful coding activity together in their homes. Our analysis reveals how parents support children during meaning making by strategically coordinating multiple modalities of communication, which become more concrete throughout the episodes. These concrete modalities, including physical artifacts and embodiment, support children's understanding of spatial and mathematical concepts, which facilitates their continued play with the robot.

Introduction

Recently, the popularity of codable robot toys in homes has grown exponentially. Codable robots are small robotic toys that children control with programming apps (Bers, 2010). These toys are designed to engage computational thinking skills, such as problem scoping, iterating and debugging, and computational thinking concepts, such as sequencing and logic (Brennan & Resnick, 2012). To date, research on children's play and learning with codable robots has primarily been conducted within formal learning environments (Ohland et al., 2019). However, there are many attributes of the home that are not available in schools which may contribute positively to children's learning with these toys. In particular, the availability of parents may shape children's thinking and learning (Rogoff, 2003). Thus, we examine parent–child interactions during play with a codable robot at home and ask how pairs communicate and make meaning about computational concepts that are central to their coding goals.

Codable robots may be ideal for children's learning at home because they afford constructionist principles like learning-through-doing (Papert, 1980). During play with codable robots, children practice generating procedures by setting their own goals for their robot's behaviors. The child must engage in problem solving to translate these goals into logical computational sequences. Because the coding programs associated with the robots use block-based codes, children are able to prioritize their attention on arranging commands selected from a list, rather than on syntactic elements like punctuation. As a result, children can more readily test and iterate their code. During testing, children receive visual feedback that connects their block-based codes to tangible objects and observable events, revealing errors and inspiring reflection and iteration (Bers, 2010; Papert, 1980). Essentially, the clarity of the block-based codes paired with the tangibility of the robot creates an accessible way for children to practice computational processes.

However, knowing how to program their robot to may require engagement with spatial and mathematical concepts. For example, children often need to insert numerical values into their codes to indicate the distance, speed, and direction at which their robot should travel. Despite the tangibility of the robot, children may be challenged to connect these spatial and mathematical concepts to how their robot moves, resulting in impasses in children's coding process. Yet due to the possibilities for fun and play involved in making a robot move, children may feel particularly motivated to overcome these impasses (Papert, 1980). Nonetheless, children may need additional support to apply spatial and mathematical concepts to continue making progress toward their goals. At home, parents may work with their children to overcome these impasses together, even though parents may be new to coding or may not have established pedagogical tools for supporting their children during coding activities. Thus, we ask how parents and children make meaning about spatial and mathematical concepts when working to overcome impasses during a coding activity. To answer this question, we virtually observed parents and children completing a playful coding activity with a robot together in their homes. This activity presented parent–child pairs with spatial and mathematical concepts that fell within children's zone of proximal development (Vygotsky, 1978), such that children could make meaning about these concepts with the help of a parent.

Framework

We draw from work that considers a sociocultural approach to learning (e.g., Rogoff, 2003; Vygotsky, 1978), which emphasizes that knowledge is co-constructed through social and conversational exchanges. Each person in a social context contributes to the learning through their unique knowledge, skills, and repertoires of practice. For children, the social context of the home environment includes the availability and contributions of parents, who provide a critical social context for children's meaning making and knowledge construction. Parents contribute to meaning making by taking on a guiding role, involving asking questions and directing children's attention (Callanan & Oaks, 1992; Eberbach & Crowley, 2017). During learning interactions, parents closely monitor and assist with their children's understanding and progress with a task by interpreting their verbal and nonverbal cues while attending to subtleties of the interaction (Goodwin, 2018). During play with codable robots, this monitoring behavior may allow parents to provide support to children in moments of impasse.

To provide the support necessary to overcome coding impasses, parents may call on the material artifacts and tools in their homes. In problem solving situations, such as coding a robot, cognition can be distributed among available material artifacts in the environment. People interact with these artifacts in social ways through embodied movements and actions (Hall & Stevens, 2015; Hutchins, 1995). Moreover, material artifacts support collective thinking by facilitating the construction of a shared visual representation, which promotes intersubjectivity and a common understanding of the relevant concepts (Stevens & Hall, 1998). A potential barrier to achieving intersubjectivity with material artifacts is that these objects and representations may be cognitively opaque cultural forms, such as complex tools (Goodwin, 2018). When these barriers arise, more experienced learners can support less experienced learners in using and understanding these forms to achieve intersubjectivity.

In addition to material artifacts, parents use a variety of strategies, many of which can be very subtle, to attune to their child's understanding and find alternate means of explaining concepts. These strategies are often embedded in various forms of communication, such as talk, gestures, the use of physical artifacts, and subtle bodily movements to direct children's attention (Tulbert & Goodwin, 2011), and could easily be overlooked. Studies of multimodality (Kress, 2010) inform our work because they help us tend to the affordances and functional specialism of these various *modalities* of communication and provide additional clues to *why* parents and children rely on different modalities at different times and for different purposes to convey meaning. Often, modalities are layered and used simultaneously or in contrast to nuance meaning (Kress, 2010). Given that children's meaning making about mathematical and spatial concepts can be difficult to elicit verbally in the context of a computational activity, we look closely at how parent–child pairs orchestrate various modalities as an indication of how the pair are making meaning together during their task. Thus, we implemented a method that facilitated close examination of these elements, namely interaction analysis. This microgenetic method offers a more fine-grained and systematic approach to understanding how learning happens interactionally.

Methods

We delivered a materials kit, containing a Sphero Bolt robot, two tablets (one for communicating with researchers and recording the process, and another for controlling the robot), and a felt rug with a map of an imaginary town, to families' homes. During the study session, we guided families through the setup of materials, led a short tutorial on how to use the Sphero, and facilitated participation in a thirty-five-minute coding task. This task required pairs to "take their robot on a trip" to different locations on the floor map. Researchers turned off their cameras and microphones and took field notes throughout the activity. The tablet used to control the robot captured the pairs' on-screen coding activities via a screen recording app. The second tablet was mounted on a tablet stand to record families' interactions and movement through Zoom's recording feature. For analysis purposes, the videos from both recordings were synced, enabling simultaneous viewing of the families' activities, interactions, and code.

Basing our analysis on traditions of interaction analysis work (e.g., Erikson, 2006; Jordan & Henderson, 1995) we began by taking field notes during observations of the pair's interactions and continued as we re-watched the video recordings alongside the pair's on-screen code inputs. We grounded our observations and notes in a variety of modalities of interaction, which meant tending to details like changes in the pace of the activity, shifts in bodies, and evolving expressions of affect as indicators of important moments. In this way, we located key moments where children relied on assistance from their parent to overcome a challenge in their computational tasks. Using these aforementioned cues, we chose episodes that we saw as beginning with initial moments of impasse in achieving the activity objectives and concluding with moments of resolution. Then we generated multimodal transcripts to document content and characteristics of talk, gesture, gaze, and manipulation of material artifacts and the on-screen code. We relied on varied transcription styles allowing us to tend to and report on the information that we observed was relevant to the participants during their interaction. Through careful attention to these transcripts during interaction analysis work, our research team documented and shaped our analysis by considering the sequence and context of each utterance and action, and how the interaction progressed towards a solution. This method of collaboration allowed us to draw on interdisciplinary expertise from the areas of learning sciences, developmental psychology, and computer science as we engaged in the process of discovering meaning making in the interaction. We see this spiraling process of data analysis (Creswell & Poth, 2016) as part of our foundation for identifying and refining the foci of our ongoing work, and also as our effort to see and notice meaning making happening from the perspectives of both the parents and the children (Hall & Stevens, 2015).

Findings

The following episodes show parents and children co-constructing visual representations and coordinating their interactions around those representations to understand mathematical and spatial concepts related to their task. Our findings provide detailed descriptions of how and why this process helps the pair to overcome moments of impasse. Similarities among these episodes reveal patterns in the interactions and demonstrate ways that parents and children use everyday meaning making to solve problems. The differences demonstrate the adaptability of this process in response to the nature of the concepts the pair encounter and the resources available to them.

Episode 1: Co-creating a computational plan using a durable representation

This segment of interaction follows Landon and his mother as they plan the trip their robot will take on the map (Figure 1a). The pair agree their robot will visit six non-adjacent destinations. These criteria play a role in how they choose their destinations while planning. Landon begins by communicating that his plan involves moving the robot from a house to the swimming pool, and then to school, but he soon demonstrates difficulty by starting over several times. As he recites this plan, his mother gazes at each location on the map and responds to him verbally. This creates a back-and-forth flow of talk consisting of his supplied information, her response, and their changing tones (see Table 1). At the moments when his mother is following along, she provides verbal affirmation (e.g., lines 2 and 6). When she is not following along, she pauses their flow (lines 4 and 18) with questions meant to clarify the locations to which Landon is referring. At these moments, Landon responds by recruiting gesture (Figure 1a), which he eventually adds to his communication of every destination. In line 10 the mother's pause serves to draw Landon's attention towards the adjacency of his two sequential stops, which violates one of their established criteria. On Landon's third attempt, his mother halts their sequence of talk and shifts her orientation away from their activity on the map by sitting up and looking around the room while looking around for tape and a marker to label their routes (line 24). She recruits material artifacts for co-constructing a visual representation to help keep track of their plan, allowing the pair to proceed with more certainty (Figure 1b).

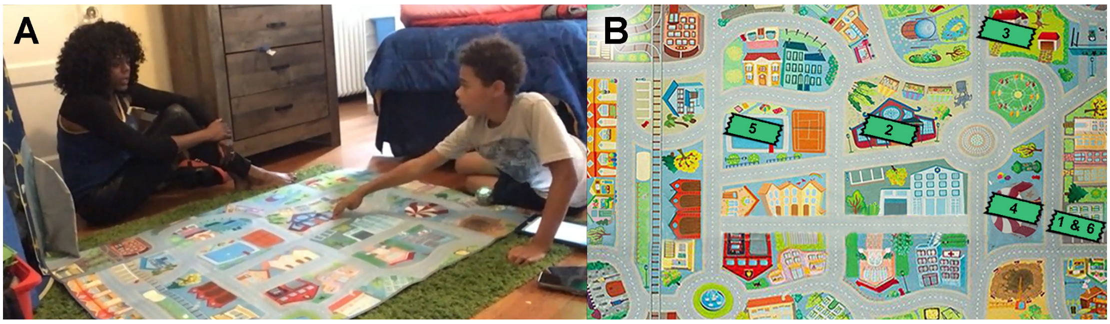

Figure 1. Landon gestures to refer to stops on his route (a). Recreation of Landon's final route (b).

Table 1. Transcript of Landon and his mother discussing the procedure for their code.

Line	Talk	Action
1	Landon: Right. So the ↑swimming pool.	
2	Parent: Yeaa↑ah	*moves gaze to swimming pool)*
3	Landon: To schoo↓ool.	
4	Parent: (.) Where's school?	*searches the map with gaze*
5	Landon: Hhh. Um, so actually- so- to our ↑house. to ↓school	*points to each spot as he names them*
6	Parent: Okay.	

Line	Talk	Action
7	Landon: To the swimming pool	
8	Parent: Right.	
9	Landon: And then-	
10	Parent: Oh wait. But they can't be right next to one another.	*points back and forth between spots*
11	Landon: °Oh° ((grunted))	
12	Parent: ↑It's okay.	
13	Landon: So, let's go to our ↑house.	
14	Parent: Yea	*starts following stops with gaze*
15	Landon: To the. ↓School	
16	Parent: Right	
17	Landon: To Craig and ↑Chris' house.	
18	Parent: Which is?	
19	Landon: Right here	*points to spot*
20	Parent: Okaaay	*places her finger on the spot also*
21	Landon: To. The Circus? (.) Which is right here	*points*
22	Parent: Mhmm.	
23	Landon: And toooo ↓the swimming pool.	*points*
24	Parent: Okay, so you know what we should do?	*sits up and looks around*

Note. In this first episode, we use a modified version of Jefferson's (2004) transcription notation to emphasize features of talk. Arrows represent rising or falling pitch, dashes mark cut-offs, degree signs enclose quieter talk, and a period in parentheses marks a short pause.

At a phase in their activity when the pair had to establish and agree on specific plans, the meaning that was communicated between them to achieve intersubjectivity happened interactionally and was built step-by-step with each utterance and action. Over time, pairs successively layered modalities of communication to offer clarity and stabilize understanding of their shared plan (Stevens & Hall 1998). Accordingly, the pair incorporated more physical and durable representations as time progressed, which leveraged their respective affordances towards more effective descriptions. They started with talk, making use of specific organizational features of their exchange like sequenced turn-taking and patterns of shifting intonation (Goodwin & Heritage, 1990). These subtleties allowed them to specify points where their understanding needed alignment for continued cooperation. To further align this understanding, they next relied on gestures (pointing) and then material objects (tape). This material numbering system had several affordances allowing them to carry out their task effectively. Their placement helped visualize the sequence of stops with a durable representation, yet their placement was malleable, which reserved room for changes to the plan. The labels also highlighted the spatial relationships necessary to confirm that they were aligning to the non-adjacent stop criteria.

Background information for the next two episodes

In the following episodes, parents and children are working on their code and have set a critical variable for navigating their robot called a *reference heading*. Thereafter, *heading commands* that incorporate numerical heading values tells the robot which direction to move. Initially setting a reference heading allows the child to arbitrarily decide a direction at which the robot is facing forward, or at zero degrees (0°). All subsequent heading choices within these individual codes are in relation to this global reference direction. For example, the code *Spin* asks children to input a heading. If the child inputs *90°,* the robot will turn ninety degrees with respect to the forward-facing direction chosen for the reference angle. Setting headings is central to the following episodes.

Episode 2: Employing embodiment to make sense of headings

Alan and his mother have set their reference heading to the direction facing away from the wall and are troubleshooting the headings needed to move their robot from the police station to the train station (Figure 2a). After a few missed attempts, Alan's mother attempts to clarify by tracing the desired route by pointing from "the police station" (Figure 2b) to "the train station" (Figure 2c). However, Alan's gaze is instead fixated on the tablet as he inputs a new heading for another iteration, which does not go as planned. His mother now suggests that he sits against the wall while physically moving him to align his body's forward-facing position to match the direction they set as zero before she tries to explain again (Figure 2d). After another attempt from his position against the wall, Alan's mother leans over, again demonstrating with her hand the direction the robot needs to go. However, at this moment, her speech and physical orientation are not aligned with Alan's perspective (Figure 2e), and his next result is still off. Then, Alan's mother demonstrates a reflexive awareness of how she can respond differently to her son's understanding by recruiting a new modality of communication (Goodwin, 2000), insisting that they stand up together to embody the robot in the same position on the map. Facing their reference heading while looking together at the tablet (Figure 2f), she shows Alan with her arm that the angle is behind and to the right. With this embodied enactment, he finally makes sense of the values and inputs *116*°, a heading that works.

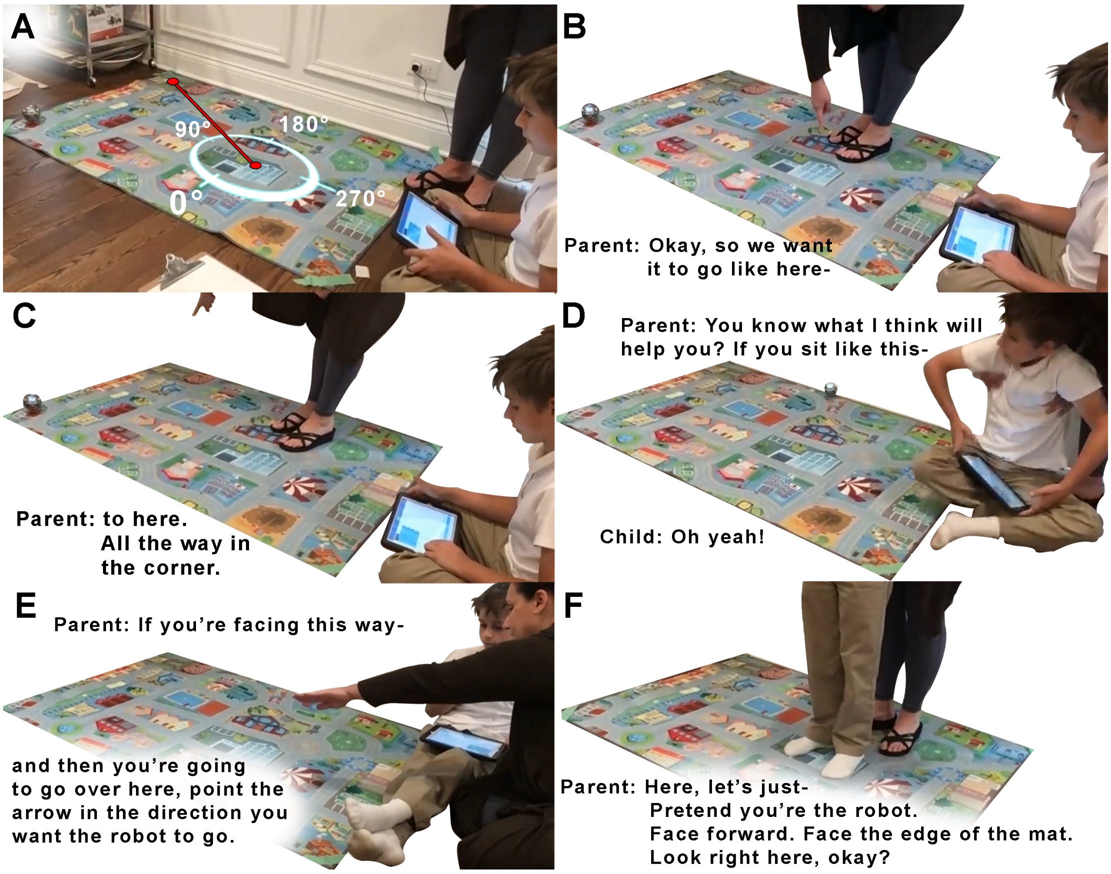

Figure 2. Alan and his mother embody the robot position to understand headings.

The tangible representations of a walkable map, along with the observable and physical outcome of the code enacted on it, allowed the pair to share knowledge and grapple with spatial and mathematical relationships of angles and headings (Horn, 2018; Ramey & Uttal, 2017). At key moments, Alan's mother led their meaning making through her multimodal communication, facilitating Alan's exploration of spatial relationships. By attuning to Alan's understanding and responding reflexively, she situated elements of their code in the material environment around them, providing rapid just-in-time feedback through both material and social mechanisms, which has been shown to support learning (Berland, 2016). Notably, she does so with an embodied relatedness that parents often possess (e.g., sitting closely to share visual perspectives, moving her son with care, and standing directly behind him while looking over his shoulder), which she employs to help choreograph his attention to the spatial relationships relevant for completing his task (Tulbert & Goodwin, 2011).

Episode 3: Sharing a material artifact to understand headings

Winter and her mother are using a compass tool placed around the robot to decide on the appropriate heading value to make it move to their next destination, "a sushi restaurant" (Figure 3a). After Winter assigns the reference heading, her mother asks what heading she chose. We see this question as an invitation for deliberation. Winter examines the compass and responds hesitantly, "Uh zero?" (Figure 3b). In response, her mother provides verbal, tonal, and gestural feedback which implicitly indicates that Winter should reconsider (Figure 3c). To process her mother's feedback, Winter briefly moves her finger counterclockwise along the compass. She then gestures with her hand to the left and asks if the direction she is pointing in is "more like 10" (Figure 3d). Her mother interprets from the response that Winter is still having difficulty estimating the angle adjustments based on a point farther away from the compass. Demonstrating reflexive awareness that her previous explanation using language and gesture was insufficient, Winter's mother pauses to suggest that they "get grandpa's ruler", which she races from room-to-room excitedly to find. This visual representation they construct with material artifacts serves to make the ephemeral radius that they both are referring to a durable representation. With the ruler in place (Figure 3e), Winter's mother sees an opportunity to reset the robot's reference heading to match the heading of their first destination. They coordinate their actions as Winter's mother holds the ruler in place while Winter positions a finger of her right hand in line with it on the compass tool. With her finger held in place marking the spot to which she needs to reset their reference heading, she sets the value (Figure 3f depicts a recreation for clarity). Next, Winter's mother checks for understanding by asking Winter the new value they need to input to reach the destination. Winter quickly responds with a definitive and punctuated "zero", an input that achieves the goal.

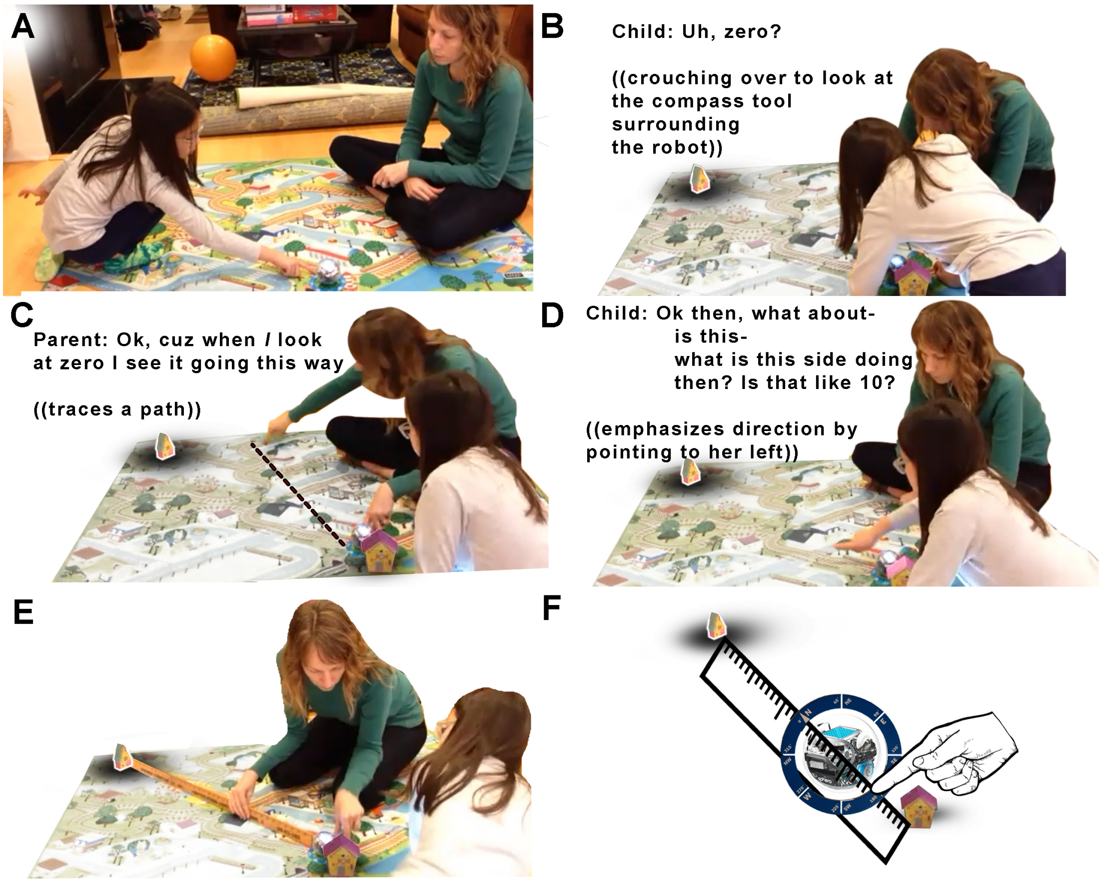

Figure 3. Winter and her mother use a ruler to help with selecting headings.

The ruler placed over the compass is simultaneously a physical representation of their prediction, a tool for greater precision, and an object around which to interact and build further meaning. Accordingly, the mother recruits this everyday object, a tool that is familiar to them both, to generate a locally productive (Hall & Stevens, 2015) flexible learning system (Hike, 1989) in support of the pair's co-construction of knowledge. In this way, they are able to use material artifacts to represent numerical headings (Hutchins, 2005). Winter's mother monitors the physical engagement with this artifact to evaluate Winter's knowledge, the focus of her attention, and the use of this strategy that is meant to help make sense of angles and headings. Staying close to the data only allows us to speculate about the cultural significance of the label "grandpa's ruler." However, the fact that the pair label it as their grandfather's possession, and that Winter exhibits such excitement as she races to various rooms in her house to locate it, indicates how the familiarity and intimacy of objects available in the home may be central to families' practices of constructing visual representations for problem solving.

Discussion and conclusion

This paper described how parents and children make meaning about mathematical and spatial concepts encountered during a playful coding activity at home. In all three cases, children reached moments of impasse during the activity when they grappled with mathematical and spatial concepts. For Landon, this moment surfaced from a need to simultaneously remember and consider information about routes, sequences, and spatial relations. For Alan and Winter, these moments were specific to understanding and manipulating numerical headings. Upon these moments of impasse, all three parents provided critical support that allowed their children to accomplish the coding task at hand. In turn, the pairs were able to continue engaging with the computational aspects of the activity.

Our analysis reveals a theme that parents adapt their communication to shift from verbal to more physical and material representations over the course of meaning making about mathematical and spatial concepts involved in computation with their children. This evolution in modalities emerged as parents closely monitored their children's use of multiple sign systems (Goodwin, 2000), including verbal communication, gestures, and computational input to the programming software. These sign systems served as representations that revealed how children were understanding the content. Parents reflexively responded to this understanding by improvising their communication strategies and recruiting various modalities, such as gestures, embodiment, and the use of material artifacts. In recruiting these resources, parents choreographed their children's bodily movements and directed their children's attention. These behaviors occurred in an intimate and seamless way that is unique and second nature to the parent–child relationship.

Ultimately, this evolution in modalities of communication was critical for the pair's meaning making about the mathematical and spatial concepts that emerged during the coding activity. By recruiting gestures and material artifacts and by coordinating embodiment, parents could reframe and reorient their children's perspectives, while also creating more stable representations of concepts (Hutchins, 2005). This reorientation led the pair to converge their attention on the same system of visual practices and to share the same reference frame. Consequently, the pair achieved intersubjectivity (Goodwin, 2000), allowing them together to establish the use of cognitively opaque cultural tools, such as the compass, and the parent to provide more complete explanations of concepts, phenomena, and practices. In this way, we see parents controlling and constraining parts of the activity that may be too challenging for the children while working alone (Wood et. al., 1976). Although not inherently computational themselves, the mathematical and spatial concepts and computation involved in the coding activity are mutually reinforcing, such that a child's understanding of these concepts supports their abilities to engage in the computation. Thus, this process by which parents reflexively adapt their modalities of communication and direct their child's attention at critical moments demonstrates the invaluable contribution of the meaning making that happens during computational thinking activities between parents and children.

In light of what we see as a dearth of information about how children learn computational thinking skills at home, this research depicts a micro-level analysis documenting the learning process that occurs when children collaborate with a parent on computational tasks. The method we employ offers a granular lens through which we could see the process of collaborative and distributed meaning making during computational tasks and identifies patterns in how this process unfolds. Moreover, our analysis works to account several attributes of the home learning environment, such as the availability of a parent, and acknowledges how this context facilitates parents' and children's abilities to call on familiar material objects, prior knowledge, and social resources that can support their meaning making. Accounts like these not only offer a more fine-grained account of computational meaning making but can incorporate and emphasize more culturally relevant and everyday forms of learning that happen across many contexts, and with many cultural forms (Horn, 2018), tools, and material resources. Therefore, this account represents an important perspective on children's computational thinking and learning at home.

References

Berland, M. (2016). Making, tinkering, and computational literacy. Makeology: Makers as learners, 2, 196-205.

Bers, M. U. (2010). The TangibleK Robotics program: Applied computational thinking for young children. *Early Childhood Research & Practice*, *12*(2), n2.

Bers, M. U., Flannery, L., Kazakoff, E. R., & Sullivan, A. (2014). Computational thinking and tinkering: Exploration of an early childhood robotics curriculum. *Computers & Education*, *72*, 145-157.

Brennan, K., & Resnick, M. (2012, April). New frameworks for studying and assessing the development of computational thinking. In *Proceedings of the 2012 annual meeting of the American educational research association, Vancouver, Canada* (Vol. 1, p. 25).
Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational researcher, 18(1), 32-42.
Callanan, M. A., & Oakes, L. M. (1992). Preschoolers' questions and parents' explanations: Causal thinking in everyday activity. *Cognitive Development*, *7*(2), 213-233.
Creswell, J. W., & Poth, C. N. (2016). Qualitative inquiry and research design: Choosing among five approaches. Sage publications.
Eberbach, C., & Crowley, K. (2017). From seeing to observing: How parents and children learn to see science in a botanical garden. *Journal of the Learning Sciences*, *26*(4), 608-642.
Erickson, F. (2006). Definition and analysis of data from videotape: Some research procedures and their rationales. Handbook of complementary methods in education research, 3, 177-192.
Goodwin, C. (2000). Action and embodiment within situated human interaction. *Journal of pragmatics*, *32*(10), 1489-1522.
Goodwin, C. (2018). Co-operative action. Cambridge University Press.
Goodwin, C., & Heritage, J. (1990). Conversation analysis. *Annual review of anthropology*, *19*(1), 283-307.
Hall, R., & Stevens, R. (2015). Interaction analysis approaches to knowledge in use. In Knowledge and Interaction (pp. 88-124). Routledge.
Hike, D. D. (1989). The family as a learning system: An observational study of families in museums. Marriage & family review, 13(3-4), 101-129.
Horn, M. S. (2018). Tangible interaction and cultural forms: Supporting learning in informal environments. Journal of the Learning Sciences, 27(4), 632-665.
Hutchins, E. (1995). Cognition in the Wild (No. 1995). MIT press.
Hutchins, E. (2005). Material anchors for conceptual blends. *Journal of pragmatics*, *37*(10), 1555-1577.
Jefferson, G. (2004). Glossary of transcript symbols with an introduction. *Pragmatics and Beyond New Series*, *125*, 13-34.
Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. The journal of the learning sciences, 4(1), 39-103.
Kress, G. R. (2010). Multimodality: A social semiotic approach to contemporary communication. Taylor & Francis.
Ohland, C., Ehsan, H., & Cardella, M. (2019). Parental influence on children's Computational Thinking in an informal setting. In 126th ASEE Annual Conference & Exposition (pp. 15-18).
Papert, S. (1980). Mindstorms: Computers, children, and powerful ideas. *NY: Basic Books*, 255.
Ramey, K. E., & Uttal, D. H. (2017). Making sense of space: Distributed spatial sensemaking in a middle school summer engineering camp. Journal of the Learning Sciences, 26(2), 277-319.
Rogoff, Barbara. The cultural nature of human development. Oxford university press, 2003.
Stevens, R., & Hall, R. (1998). Disciplined perception: Learning to see in technoscience. *Talking mathematics in school: Studies of teaching and learning*, 107-149.
Tulbert, E., & Goodwin, M. H. (2011). Choreographies of attention: Multimodality. Embodied interaction: Language and body in the material world, 79-92.
Vygotsky, L. S. (1978). Mind in society. Cambridge, MA: Harvard University Press.
Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of child psychology and psychiatry*, *17*(2), 89-100.

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Bridging the Divide: Exploring Affordances for Interdisciplinary Learning

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Abstract: This study investigates how the design of hybrid mathematics and computational activities influences the ways in which students leverage ideas from both disciplinary topics. We examine two design cycles of a computer programming summer camp for middle school students which foreground computational thinking and then mathematics alongside computational thinking respectively. We review the rationale for each design iteration, the trends we saw in students' engagement, and the implications for students' reasoning. Findings of this study demonstrate the importance of thinking critically about the boundary objects that are included in design that support students to make bridges between multiple disciplinary practices.

Introduction

There is significant support for the integration of computational thinking into mathematics classrooms due to content similarities in the domains of computer programming and mathematics (Pérez, 2018; Weintrop et al., 2016). These similarities suggest that learning programming and mathematics simultaneously might be a reasonable way to accomplish a goal of integrating computer science into K-12 classrooms (Harel & Papert, 1990; Gadanidis et al., 2017). However, little research has investigated these claims or, more profoundly, how the synergies between these disciplines might be designed for in such a way that both mathematical thinking and computational thinking would develop. Indeed, bringing two fields together necessarily creates tensions for designers, teachers, and learners; it is these tensions that constitute the focus of this paper. Specifically, we examine two rounds of design in a design-based research project that took two different approaches to support students to leverage mathematical and computational tools with personal agency. We review the design and rationale for each round of implementation, and then consider the implications for students' interdisciplinary reasoning as it is connected to design.

Background and framing

Computer science education is becoming increasingly common in the K-12 curriculum, and educators are adapting to the demand to equip their students with new computational thinking skills (Yadav et al, 2016). This has led teachers and other educational leaders to incorporate computer science through the adjustment or expansion of frameworks, pedagogies, standards, and lessons in the K-12 curriculum (Sentance & Csizmadia, 2016; Yadav et al, 2016).

However, it has been well-established that integrating different learning contexts is neither easy nor straightforward; whether the goal is to connect two disciplines or to connect in-school with out-of-school learning, there is significant evidence that learning is supported and transformed by the norms, tools, and practices of the contexts in which activity is situated (Nasir & Hand, 2008). Central to this idea is that the ways that learning environments are designed (for example, inviting students to think collaboratively one or two open-ended questions versus asking them to work independently on a set of 20 similar questions) fundamentally transforms the nature of what students ultimately learn. An important implication of this work is that "knowledge" is neither static nor abstract but is instead constituted in relation to the learning context (Engle, 2006), and therefore it is no simple or straightforward thing for knowledge to travel between contexts or to connect with new and different knowledge communities (Redish & Kuo, 2015). If learning is truly a *joint accomplishment*, then careful attention needs to be paid both to design and to learning.

How should an activity that invites mathematical and computational thinking be designed? Can one idea be introduced in service of another? Can one set of practices find a home amongst a set of sometimes intersecting but distinctly different practices? To better understand these questions, we draw from work on hybridity, which involves integrating norms and practices from one cultural activity into another. Although there have been many frameworks offered that address hybridity, here we rely on the idea of *boundary crossing* as a lens to examine student activity. As Akkerman & Bakker (2011) write, "A boundary can be seen as a sociocultural difference leading to discontinuity in action or interaction" (p. 133). While the practices and content of mathematics intersect with that of computer programming, there are clear sociocultural differences between the disciplines of mathematics and computer programming. This is especially true with respect to school-based mathematics, the context in which the participants of this study are most familiar with mathematics, which often involves engaging a set of facts and rules to be taught and practiced as an end in itself, in contrast to computer programming which includes design (Kafai, 2016), iteration, and revision. In this work we explore whether and how the particular designs that we undertook served to create bridges between the two disparate worlds of mathematics and programming. Using in-depth analysis of student and teacher discourse, we consider how the boundaries were drawn around these worlds, and how individuals and tools served as boundary objects to connect them. In using this lens, we seek to better understand not whether one design was more successful than another, but rather, how our specific design decisions played out with respect to how different worlds were connected.

Methods

The designs and data presented in this paper come from a larger design-based research study about how student thinking about computation and mathematics might co-develop. Design-Based Research (DBR) is an approach to conducting research with the goal of uncovering why something works and involves testing conjectures and investigating the relationship between activity and outcomes (Sandoval, 2014). As such, DBR is explicitly a theory-building activity, and requires intentional specification of the theories that underlie both initial assumptions and interpretations of data. In particular, theories of how people learn necessarily inform the initial designs undertaken. In contrast to implementation studies that examine whether a particular design is effective, design-based research includes multiple iterations and should specify the changes implied for next rounds of implementation. These cycles of research are a key distinction between understanding why this particular design might function and developing a more nuanced understanding of the relationship between designs and learning more broadly. Thus, the goal of these design iterations is to move beyond understanding what works to consider and be able to account for why it might have worked, with an eye towards not only the success of this design, but the potential success of future designs.

Participant description

The study focuses on the first two rounds of DBR; two free five-day summer camps that were held in two consecutive years. The camps, called *Code Your Art,* were designed for and attended by middle school students and advertised in public middle schools in a medium-sized city in the southern United States. In each year two classes were taught that focused on similar sets of activities; in Year one 30 students enrolled and were split across two classrooms; in Year two 24 students were enrolled and split across two classrooms. Each class was co-caught by two experienced teachers who taught elementary or middle school mathematics during the regular school year. Each classroom was also supported by teaching assistants and researchers who rotated through the classes as needed. The researchers, teachers, and teaching assistants made up the research team that designed and implemented these camps. For this analysis we will focus our interaction analysis on one participant from each year who both consented to all data collection for this study.

Design description

Code Your Art camp introduced students to the ways that a programming environment could produce visual effects and dynamic images. Students used a programming environment called NetLogo (Wilensky, 1999), a multi-agent environment that uses a text-based programming language to manipulate static pixels (patches) and movable agents (turtles). Students were told that by the end of the week their goal was to create a “final design,” which they would share with visitors at a “Gallery Walk” on the final day. Each day students learned a new set of ideas or strategies for creating different visual effects, with the idea that students would use and incorporate those effects that they found relevant to their envisioned design. The explicit stated goal of the research team was for students to see NetLogo as a set of tools that they could use expressively, but how to best position students to think of programming in this way was an open question. One specific question involved whether and how to engage the underlying mathematical ideas that are central to NetLogo, including the coordinate plane, inequalities, number lines, slope, angles, absolute value, distance, quantity and scale.

In Year 1 the design of the camp foregrounded computational thinking, accomplished by offering students a set of NetLogo models that they could explore and modify. Although many of these models involved mathematical ideas, the intentional design of the camp was to engage with underlying mathematical ideas when they were raised by students, such that students’ goals for their own expressive models guided the conversations. In Year 2, based on analyses from Year 1, the design team modified the camp, developing a set of activities that foregrounded mathematics and mathematical connections to NetLogo. Our analysis will focus on how this design iteration changed students' engagement in authoritative problem solving and expressive design in this hybrid math and computational learning space.

Debugging activities

At the end of the third day of Year 1, teachers and researchers designed a set of *debugging models* as an emergent response to significant growth but also some common challenges that students were facing. These models were intended to help students wrestle with and understand the challenges that they were facing as well as see how much they had already learned in NetLogo in order to shift students' ownership of the code.

Each debugging model contained a short description of what should happen in the model if it worked properly; students could read and edit the code embedded in a button in order to fix the "bug." In this analysis, we will focus the first of seven debugging models, *Paint a Square*. The Paint a Square debugging model is a hybrid activity in that its solution requires thinking about mathematics and about programming to create a white square by operating on a set of "patches," squares laid out on a coordinate grid in the model. Changing the color of specific patches requires specifying the patch's x-coordinate (pxcor) and y-coordinate (pycor) using the NetLogo coding language. In Paint a Square, when students clicked the "Setup" button, all of the patches in the window turned blue. When they clicked "make white square in center" a vertical white stripe appeared (Figure 1 Left). The code that produced this effect in Year 1 was "ask patches with [pxcor > 50 and pxcor < 150] [set pcolor white]" which asked all of the patches in the model with an x-coordinate greater than 50 and less than 150 to turn white. Because the window was set up for all students to operate on a coordinate grid with x-coordinates and y-coordinates from 0 to 200, this button colored a white stripe in the middle of the screen. In Year 2 the model was adapted to give directions from the perspective of a client and provide the student with "challenges" rather than a statement about what the model was expected to do (Figure 1 Right). In Year 2 the coordinate plane that is operating behind the NetLogo model ranged from -16 to 16 on both the x and y axis, and therefore the buggy code given to students in Year 2 was "ask patches with [pxcor > -5 and pxcor < 5] [set pcolor white]".

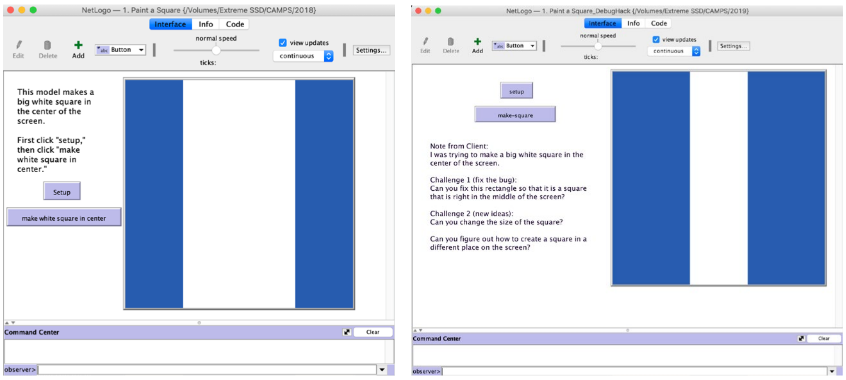

Figure 1. (Left) The Year 1 model after pressing "Setup" and then "make white square in center"; (Right) The Year 2 model after pressing "Setup" and then "make-square."

As stated, we argue that these debugging activities were specifically hybrid activities as "fixing the bugs" required using mathematics within a text-based computer programming activity. To solve this debugging model, students needed to use correct NetLogo syntax, have an understanding of patches as an agent in NetLogo, and use appropriate mathematical concepts such as the coordinate plane. Because of this intersection of mathematics and computational thinking, this set of activities in the camp was ideal to investigate the foregrounding of computational thinking in Year 1 as compared to the foregrounding of mathematics in Year 2. Our analysis will therefore specifically focus on Paint a Square, the first of these seven debugging activities. Because Paint a Square was students' first engagement with debugging this analysis gives a good representation of how the design of the camp and the implementation of the activities that led up to debugging led to differences in how students leveraged ideas from mathematics and computation in the debugging models.

Data collection

Data was collected throughout both camps through whole group video recordings, screen capture video from software installed on every computer, pre- and post-camp written surveys, and interviews. A go-pro was worn by a teacher in each class, a pivoting camera tracked and recorded teacher-student interactions, a standing camera recorded whole group interactions, and individual screen captures recorded individual students' work. Most of the screen-capture videos have a record of both the entire screen and the students face, but on some videos only the screen is visible. The focus of the analysis will be only on the data collected about the foregrounding design and student engagement in the Paint a Square debugging activity described above.

Analysis

Our analysis focused on two aspects of the camp: 1) the ways the designs created opportunities to bridge the disciplines of mathematics and computer science, and 2) how students' engagement bridged the two disciplines, and what designed supports appeared to help make that occur. To make sense of designed opportunities, we reviewed all whole-class activity that took place before the debugging episodes and marked times when mathematics and computational thinking co-occurred. We then considered those episodes, paying attention to when they took place and in what form.

To understand student engagement, we focus on two cases (Brianna from Year 1; Caleb from Year 2), who are representative of the trends in disciplinary approaches to problem solving in the first debugging activity, Paint a Square (Gresalfi et al, 2020), from each of their respective years. These cases represent times when the coordinate plane was operationalized concurrently with the NetLogo code. Using methods of discourse analysis, we looked for times when a participant made connections between the mathematics behind the NetLogo model (such as inequalities and the coordinate plane) and the code that communicates with the NetLogo model. For example, to draw a vertical line at x=-50 and a horizontal line at y=150, one might type "ask patches with [pxcor = -50 and pycor = 150] [set pcolor white]". This code would color a single patch located at the coordinate (-50, 150) white and therefore not reach the goal of the participant, but it would demonstrate that the participant is making a connection between coloring the patches at pxcor = -50 white and coloring the x-coordinates in the model that create a vertical line at x=-50 white. Evidence of bridging math and computer programming holds no matter if the code accurately achieves the mathematical goal in mind. In contrast, if a participant wanted to color a single patch at (-50, 150), they might type "ask patches with [pxcor < -50, 150] [set pcolor white]". This would demonstrate that the participant is not attuning to how the code pxcor relates to the x-coordinate or the relationship of the inequality to the values typed in the code, and therefore not engaging in bridging math and computer programming. These scenarios are also dependent on the context in which the code is typed and include the discourse around the creation of the code.

Findings

In the moment-to-moment interactions between teachers and students, we saw evidence that the different designs in Years 1 and 2 offered different resources that allowed participants to leverage computational and mathematical disciplinary ideas and practices. Specifically, we demonstrate how the Year 1 focus on ensuring that students' work and thinking drove the introduction of new mathematical content meant that there were clear boundaries between the worlds of math and computer programming, that were mainly bridged only by adults who served to broker relationships. In the examples from Year 1, students were reliant on one-on-one interactions with adults to help them connect mathematical ideas with the concepts and syntax of NetLogo. In contrast, the design in Year 2 meant that there were several tools that were provided by adults in anticipation of students needing mathematical connections to NetLogo that appeared to serve as boundary objects to connect the two disciplines. Our analysis of the whole group video data in both years revealed differences in the timing, resources, and motivations behind the opportunities that served as boundary objects for the Paint a Square debugging activity which resulted in changes in the ways in which students leveraged mathematics and computation concurrently.

Opportunities to bridge mathematical and computational thinking

As noted above, in Year 1 the design of the camp approached activities with an explicit goal of open exploration and modification of models in NetLogo. This meant that the underlying mathematics of the models was engaged as students generated a need for those ideas. Therefore, while students did often initiate conversations based around a need for a bridging opportunity between mathematics and NetLogo, it was generally adults who offered information about those bridges, becoming brokers between mathematics and NetLogo. In addition, in Year 1 an designed bridging activity took place on the second day of the camp that asked students to act as patches by holding colored cards and standing on a coordinate grid. The activity introduced a new set of commands that involved patch coordinate location (for example, "Ask patches if [pycor > 1] [set pcolor green]"). Before the commands were given, teachers noted that students were standing on a coordinate plane and each student was assigned a point (for example, 0,1) on which to stand. They engaged in a discussion about how the coordinate plane they were standing on was a limited version of the NetLogo model which was a limited (only positive integers) version of the coordinate plane. In this discussion, teachers also reviewed some basic properties of the coordinate plane. Students then held up various colored cards based on their location in response to NetLogo commands given. We argue that this moment of coordinate plane review offers a bridge between NetLogo and the mathematics of the coordinate plane.

In Year 2, based on analyses from Year 1, the design team modified the camp, developing a set of anticipatory activities that foregrounded mathematics and mathematical connections to NetLogo. For example, on the first day of camp in Year 2 students engaged in a Stadium Card activity similar to Year 1 but were much more explicit about the coordinate plane. Teachers led a whole group discussion that involved every student in the room contributing something they knew about the coordinate plane. At the same time, a researcher modeled students' inputs on the NetLogo model on the projected screen while another teacher drew students' suggestions on a white board. As students gave suggestions, the NetLogo model and white board representation of a coordinate plane were used interchangeably. This allowed students and teachers to bridge traditional school-math language such as words like "quadrant 1" and "x-coordinate" in place of or in conjunction with the NetLogo equivalent such a "top right of the model" or "pxcor." This is just one of four similar bridging activities that took place before debugging. This anticipatory design of utilizing the mathematics allowed for boundary crossing between mathematics and computation to occur collectively rather than in on-on-one interactions as it did in Year 1. The ways in which these boundary crossing opportunities were enacted had repercussions for student engagement and interactions with teachers in each year. We will also note that there were drawbacks to this emphasis on mathematics, as some students' interest in the camp waned that day, which was a noticeable difference from Year 1. We will look more closely at the result of these activities on student engagement through two representative cases from each year.

Year 1 paint a square

Our case in Year 1 focuses on Brianna, age 12, as she learns the connections between her model and the coordinate plane toward the beginning of her work with Paint a Square. At the start of the activity, she overheard a teacher saying that squares are equal on all sides. This led Brianna to change all of the inequality symbols in the code to equal signs and to make four statements in the code saying pxcor = 150, creating a thin vertical white line at x=150. She becomes frustrated and says "Oh, my gosh. I need help." A teacher (T) comes over to the table to check in. In this episode Brianna demonstrates confidence in her ability to use NetLogo as she adds new code and is also attempting to incorporate the mathematical properties of a square into her model.

Code:
```
ask patches with [pxcor = 150 and pxcor = 150 and pxcor = 150 and pxcor = 150] [set pcolor white]
```

1 **T:** How's it going at this table?
2 **Brianna:** Terrible.
3 **T:** Terrible?! You want to talk about it?
4 **Brianna:** Yeah.
5 **T:** Okay, what are you looking at?
6 **Brianna:** I'm trying to turn this into a square but it ain't working.
7 **T:** Okay. What's going on?
8 **Brianna:** I added two more pxcors because there are, because they're supposed to have four equal sides.

Brianna is attempting to utilize her knowledge about both mathematics and NetLogo, as her code is reasonable and her ideas about a square are sound. However, she doesn't yet seem to know how these mathematical properties can be communicated in her NetLogo model; it appears that she believes that "pxcor" relates to the length of the side of the square instead of the x-coordinate of a patch in the model. While it is true that she was attempting to connect mathematics with the NetLogo syntax, this connection was superficial and did not engage with the overlapping content between the code and coordinate grid. To truly hybridize the two, an adult needed to serve as the "boundary object" in the interaction. In this second episode that immediately follows, the teacher reads Brianna's code and assesses her knowledge of this code's connection to the coordinate plane. Based on Brianna's response, the teacher proceeds to teach Brianna about the connections between the code that she has typed, the coordinate plane in the model, and the resulting white stipe that she sees appearing when she runs her model.

11 **T:** *(continues reading code)* "and pxcor = 150 and set pcolor white." Okay, so just this, when it says, "pxcor = 150," where are all the patches with pxcor = 150?
12 **Brianna:** I don't know.
13 **T:** Well, what do they mean? Let's look. Let's hit 'Okay'. (*Brianna runs model)* And if you - oh, no. What happened when you clicked that button?
14 **Brianna:** Just made a skinny line.
15 **T:** It made a skinny line [chuckle]. That's not what you wanted, was it?

16 **Brianna:** No.
17 **T:** No. Awesome. Okay, so where, if I'm looking on the XY plane, where are my X coordinates? Are they horizontal or vertical?
18 **Brianna:** Horizontal.
19 **T:** Horizontal. Awesome. Okay. Where do you think maybe the X coordinate 150 is?
20 **Brianna:** Somewhere over here. (*Gestures to the screen)*
21 **T:** Somewhere over here. Okay. What did you ask the patches to do? Yeah, open that up. (*Right clicks on 'make white square in center' button and opens the edit code tab)* When you say, "Ask patches with pxcor = 150, turn your color white," what are the patches doing? Which ones are turning white?

In line 17 the teacher makes a direct connection to the coordinate plane, and Brianna responds correctly to inquiries about the x-axis (line 18) and the general layout of the coordinate plane in her model (line 20). The teacher then proceeds to help Brianna cross the boundary between mathematics and NetLogo by relating her code "pxcor =150" to the patches on the coordinate plane that she sees turn white in her model (line 21). This line of inquiry and instruction continues between Brianna and the teacher who works one-on-one to connect the NetLogo model and the code used to communicate with it to mathematical concepts needed to solve the problem. Throughout, Brianna communicates to the teacher what she wants to do mathematically in the model and the teacher helps Brianna to understand how to communicate these mathematical concepts to NetLogo. Together, they finalize a model that makes a big white square in the middle of the model.

Brianna's interactions with the teacher were indicative of many students' engagement with Paint a Square in Year 1. It often seemed that they knew how to use the mathematical concepts needed to solve this model, but they are unable to bridge the gap of communicating the mathematics with NetLogo. Therefore, while mathematics and computation are used frequently and concurrently in the debugging models, it is almost always prompted by the mathematical ideas and their connections to the NetLogo code in one-on-one interactions with a teacher. As Akkerman & Bakker (2011) state, "individuals crossing boundaries show how they not only act as bridge between worlds but also simultaneously represent the very division of related worlds" (p. 140). This seems to be the case in examples from Year 1; the boundaries between mathematics and programming remain very clear, and requires the engagement of a broker, in the form of a teacher, to help bring those worlds into contact and conversation. Akkerman & Bakker (2011) characterize this kind of boundary learning as *identification,* which involves "…a process in which previous lines of demarcation between practices are uncertain or destabilized because of …increasing similarities or overlap between practices. The reported processes of identification entail a questioning of the core identity of each of the intersecting sites" (p. 142).

Year 2 paint a square

Our case in Year 2 focuses on Caleb, age 12, during his first attempt on his debugging model. He begins by changing "pxcor < 5" to "pycor < 5" in the original code which changes all the patches in the bottom right corner of the model white. This was a common first attempt in both Year 1 and Year 2. A teacher looks over Caleb's shoulder as he runs his model and engages him in conversation. During the following interaction, Caleb uses some of the school-math vocabulary that was incorporated into the camp by students the day before and uses the concepts from that discussion to create a unique potential solution.

Code 1:
```
ask patches with [pxcor > -5 and pycor < 5] [set pcolor white]
```
1 **Caleb:** Huh
2 **T:** Oh. You got a square but it's just not in the middle
3 **Caleb:** Oh, I see.
4 **T:** He had a square, but it wasn't in the middle. *(directed at another teacher)*
5 **Caleb:** Oh, I know what to do! I know what to do! I know what to do. *(rubs hands together with excitement)*. So, you do, um, you do, you do a square in the first quadrant, second quadrant, third quadrant, fourth quadrant. *(motions in the air to four corners of an imaginary box)* =
6 **T:** = I mean. Okay! Okay! Okay! =
7 **Caleb:** = And it's a square. *(Copy and pastes first line of code three more times and changes each of the inequalities to be either less than or greater than 1 or -1. Runs code to get a smaller white square in the bottom right of the model.)*

Code 2:
```
ask patches with [pxcor > -1 and pycor < 1] [set pcolor white]
ask patches with [pxcor > 1 and pycor < -1] [set pcolor white]
ask patches with [pxcor > -1 and pycor < -1] [set pcolor white]
ask patches with [pxcor > 1 and pycor < 1] [set pcolor white]
```

8 **Caleb:** Wait, what?!

Despite this confusion when getting a square in the corner of his interface when he ran his code (line 1), Caleb quickly assesses this feedback (line 3) and excitedly begins a new strategy, to make one square in each quadrant (line 5) which would come together to make one big square in the middle. His use of the uniquely school-math term “quadrant” as it relates to the coordinate plane in his explanation was common in Year 2 as it referenced the whole group discussion and brainstorming activity that involved identifying the four quadrants of the coordinate plane. With this idea of using quadrants in mind, Caleb replaces all of the numbers in the model to four combinations of 1 and -1, representing the four coordinates closest to the origin in the (line 7 and Code 2). The result is unexpected (line 8). After making a few unsuccessful edits (not shown here but named Code 3 and Code 4) he returns to Code 2 and proceeds with his potential solution.

14 **Caleb:** Oh, I could just delete this. *(deletes all inequalities)*
15 **T:** But you’ve got to have some kind of inequality!
16 **Caleb:** I could just do that. *(Replaces all inequalities with equal signs. Runs code. Gets error due to 1 missing equal sign)* Oh and right here *(types in equal sign)*. Setup. Make Square *(Runs code. Four patches turn white surrounding the origin of the coordinate plane)*

Code 5:

```
ask patches with [pxcor = -1 and pycor = 1] [set pcolor white]
ask patches with [pxcor = 1 and pycor = -1] [set pcolor white]
ask patches with [pxcor = -1 and pycor = -1] [set pcolor white]
ask patches with [pxcor = 1 and pycor = 1] [set pcolor white]
```

17 **Caleb:** *Smiles and looks around to people in his vicinity.*
18 **T:** Ohhhhhh! Okay! Okay! We got 4 squares! *(smiling)* They are -
19 **Caleb:** They are in the middle! *(turns computer to show the people around him)*
20 **T:** You need one square though. That IS kind of awesome.

While, Caleb’s code didn’t initially work because he wasn’t attending to the inequalities in the code, it was apparent from his conversation with the teacher (line 5) that he was attempting to paint the patches located at (-1,1), (1,-1), (-1,-1) and (1,1) white. This is confirmed when he replaces the inequalities with equal signs in Code 5. With his code, Caleb gets 4 small squares that are separated by the points on the x-axis and y-axis of his model which remain the background color of the model. While this isn’t what the “client” in the model asked for, both Caleb and the teachers in the room are impressed and proud of this move toward a solution (lines 17-20). This episode demonstrates Caleb’s use of relevant mathematical concepts based on the whole group discussion about the coordinate plane that preceded the debugging activity, but also his ability to concurrently use those mathematical concepts with the NetLogo code to manipulate the objects that make up the coordinate plane in the model to authoritatively produce an interesting and unique solution alongside but without direct instruction from a teacher.

Caleb demonstrates behavior and interactions with teachers that were typical of his fellow campers in Year 2. Notably, in Year 2, while students still interacted with teachers regularly, the mathematical ideas and the ways to communicate those ideas to NetLogo were largely initiated and pursued by the students. As in Caleb’s case, students often even ignored or corrected teacher’s advice or suggestions, but they did seek assistance when needed to develop new syntax vocabulary or mathematical connections when models didn’t work as expected. Students in Year 2 appeared to demonstrate more authority in their problem solving as a result of having tools necessary to utilize the mathematical content that they knew alongside the computational skills they learned about NetLogo during the camp. This led to more unique solutions to problems and increased ability to develop expressive designs through code.

Conclusion and discussion

In this paper we have focused our analysis on two cases which are examples of the kinds of interactions that we routinely observed in each year of the camp. However, we are mindful that single contrasting case studies are not intended to offer generalizations, and thus we offer a set of conjectures that we feel come out of this analysis. While there are many factors that contributed to differences between students’ experiences in the two years of the Code Your Art camps, the representative cases of hybrid math and computational reasoning that we have explored demonstrates that the design of boundary crossing activities was crucial to students’ engagement in this hybrid learning activity. These bridging activities are ones which enabled students to explore and make connections between multiple disciples. While students in Year 1 successfully completed the Paint a Square activity and did so with high levels of engagement, their success required an expert teacher to broker the connections between mathematics and the computer model in one-on-one interactions, much like we saw in Brianna’s episode. This means that students in Year 1 were constrained in exercising their own agency in exploring different solutions to the debugging problems. Students in both years were certainly productive and knowledgeable of both mathematics and computation, but they demonstrated differences in their agency, problem solving, and expressive designs in the context of debugging. This indicates that the ability to utilize mathematics and NetLogo concurrently is significant to authoritative problem solving in this debugging model. As seen in Year 1, it wasn't enough for students to know the mathematics and to know NetLogo, they had to shift into using both of these disciplines concurrently, which was made more likely to occur independently in Year 2 as a result the implementation of collective boundary crossing activities. Students' engagement with these activities, which elicited relevant mathematical and computational knowledge and skills, demonstrated how both disciplines were connected and could be used concurrently and fluidly to pursue and find unique and interesting solutions to this debugging model.

In order for students to productively engage in learning spaces that require engaging multiple disciplines to solve problems, the designers of those spaces could attune to the areas of intersection between the two disciplines. Preparing students to bridge disciplines requires that the design elicit and demonstrate necessary ideas from each discipline but also demonstrate how these disciplines are connected. As in the Year 2 iteration of the camp outlined in this study, this could come in the form of designing bridge activities within which students can learn to engage in a new form of hybrid participation, one that is neither strictly mathematics nor strictly computer programming. This could offer the potential to develop authority in their problem solving that leads to unique solutions to open problems as the result of the resources available to students based on design. As we see technology and the computer sciences expand into nearly every domain of our global community, the implications for this kind of participation in multidisciplinary learning and problem solving with computers across various disciplines is far reaching and relevant now more than ever.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. Review of educational research, 81(2), 132-169.

Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. The Journal of the Learning Sciences, 15(4), 451-498.

Gadanidis, G., Hughes, J. M., Minniti, L., & White, B. J. (2017). Computational thinking, grade 1 students and the binomial theorem. Digital Experiences in Mathematics Education, 3(2), 77-96.

Gresalfi, M., Brady, C., Knowe, M., & Steinberg, S. (2020). Engaging in a New Practice: What Are Students Doing When They Are "Doing" Debugging?.

Harel, I., & Papert, S. (1990). Software design as a learning environment. Interactive learning environments, 1(1), 1-32.

Kafai, Y. B. (2016). From computational thinking to computational participation in K--12 education. Communications of the ACM, 59(8), 26-27.

Nasir, N. I. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. The Journal of the Learning Sciences, 17(2), 143-179.

Pérez, A. (2018). A framework for computational thinking dispositions in mathematics education. Journal for Research in Mathematics Education, 49(4), 424-461.

Redish, E. F., & Kuo, E. (2015). Language of physics, language of math: Disciplinary culture and dynamic epistemology. Science & Education, 24(5-6), 561-590.

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. Journal of the learning sciences, 23(1), 18-36.

Sentance, S., & Csizmadia, A. (2017). Computing in the curriculum: Challenges and strategies from a teacher's perspective. Education and Information Technologies, 22(2), 469-495.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. Journal of Science Education and Technology, 25(1), 127-147.

Wilensky, U. (1999). Center for connected learning and computer-based modeling. In NetLogo. Northwestern University.

Yadav, A., Hong, H., & Stephenson, C. (2016). Computational thinking for all: pedagogical approaches to embedding 21st century problem solving in K-12 classrooms. TechTrends, 60(6), 565-568.

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Teacher Learning of Novel Computer Science Concepts and Practices: A Collaborative and Expansive Approach

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Abstract: This paper presents findings from a study of elementary teachers participating in professional development (PD) developed to accompany a novel computer science instructional unit. This 7-lesson unit introduces students to programming concepts by having students first play an "unplugged" tabletop board game and then create game levels in Scratch. The PD sessions were structured as a set of participatory routines where the previous week's lesson was reviewed, the upcoming lesson was modeled, and then adaptations to it were discussed. Teacher discourse analyses during PD revealed three kinds of sense-making episodes (reflections, connections, suggestions). Analyses also showed that connection and suggestion episodes were frequently grounded in the board game, matching the intent of the instructional approach for supporting teacher learning. Finally, a majority of the suggestions made by teachers during PD were used during subsequent classroom enactments, indicating teachers' reliance on each other despite their collective lack of experience teaching this content.

Introduction

Elementary level teachers are increasingly being asked to teach computer science (CS) in their classrooms (Blikstein & Moghadam, 2019). However, these teachers often have limited prior knowledge related to CS content, practices, and pedagogy. Teacher professional development (PD) is the typical means for addressing such gaps. Yet evidence on the effectiveness of PD in supporting teacher learning and creating sustainable change in classroom practice is decidedly mixed (Lefstein et al., 2020). This could be because many PD experiences are often in the form of presentations of curriculum and content to teachers rather than opportunities for teachers to reflect and more actively participate in the PD experiences.

In response, new approaches, called collaborative PD, have been developed that invite teachers to be active participants in the process. Examples of activities in such PD approaches for CS include engaging teachers in collaboratively designing (Biddy et al., 2021), modeling (Goode et al., 2014), and reflecting (Yadav et al., 2018) on CS curricula and curricular activities. While these approaches are promising, there is a need to better understand how teachers engage in collaborative PD and the interactions that take place during these kinds of experiences (Walkoe & Luna, 2019). This is especially true for elementary level CS, where little is known about how teachers learn about and teach unfamiliar CS content and curricular activities. Given that the demand for elementary teachers to integrate CS into their instruction is only going to grow, it is important for learning scientists interested in teacher learning to more closely examine teacher PD in this area.

This study attempts to do some of that work. This study is part of a larger design-based implementation research (DBIR) project (Penuel et al., 2011), centered on designing and supporting a CS unit for fifth-grade students. During our second iteration of this design (and the focus of this paper), we were especially interested in the teacher experience of learning, adapting, and enacting this new unit. Our analyses thus focused on teacher discourse during PD experiences to gain insights into how teachers participated, what they learned, and how this influenced their subsequent classroom enactments. Our study was guided by the following research questions: What was the nature of teachers' discursive participation in collaborative PD for this new CS unit? How did collaboration within the PD influence teachers' learning of CS content and pedagogy in ways that influenced their classroom enactments?

Curricular and professional development approaches

The curriculum followed a model for designing CS instruction that we call "Expansively-framed Unplugged" or "EfU" (Lee & Vincent, 2019). The underlying intent of the EfU model is to engage learners with relevant CS content and practices through activities that are personally familiar or accessible and typically do not involve digital technology. These approaches are typically referred to as "unplugged" (Bell et al., 2009). One motivation for using an "unplugged" approach at first is to shift learner's expectations about what one needs to know and understand in order to engage with computing.

EfU is based on the theory of expansive framing (Engle et al., 2012). This theory of transfer posits that making frequent connections back and forth between the context of learning and the context of transfer can help learners create an encompassing context that aids in knowledge transfer. That is, the framing of what kind of activity is being completed is broadened to encompass both the unplugged experience and the digital instantiations (usually in the form of a written computer program).

To enable expansive framing to happen, Engle et al. (2012) identified several specific ways in which connections can be made to help create and strengthen that encompassing context. These include supporting learners in *connecting* settings in order to cue relevant prior knowledge, *understanding* how skills and practice in one setting are useful in a future setting, and *authoring* and *creating* in the new contexts. This model has been used to design more broadly appealing instruction (e.g., Hickey et al., 2020), as well as computational thinking curriculum and assessments (e.g., Grover et al., 2014). In our work, it has been the basis for a design framework for sequences of unplugged-to-plugged CS learning activities (Lee et al., 2020).

Collaborative and participatory professional development

CS represents new territory for elementary teachers to include in their teaching. And while PD has long been used to support teacher learning of new content and curricular approaches, more recent collaborative PD approaches have emerged. These aim to scaffold teachers in engaging in peer discussions, reflecting on the intentions and enactments of new curricula (Borko, 2004; van Es & Sherin, 2008), and developing a shared process for designing and planning adaptations to the lessons to support classroom enactments (e.g., Biddy et al., 2021; Severance et al., 2016; Voogt et al., 2015). These activities offer opportunities for teacher learning as they are closely linked to their everyday experiences and challenges (Putnam & Borko, 2000). Within these collaborative PD approaches, what has been less studied is the *process* of teacher learning during the course of PD engagement; for example, how teachers make connections to their prior knowledge, and how they take ownership of these new ideas in ways that influence their classroom enactments (Walkoe & Luna, 2019).

Although EfU was intended as a situated approach to support student learning and transfer, we posit that it also applies to teachers with little CS and programming background by helping them, like their students, make connections from their prior knowledge to new CS content. Unlike the other topics they may teach, elementary teachers are often also learners in the CS content area, and the EfU model designed for students may benefit teachers as well. Thus, we posit that designing a CS curriculum informed by unplugged ideas and expansive framing will lead to activities with low threshold for *both* teachers and learners. Further, when the accompanying PD is supportive and collaborative, it will help teachers with little computer science background successfully engage with, adapt, lead, and support such activities. We next describe a study to examine these conjectures.

Methods

Setting and participants

The project was oriented as design-based implementation research (Penuel et al., 2011). Specifically, we worked with a local school district to address a problem of practice (offering CS education at the elementary level), to commit to iterative design (implementing in different schools), to contribute to theory (examining design implications of EfU for students and teachers), and to design for sustainable change (involving teachers in collaborative PD).

To address this problem of practice, we designed a new instructional unit that could accommodate the time constraints faced by teachers. We also deliberately involved school library time and school librarians as per the partnering district's request. As discussed elsewhere, librarians, and school librarians in particular are beginning to take on some of the role of providing CS learning opportunities for their library patrons (Lee et al., 2020). We worked closely with two rural elementary schools, one each year over two years. For the current study, we focus on the second iteration, involving three fifth-grade teachers (Maria, Teresa, and Debbie; all names are pseudonyms), one teacher librarian (Julia). The fifth-grade classes enrolled 74 students.

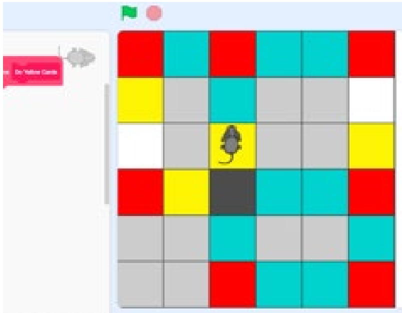
Expansively-framed unplugged CS curriculum

Following the EfU model, we designed a seven-lesson CS curricular unit to fit within teacher and librarian allotted time for this unit. The initial draft of the scope and sequence of the unit was sketched at a high level by the researchers with the intention of using the collaborative PD sessions (described below) as a space for teachers and the librarian to propose adaptations for their specific school context.

In this unit, students first play an unplugged tabletop board game, *//Code: On the Brink* (see Figure 1) which, as a game, may be more broadly appealing while also serving as a rich space to explore several computing concepts. Students then play a digital version of the same board game programmed in the block-based programming language, Scratch (see Figure 2). Finally, students create and program their own game levels and challenge other students to play them.

The lessons were designed to span both the classroom (preparatory lessons introducing CS concepts) and school library (playing the board game and programming the digital version of the game). Game playing was situated in the school library because it aligned with the partnering district goals, and, as found in prior research, board games were a common library activity for students in the district (Lee et al., 2020). Classroom and library enactments for a lesson each lasted approximately 20 to 30 minutes.

Table 1 shows an overview of how the unit unfolded across lessons and classroom and library settings, and the specific CS concepts addressed. Specific lessons also highlighted EfU phases, including connecting to prior knowledge (lessons 1-3), connecting between settings (lessons 3-6), and authoring (lessons 6-7).

Figures 1 & 2: Sample Levels from *//Code: On the Brink* tabletop board game and Scratch version

Collaborative professional development: structure and routines

The three classroom teachers, teacher librarian, and two researchers participated in weekly 45-minute collaborative PD sessions that preceded each of the seven lesson's enactment. Each PD session was structured to follow a set of participatory routines: 1) reviewing the previous lesson's enactment, with a focus on noticing equitable student participation and engagement, 2) modeling the current lesson, 3) discussing the lesson and related CS concepts, 4) discussing adaptions to the lesson plan, and 4) revising the lesson plan based on that day's discussions. All lessons plans were developed using Google Docs to support easy modifications and commenting by researchers and teachers alike.

In the first three PD sessions, a researcher modeled the lesson while the teachers acted as classroom learners, thereby using a "teacher-as-learner" modeling approach where teachers engage in the unit as students (Goode et al., 2014). In the final four PD sessions, each teacher took a turn leading the lesson while the others acted as students. Note that not all teachers were able to attend all PD sessions.

Table 1: Focus of each PD session and accompanying classroom and library lessons

	Lessons 1-3	**Lessons 4-6**	**Lessons 6-7**
Classroom	Learn about conditionals and step-by-step programming	Learn about conditionals, procedures & how to program in Scratch	Review CS concepts in the game
School Library	Play board game and Scratch versions of game	Design and program own game levels	Play each other's games
CS concepts	Conditionals, algorithms, procedures	Conditionals, debugging, simulation, abstraction	Review
EfU phases	Connect board game play and prior knowledge	Understand how board game play informs game design and programming	Author (program) new game levels

Data sources and analyses

Audio recordings of the seven PD sessions and classroom enactments for all three teachers were transcribed and then inductively coded, categorizing utterances by their conversational purpose (e.g., reflection) as well as content (e.g., pedagogy). Talk unrelated to the curricular unit was not coded (e.g., "I have bus duty so we need to shift the meeting time"). Among the conversational purposes coded were *suggestion*, *reflection*, and making a *connection*.

Once utterances were coded for purpose and content, we noted that the discourse typically consisted of extended collaborative discussions. These were coded into episodes called *suggestion*, *connection*, and *reflection*, or collectively, *sense-making* episodes. These episodes framed much of the meaningful conversation that occurred during the PD, and, in what follows, we describe these episodes to provide context for the findings that they frame.

The sense-making episodes consisted of at least one of the three types of utterances, as well as a *triggering event* that caused the utterance to be made. This would often take the form of the first part of an adjacency pair (Schegloff & Sacks, 1973), such as a peer's question. The focal utterance (i.e., suggestion, connection, or reflection) would be the second half of the adjacency pair. Then we examined the "trailing" conversation that occurred after the utterance was made. This tended to contain concurrences or clarifications from other participants. The episodes were bounded by the presence of the adjacency pair or statement of a new topic. All utterances coded as suggestion, reflection, and connection were included in episodes, although some were grouped into the same episode if they focused on the same conversational topic and occurred close to one another. This would happen, for example, when two teachers would make suggestions in response to the same question.

After identifying these sense-making episodes, they were coded to determine their topic and the type of triggering event for each. We also analyzed them for various other features, such as length, placement within the PD, and the type of utterances that occurred in the trailing conversation. Finally, after identifying all episodes, we looked for evidence of the use of a suggestion or connection made during the episodes that translated to the classroom by reviewing the classroom enactment transcripts.

Findings

Overall, we found increasing teacher participation in the PD over the course of the 45-minute PD sessions. Figure 3 shows how the number of sense-making episodes grew over the seven sessions, with a 60% increase in the number of episodes in the final three sessions as compared to the first four. In those final three sessions, the teachers, rather than the researchers, were modeling the lessons.

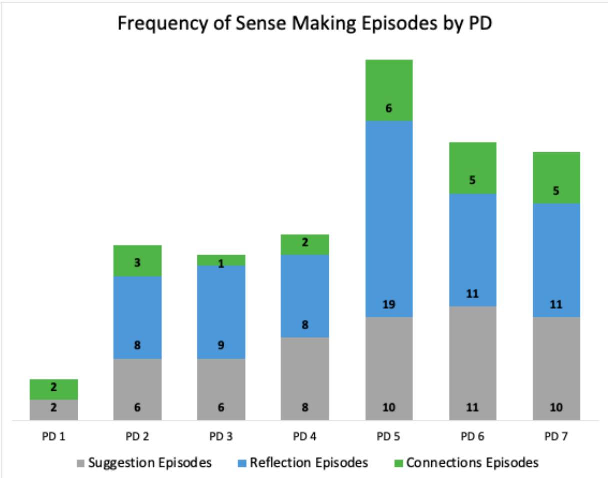


Figure 3: Frequency of sense-making episodes over PD sessions

We found that conversations during suggestion and connection episodes in particular were important in affecting the ways that teachers made sense of CS ideas. We next describe these two types of episodes in more detail and illustrate how they affected teachers' pedagogical choices during classroom enactments.

Suggestion episodes

Suggestion episodes occurred when teachers recommended changes to the lesson plans for the CS unit. While some of the episodes contained only one suggestion made by a single teacher, many contained multiple suggestions made by multiple teachers as they engaged in conversation about a particular topic, such as how to teach the concept of a procedure to students.

In the following example suggestion episode, Maria, a teacher, is modeling the upcoming lesson where game cards specify moves (e.g., hop forward) made by the game piece (a sprite) and acting as if she were talking to her students (Macey and Jacob):

Maria: So, if you made your own card, like 'I know, Macey [a student], you did a hop forward', 'I don't know what hop forward means'. 'I'm the sprite, so you're gonna have to tell me'. So, we're gonna have to make our own procedures right here for what it means to hop forward.

Julia (Librarian): Well, it means 'just hop forward', is what they [the students] said to me.

Maria: ‘Okay, Macey, what does the hop, hop forward mean to you, think it in your head’. ‘Jacob, what does it mean?’ ‘Ok, what does it mean, Macey’, she tells me, ‘Jacob [a student] tell me.’ ‘Oh, so like this, or like this?’ (*Maria hops twice)*. ‘Which one? Who's right? How do I know?’

Debbie: Okay, that works.

Here we see Julia, the librarian, make a comment about what students have said to her in the past and therefore how they would likely respond. Taking this into account, Maria then incorporates the suggestion seamlessly into her modeling of the lesson, showing how the teacher can have students demonstrate their personal definitions of a procedure to show the importance of procedural precision.

Over the seven PD sessions, teachers generated a total of 53 suggestion episodes (see Figure 3). Further, teachers made 41% more suggestion episodes during the final three PD sessions, when the format of the PD was more teacher-led. Suggestion episodes covered a variety of topics—the use of Scratch, general pedagogy, and CS-specific pedagogy. In particular, 41 (77%) of these suggestions were pedagogical in nature, with half of those being specifically related to CS pedagogy.

Finally, we note that peer questions and peer reflections triggered a majority of the suggestion episodes, accounting for 36 of the 53 (70%). This is indicative of the value of teacher-led conversations and peer collaboration in helping teachers develop agency in recommending adaptations to the lessons. This claim is further supported by the fact that 10 additional suggestions were made when teachers were modeling upcoming lessons—a component of the PD that was teacher-centered and teacher-led.

Connection episodes

Connection episodes illustrate how teachers make connections between the CS content and other content. The connections focused on their growing understanding of programming and the Scratch interface, and often drew on past experiences, prior understandings, and the board game used to frame the unit. In the following example, teachers are discussing the concept of programming abstraction and are beginning to differentiate between procedures and abstraction:

Maria: I mean, I don't think I knew the word abstraction.

Teresa: The kind of all, I mean, is like, well, the procedure isn't a small abstraction.

Maria: Yeah, maybe I was actually like, so procedure was like all the steps, right? And abstraction is like the act of doing it. Maybe I wasn't, I don't know if I taught that completely correctly.

Teresa: You could have really big abstractions—

Maria: Well, cuz like I said, like I gave a similar example about the sharpened pencil like, when I say get out your Elevate [district curriculum] stuff, we know that means get out this, this, this, start your language sheets, like you don't have to say all those steps.

Teresa: Right.

Maria: So, I kind of said that, but—

Teresa: Yeah, and the algorithms are all the instruction—

Maria: And those are the procedures, the abstraction is like the act of making it smaller?

Researcher: Yeah.

Here, the teachers connect the concepts to their classroom teaching and use “Elevate”, the district-authored writing curriculum, as an analogy to explain their thinking.

Many of the connection episodes consisted of analogies meant to help relate the content to every-day occurrences, like the weather or classroom routines. Furthermore, half of the connection episodes involved comparing CS content to the board game, suggesting the value of the expansive framing instructional approach. One example of such an episode occurred during the second PD session, when teachers were trying to make sense of the definition of CS events and turned to the board game’s rules to define the meaning of the term:

Researcher: So, level 15 would be right here. Okay. Right. And so, looking at level 15, we would say what are some of the events that you see? And there's two ways to answer this, right? One of this we could say, actually, we'll just have you guys, what are the events that are on here?

Maria: I think as a kid, I would be like, ‘wait what do you mean, like what—'

Julia: Yeah, I wouldn't understand what the word events means either. […]

Debbie: Well, if it's, like what you're saying with the games, are you meaning like when I land here, I need to turn left, is that what you're wanting as an event? […]

Teresa: Or this guy has to turn right or left before he—

Maria: Yeah, they're gonna start telling you what to do, I think. […]

Debbie: And is that considered an event?

Researcher: Yeah, I mean, that would be an event, and probably what I would consider is that if you're on red, do the red cards.

Maria: So, landing on red is, or being on red is the event.

Researcher: Yeah. So being on red is the event.

As seen in this episode, teachers used the board game mechanics of determining movements based on the color that the sprite is touching (“being on red”) to understand the meaning of a computational event. Across all PD sessions, teachers generated a total of 24 connection episodes (see Figure 3). While the number of connection episodes was lower than other sense-making episodes, they almost doubled during the final three PD sessions—again, sessions which were more teacher-led.

Classroom enactments

We examined the three types of episodes to see how the collaboration within the PD influenced teachers' classroom enactments. First, connection episodes impacted the way that teachers described CS content to their students. An example of this was the enactment of the previous excerpt, where all three teachers explained events or conditionals using the game mechanic of how touching different colors caused the sprite to perform different moves.

Second, we also found that suggestion episodes influenced teachers' CS pedagogical enactments. Of the 53 suggestion episodes that occurred during the PD sessions, 33 had the potential to be used by teachers in future lesson enactments. Of those suggestions, 23 (about 70%) were enacted by at least one teacher, 14 (42%) were enacted by two of the three teachers, and 10 (30%) were enacted by all three teachers.

For example, a suggestion that was enacted by all three teachers was to have students physically stand up and move their bodies to demonstrate new game procedures during lesson 3. This was used by each teacher but enacted in slightly different ways. Maria had one student stand and demonstrate the new procedure, Teresa had all the students do it simultaneously, and Debbie had students individually demonstrate procedures before having the whole class do it together. The use of an idea that was not in the lesson plan and the varying ways in which teachers took ownership of the pedagogical choice shows their agency in classroom practices as well as their engagement in the PD.

Figure 4 shows the flow of suggestions between teachers, with the arrow pointing from the teacher who made the suggestion to the teacher who used it. A circular arrow represents a teacher enacting her own suggestion. As can be seen, each teacher relied on suggestions made by peers, as well as a smaller number of suggestions made by the librarian.

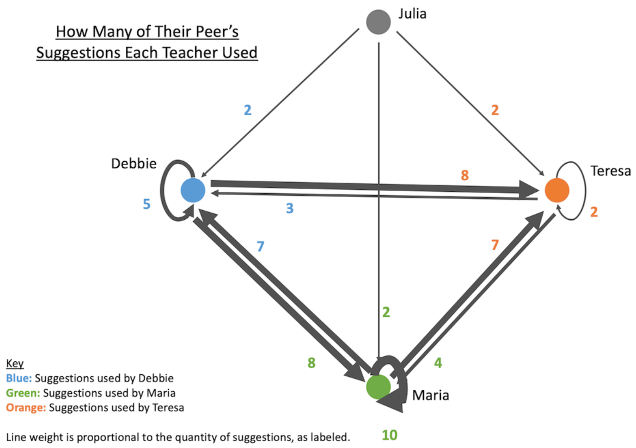


Figure 4: How teachers enacted peer suggestions (circular arrows represent a teacher taking her own suggestion)

Figure 5 shows the percent of topics of suggestions enacted by teachers in their classrooms. Suggestions regarding CS-specific pedagogy were taken up the most by all three teachers, as would be expected given the unfamiliarity of the CS content. In particular, 12 out of 16 (75%), of all CS pedagogical suggestions were used by at least one teacher. Thus, teachers appeared to rely on each other to find enactment advice, despite their collective lack of experience in the subject matter.

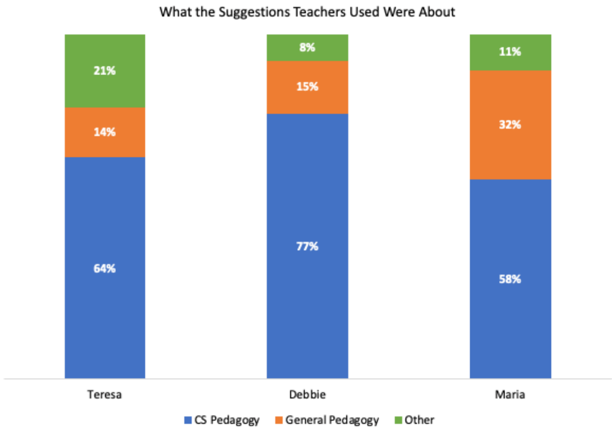


Figure 5: Topics of suggestions enacted by each teacher

Finally, teachers also used a large proportion of suggestions that occurred during lesson modeling. In particular, 91% came from the modeling portion of the PD or the conversation immediately following their modeling, where teachers were still discussing their plans for the upcoming lesson. While modeling activities did take up more time and therefore were more likely to generate suggestions, the highest percentage of the suggestions made during the modeling portion —which was more teacher-centered and directed—were enacted than from any other PD activities.

Discussion

This paper investigated how elementary teachers participated in a collaborative PD for a 7-lesson unit that was new to them both in content (CS) and pedagogy (EfU). The PD sessions were structured as a set of participatory routines where teachers reflected on the previous week's lesson, modeled the upcoming lesson, and discussed adaptations to it. While these kinds of routines have been incorporated in other PD designs, our study closely examined teachers' utterances to characterize the kinds of sense-making episodes they engaged in during the PD sessions. We identified three episode types and found that episode frequency increased over the course of the PD sessions as teachers gained agency in the PD process.

By closely analyzing the specific episode types, we unpacked how teachers participated in the PD, what they learned, and how these interactions influenced their classroom enactments. The connection episodes showed how teachers made connections between their teaching and the content as well as between the board game and the content. While the EfU approach is intended to support student sense-making, the findings suggest it also supported teachers' sense-making. Further, the vast majority of suggestion episodes, where teachers recommended adaptations to the lessons, were pedagogical in nature, with half of those being related to the specific CS pedagogy. Our findings thus show how the teachers developed a repertoire for teaching CS despite its relative unfamiliarity and, like previous work, show how teacher agency during PD can lead to curricular changes (Severance et al., 2016; Voogt et al., 2015).

Conclusion

Elementary teachers with little CS background are increasingly being asked to include CS in their instruction. To help prepare teachers for this, learning scientists need to better understand the process of teacher learning in order to design impactful PD. In this paper, we examined how teachers in our study actively made connections and took ownership in suggesting adaptations to the curriculum in ways that influenced their classroom enactments.

DBIR approaches can be powerful ways to address local and meaningful problems. Nonetheless, questions remain about their scalability and sustainability. The study highlighted several routines, tools, and strategies to structure collaborative PD that appeared to result in fruitful teacher engagement and agency in lesson enactments. Future work should examine to what extent these can be productively employed in other PD settings without researcher support. Further, the content in the current study only addressed introductory CS ideas—engaging teachers around advanced CS concepts might be harder to realize in this setting.

References

Bell, T., Alexander, J., Freeman, I., & Grimley, M. (2009). Computer Science Unplugged: School students doing real computing without computers. *Journal of Applied Computing and Information Technology, 13*(1), 20-29.

Biddy, Q., Gendreau, A., Bush, J., Hennessy Elliott, C., Jacobs, J., Recker, M., Sumner, T., & Penuel W. (2021). A professional development model to integrate computational thinking into middle school science through codesigned storylines. *Contemporary Issues in Technology and Teacher Education, 21*(1).

Blikstein, P., & Moghadam, S. (2019). Computing education: Literature review and voices from the field. In S. Fincher & A. Robins (Eds.), *The Cambridge Handbook of Computing Education Research* (pp. 56–78). Cambridge: Cambridge University Press.

Borko, H. (2004). Professional Development and Teacher Learning: Mapping the Terrain. *Educational Researcher*, *33*(8), 3–15.

Engle, R. A., Lam, D. P., Meyer, X. S., & Nix, S. E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist, 47*(3), 215-23.

Goode, J., Margolis, J., & Chapman, G. (2014). Curriculum is not enough: The educational theory and research foundation of the exploring computer science professional development model. *Proceedings of the 45th ACM Technical Symposium on Computer Science Education - SIGCSE '14*, 493–498.

Grover, S., Pea, R. D., & Cooper, S. (2014). Expansive framing and preparation for future learning in middle-school computer science. *Proceedings of 11th International Conference of the Learning Sciences (pp. 992-996).* ISLS.

Hickey, D. T., Chartrand, G. T., & Andrews, C. D. (2020). Expansive framing as pragmatic theory for online and hybrid instructional design. *Educational Technology Research and Development*, *68*:751–782.

Lee, V. R., & Vincent, H. (2019). An Expansively-framed Unplugged Weaving Sequence Intended to Bear Computational Fruit of the Loom. *In P. Blikstein & N. Holbert (Eds.), Proceedings of FabLearn 2019* (pp. 124-127). New York, NY: ACM.

Lee, V. R., Poole, F., Clarke-Midura, J., Recker, M., & Rasmussen, M. (2020). Introducing coding through tabletop board games and their digital instantiations across elementary classrooms and school libraries. In *Proceedings of ACM Technical Symposium on Computer Science Education (pp.* 787–793). New York: ACM.

Lefstein, A., Vedder-Weiss, D., & Segal, A. (2020). Relocating Research on Teacher Learning: Toward Pedagogically Productive Talk. *Educational Researcher*, *49*(5), 360–368.

Penuel, W. R., Fishman, B. J., Haugan Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational researcher*, *40*(7), 331-337.

Putnam, R. T., & Borko, H. (2000). What do new views of knowledge and thinking have to say about research on teacher learning?. *Educational researcher*, *29*(1), 4-15.

Schegloff, E., & Sacks, H. (1973). *Opening up closings.* Semiotica, 8, 289-327.

Severance, S., Penuel, W. R., Sumner, T., & Leary, H. (2016). Organizing for teacher agency in curricular co-design. *Journal of the Learning Sciences*, *25*(4), 531-564.

van Es, E. A., & Sherin, M. G. (2008). *Mathematics teachers "learning to notice" in the context of a video club.* Teaching and Teacher Education, 24, 244-275.

Voogt, J., Laferrière, T., Breuleux, A., Itow, R., Hickey, D. T., & McKenney, S. (2015). Collaborative design as a form of professional development. *Instructional Science, 43*, 259–282.

Walkoe, J. D., & Luna, M. J. (2019). What We are Missing in Studies of Teacher Learning: A Call for Microgenetic, Interactional Analyses to Examine Teacher Learning Processes. *Journal of the Learning Sciences, 29*(2), 285-307.

Yadav, A., Krist, C., Good, J., & Caeli, E. N. (2018). Computational thinking in elementary classrooms: measuring teacher understanding of computational ideas for teaching science. *Computer Science Education*, *28*(4), 371-400.

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The Tragedy of Lost Ideas: Examining Epistemic Injustice in Pair Programming

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Abstract: This paper explores an episode of epistemic injustice that develops between two students with help from two teachers. Our analysis seeks to demonstrate not only *that* epistemic injustice has occurred, but also, how, and why it matters. In particular, we explore the idea of credibility deficit as helping to account for how and why one student's contributions were routinely sidelined or ignored, and how that repeated positioning led to the ultimate act of testimonial injustice and its outcome, a wrong in the form of a loss of opportunity to learn.

Introduction and framing: Situating the problem

Despite the many calls and enthusiasm for "equity-oriented" instruction, it continues to be true that American schools are generally organized in an unsafe manner for students of non-dominant cultures to learn, engage, and thrive (Dumas, 2014; Martin, 2019; Ryoo et al, 2020). This is particularly true in STEM, where success is often associated with overall smartness (Leyva, 2017). At the same time, STEM fields often contribute to and are organized by persistent structural racism seen both in instructional practices and in the ways that resources and opportunities are made available to some students but not others. Combined, this ensures that only some students are recognized as successful, and that those who are denied such recognition are doubly damaged by narratives that claim failure in STEM to be central to overall failure.

This well-documented situation is often the focus of research and reform efforts. However, as Martin (2019) has pointed out, the extent to which such reform efforts engage beyond a surface-level concern with test scores vary widely. Efforts to transform education must take broader institutional and instructional practices seriously, for without such attention, the very same patterns that lead to inequities can flourish (Ryoo et al 2020). Reforms should focus not on how to ensure that students are successful within existing structures, but rather, should ask how existing structures should be transformed to promote success. As Ryoo et al (2020) say: "CS education should not simply thrust minoritized students toward status quo and middle-class ideas of working as uncritical programmers, but instead encourage students to utilize their diverse lived experiences and voices to ask the critical question: computing *toward what ends?*" (p. 339). Without focus on transforming these structures, classroom spaces continue to be unsafe for some students; without attention to students' interaction, broader narratives about success and status permeate interactions.

Care about others' humanity should be sufficient justification to ensure that classrooms and schools—sites of mandatory participation—are both safe and sustaining for students. But in addition, it has been well established that our experiences drive the identities that we develop—how we participate and learn, what we believe about ourselves, and what decisions we make about our future (Nasir & Cooks, 2009). Thus, the ways we organize classrooms have implications not only for the moment, for the year, but for a lifetime.

In this paper, we examine a 45-minute interaction between two boys, one Black and one white, who are working on an open-ended programming challenge that requires both mathematical and computational thinking. In our analysis, we ask how the relationship between two pair programmers changed dramatically over the course of a 45-minute episode, leading to an outcome of *epistemic injustice*. Specifically, we ask: How did the interactions between two students serve to systematically position an older and more knowledgeable student as less competent? And what are the implications for identity development and learning?

Conceptual framework

To conceptualize the unsafe nature of STEM environments for minoritized students, we draw on Miranda Fricker's concept of *epistemic injustice*. According to Fricker (2007), epistemic injustice is harm done to someone as a knower due to their identity. Identity markers, such as race, gender, class, or accent can increase or decrease trust that a person knows a certain type of information. Although there is more than one form of epistemic injustice, here we focus on *testimonial injustice*, when a knower tries to convey knowledge, or give testimony, but is not seen as credible. Certain identities in certain contexts can create a *credibility excess* or *credibility deficit*, where a speaker's word is either unfairly inflated or deflated due to who the speaker is. Fricker also highlights the many wrongs of testimonial injustice. First, to be wronged as a knower is an intrinsic injustice because it undermines a person's worth, identity, and capacity to reason. Not only is undermining a person as a knower often hurtful, but further, as Fricker states, "[I]n contexts of oppression the powerful will be sure to undermine the powerless in just that capacity, for it provides a direct route to undermining them in their very humanity," (p. 44). In addition, persistent undermining will cause a knower to lose confidence in what they believe and why they believe it, which results in the knower literally losing knowledge. And finally, such prejudice can have a self-fulfilling power that can cause the person subject to the prejudice to start to believe and behave as if such prejudice is true. Overall, testimonial injustice is one of the ways that we can understand why some people are systematically ignored, dismissed, or undermined in interaction, and what repeated instances of this injustice can do over time. In this paper, we will show the ways in which one student subject to testimonial injustice not only conceded to the prejudice he was subject to, but in the process lost knowledge.

Although epistemic injustice is largely a philosophical concept in its origin, it has a clear utility in studies of learning and interaction. For example, Miller et al. (2018) state that epistemic injustice is highly relevant to the context of implementing Next Generation Science Standards (NGSS). Specifically, they argue that if minoritized learners are not granted epistemic agency in science, not only will they lose confidence in themselves as knowers, but there will be a net-loss in the science community due to the lack of opportunities for these groups to foreground their knowledge and shift our collective scientific understandings (Miller et al., 2018). In mathematics, Tanswell and Rittberg (2020) critique a norm of mathematical practice that presents mathematics as acontextual. Further, university math programs often use a streaming model to weed out lower performing students, which diminishes the social aspects of mathematics (Tanswell & Rittberg, 2020) and instead promotes an individualistic, competitive environment, which runs contrary to many minoritized communities that value collectivism (Bills & Hunter, 2015). Hunter et al. (2016) show that when students are allowed to make sense of math by communicating in a shared language, students can mathematically reason at an advanced level, but students rarely receive the opportunity due to the credibility excess of the English mathematical vernacular. Since human learning is inherently contextual (Lave & Wenger, 1991), any practice that ignores the context of the learner is a source of epistemic injustice (Tanswell & Rittberg, 2020). Building on these efforts to investigate and understand how interactions between students in learning contexts establish epistemic injustice, our analysis explores moments in which credibility deficits are established, with what we argue to be an ultimate outcome of epistemic injustice.

Methods

We use interaction analysis (Jordan & Henderson, 1995) and positioning theory (Harre & van Langenhove, 1999; Anderson, 2009), to explore a 45-minute episode of pair programming in which two boys were engaged in a debugging activity. Details about the data, the activity, and the analytic methods employed are detailed below.

Data

The episode comes from the second day of a week-long free coding camp called *Code Your Art,* which introduced middle-school students to coding through NetLogo (Tisue & Wilensky, 1999). The students were engaged in a pair programming debugging task called "Paint a White Square" which called for students to modify "buggy" lines of code that resulted in a blue background with a white strip down the middle, rather than a white square (Figure 1). Modifying the code to create the correct image required thinking about the syntax and logic of NetLogo, as well as mathematical properties relevant to the model. However, there were many possible solutions to debugging this model that resulted in a display of a white square in the middle of the screen. After creating the white square, students had two challenge problems: to create a white square of a different size, and to create a white square somewhere else on the screen.

The specific data that we analyze for this piece comes from screencapture software from one boy (Sam's) computer, which was passed back and forth between the pair. The screencapture software includes both what is happening on the screen and the video that is captured by the embedded computer camera. This meant that whoever was typing on the computer was directly captured by the embedded computer camera, and often both students' faces were seen on the computer camera, particularly when they were both leaning in to look at the screen. The two students who are the focus of the analysis are Prince, a Black rising 9th grader, and Sam, a white rising 6th grader. Their partnership was based on their proximity of seating in the class, and the two boys had no prior relationship before the summer camp. Our analysis also includes the task that students were working on, and the adults who interacted with the pair, including Victor, a white male undergraduate teaching assistant (TA), and the lead teacher Ms. Turner, a Black female math teacher with over 20 years of teaching experience. The exercise lasted about 45 minutes.

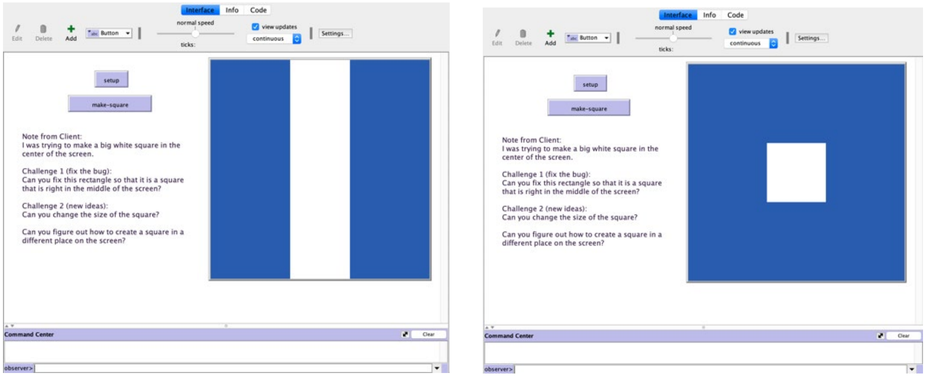

Figure 1. (Left) The model after pressing "Setup" and then "make-square." (Right) The target solution

Analytic framework

The analytic methods that we brought to bear on this episode come from principles of interaction analysis and from positioning theory. Interaction analysis (Jordan & Henderson, 1995) is a method of video analysis that draws a unit of analysis around the person and their context. Interaction analysis assumes that "knowledge and action are fundamentally social in origin, organization, and use, and are situated in particular social and material ecologies" (p. 41). This means that analyses must take seriously not only what individuals do, but also, how their participation is shaped by and responsive to the actions and affordances of other people, tools, and practices. Following these practices, our analysis began with repeated viewings of the 45-minute episode, followed by creation of a content log of the entire interaction. These initial viewings helped to make us aware of a shift in participation that we found both puzzling and troubling; what began as an apparently cordial and relatively cooperative activity shifted over time with one student becoming increasingly silent. We thus decided to look in detail at the interaction between the two students to try to better understand what happened.

For our closer analysis, we drew on positioning theory (Harre & van Langenhove, 1999; Anderson, 2009). Positioning takes place at two levels--as a moment-by-moment process through which people make bids for and establish their relative status, and in relation to broader narrative and storylines, which are both implicitly and explicitly leveraged as resources to situate particular discourse moves (Hand, Penuel, & Gutierrez, 2012). At the moment-by-moment level, positioning can be seen most easily in talk, as students and the teacher speak to each other about academic content, about themselves, and about their current work (van Langenhove & Harre, 1999). When looking over longer time periods, students can be positioned as being certain kinds of people in relation to broader storylines that are made relevant through the emergent participant framework (Goffman, 1974; Goodwin, 1990; Herrenkohl & Guerra, 1998; O'Connor & Michaels, 1996) of a classroom which shapes the ways that students are expected, obligated, and entitled to participate with content and with others in the classroom.

Findings

Figure 2 offers an overview of the content of the 45-minute episode between Sam and Prince. From the outset of the episode Prince and Sam demonstrated active engagement in the white square debugging task, as they took turns analyzing the problem presented and determining potential solutions to pursue during the first phase of problem solving. However, their first interactions with the code were generally cooperative, rather than collaborative. For example, Sam first independently explored the model and attempted two common solutions that involved changing specific symbols and numbers in the code. When those initial strategies didn't work, he rotated the laptop towards Prince and said "here, you try." Prince did so, and ultimately proposed a different strategy after exploring the model himself. As we detail below, while the content of their conversation focused on programming solutions, the interactions between the boys also served to establish their relative status. This positioning began through interactions between the two boys, and then was reinforced through interactions with the TA (Victor) and the lead teacher (Ms. Turner). Close analysis of these interactions suggests that Prince was repeatedly positioned as a non-knower. However, Prince's response over time shifted noticeably from first strongly rejecting those bids, to quietly not contesting them, to finally verbally acknowledging them. We unpack these interactions that, we argue, establish Prince's *credibility deficit in the interactions*, leading to an overall experience of testimonial injustice, and harm to Prince's identity as a knower.

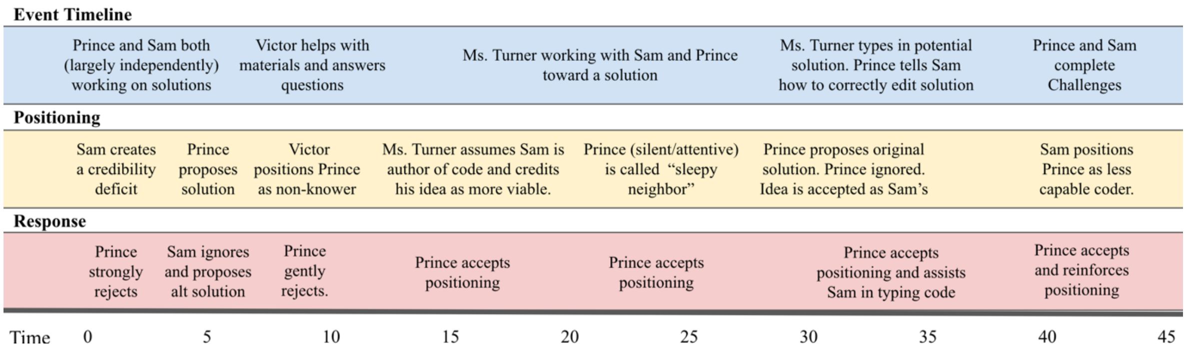

Figure 2. Overview of the 45-minute episode between Prince and Sam.

Phase 1: Positioning rejected

From the outset of their interaction, Sam positioned Prince as non-essential to the task. This happened first, subtly, when Sam ignored Prince's attempt to help him open the model, and subsequently, by Sam's initial attempt solve the White Square problem independently. These moves suggest that Sam anticipated Prince's ideas not being worthwhile (or, at the very least, that Sam did not need any assistance to solve the problem, despite being asked to work in pairs). This positioning was made more explicit when Prince was given access to the computer and made his first bid to solve the problem, an interaction in which Sam more explicitly claimed Prince's contributions as unworthy. This is seen in the transcript below, which occurred approximately 5 minutes into the video.

1	Prince (P):	Are we gonna make a square right here or right here (*pointing mouse to top right and bottom right corners of the NetLogo interface)*
2	Sam (S):	In the middle
3	P:	In the middle...
4	S:	Yeah
5	P:	We already have this (*clicks on white strip in the middle of the screen*)
6	S:	I know and now we need to just go chop, chop, take away, take away...
7	P:	Oh, it's a big *white* square
8	S:	Yeah, and then try to change the size of the square.
9	P:	So... we gotta do something with the pycor.
10	S:	You think???
11	P:	No sir, I did not think. That was all muscle memory. So... we just go down... (*begins typing new line of code*)
12	S:	Screw everything up

In turns 1-8 Prince explored the model for the first time. In turn 9, Prince made a bid for how to address the bug, focusing on an aspect of the code that is currently missing (the code in its initial state reads: "ask patches with [pxcor > -5 and pxcor < 5] [set pcolor white]"). Prince's proposal was an unusual one for students to offer at the onset of working on this problem (c.f. Gresalfi, Brady, Knowe, & Steinberg, 2020), but is a necessary path towards a solution. It was also not a solution that Sam had explicitly tried in his earlier testing of the model. However, in turn 10 Sam responded to Prince's proposal with a dismissive "You think?" In this move, Sam positioned Prince's contribution as obvious and uninteresting, offering the first assertion of Prince's *credibility deficit.* However, Prince rejected this positioning in turn 11 almost without pause, claiming that he didn't even *have* to think. Still, as he began to add a new line of code to address the y-coordinates, Sam quietly muttered "screw everything up" suggesting a lack of trust for Prince to derive the correct solution.

As Prince began to type, Sam began to work independently on his own idea, seen in turns 15-19. His lack of attention to Prince further positions Prince's ideas as unworthy in Sam's eyes. Although Prince appeared to be aware of Sam's movements and his lack of attention (for example, Prince leaned back when Sam reached in front of him but did not look away from the screen where he was typing), he did not object to or engage in any way with Sam's utterances, again serving as a rejection of Sam's positioning of his ideas as unworthy.

15	P:	Oh, I got something... ask patches, ask patches...
16	S:	(*talking over Prince*) I wish we had something we could write this down on. We never got one of those dry-erase things to write on.
17	Victor (V):	Yeah you do, he has it (*alluding to Prince having a dry-erase board*). You have to share.
18	S:	Oh okay (*reaches over the computer to grab Prince's dry-erase board*)

19	S:	I know what we need to do. We just need to make... if we find...
20	P:	Hey what's our um...
21	S:	Look, look! Look! Look!
22	P:	No, sir!
23	S:	No! Look what we need / to do, look!
24	P:	/No, nonononono, no, no! (*makes slashing motion with his hand)*
25	S:	Make zero-zero
26	P:	No, we- yeah, we have to find the zero-zero, cause then I'mma just turn the rest of it blue. What color blue is this?

In turn 19, Sam attempted to shift Prince's attention away from his own solution and towards Sam's new idea, again making a bid to position Prince's ideas as uninteresting. However, once again Prince forcefully rejected this positioning, with a strong "No sir," and a repeated "no no no no."

Phase 2: Positioning uncontested

The initial interactions between Sam and Prince suggest that Prince had a credibility deficit with respect to Sam, seen in Sam's repeated positioning of Prince's ideas as obvious and unworthy of attention. However, Prince consistently rejected this positioning. Still, as the episode went on, others entered the interactional space and contributed to Prince's positioning as having a credibility deficit. For example, about seven minutes into the interaction, Prince asked for assistance from Victor, the class TA. Prince was trying to determine the coordinates of the NetLogo canvas, with the goal of typing a command for the y-coordinates. However, the TA failed to listen, and in so doing positioned Prince as confused, once again creating a credibility deficit.

1	P:	How do we put, um, the graph on it?
2	Victor (V):	Do what?
3	P:	Put a graph.
4	V:	Hit setup. Go to code… your code. There's a problem in your code. It's fussing at you for something.
5	P:	Oh I didn't, I didn't finish, like I was looking for-
6	V:	(*Cutting off Prince*) Oh well then it won't do anything.
7	P:	I know, I was looking for the um/ the grid
8	S:	/ We need to do this! We need to write, we need to write, dude. We need to write…
9	V:	Oh, oh, the grid. You can't turn the grid on. (*Prince looking at the screen and nodding)*
10	S:	(*Starts repeatedly poking Prince on the shoulder)*
11	V:	But you can look at the code and figure it out.
12	S:	We need to write the coordinates. (*Prince nods slightly at Sam, still attending to Victor)*
13	V:	Alright, hold on (*Takes control of laptop, clicks back to code*)
14	P:	(*Following along with Victor, eyes on the laptop screen*)

By interrupting and not listening to Prince's strategy or what he is trying to accomplish, Victor appeared to approach the question from Prince with an assumption that he was confused, seen in particular in turn 4. This positions Prince again as having a credibility deficit. In turn 7 Prince gently rejected Victor's bid, stating that he knew his code was unfinished and that unfinished code wouldn't run, but he was focused on something else for the moment. At no point in the interaction was Prince asked what he was doing or trying to do, but instead Victor immediately assumed that Prince was confused and in need of explanation.

Prince ultimately completed and tested his proposed solution, which would have fixed the bug. However, he made a minor coding error. Instead of telling Netlogo to color blue all pixels with y-coordinates *greater* than five, he wrote to color in all y-coordinates *less* than five, resulting in the bottom two-thirds of the screen being colored blue, and a small white strip at the top of the screen. Seeing this failure, Prince looked at Sam and said "I tried," and while Sam looked back at him, adds "hey buddy, you failed too." Sam sat back up, grabbed the laptop and pulled it towards himself, saying "alright, watch me. Watch me." Prince asked "what are you gonna do," but Sam didn't respond and instead began typing.

As an additional example of continued positioning, Ms. Turner, the lead teacher, came to check on the boys' progress around 15 minutes into the episode. In this moment Prince made one last bid to share his idea, and Ms. Turner seemed interested, and even impressed. However, her own apparent lack of faith in Prince's ideas, along with repeated interruptions from Sam, served to re-route Ms. Turner from Prince's code, and Prince sat back to watch as the teacher and Sam began to physically talk and work over Prince.

2	Ms. Turner (T):	Where are you guys? Still on Paint a Square?
3	P:	mmmhmm. I made, um, (*unintelligible. Clicks "interface" and motions toward white rectangle in the top middle on screen*).
4	T:	Oh you did that! Okay.
5	P:	I know, like, so it's "ask patches". (*S clicking "make square" button repeatedly*) Duh, duh (*motions with his hand in an "L" shape*)
6	S:	We messed up "setup" didn't we.
7	P:	It's pycor. It's gonna be pycor less, less than, less than 5.
8	T:	Okay. Try that! Try that. He's got pxcor greater than -5. You want. Are you adding it here are you making another line?
9	P:	(*looks at teacher and opens mouth as if to answer*)
10	S:	I know what I did was wrong. But we should do this. Ask patch O 3. Well, whatever one it is O O. Ask neighbors, but also have it turn white too. That would make a square.
11	T:	Let's see it! (*directed at S. P nods)*
12	S:	I don't know how to make the one in the middle white too. Oh! After I do it, make O O white. Okay so that's how it's supposed to work. I think. (*looks to teacher. Turns computer to face himself more.*)
13	P:	(*Watching the screen, listening to Sam*)

In this interaction, Prince's idea was once again positioned as less interesting, and even as not belonging to him. In turn 4 Ms. Turner responds to Prince's code with a retort that appears surprised, saying "Oh you did that! Okay." This surprise suggests that she did not anticipate that Prince might have written advanced code, further positioning him as having a credibility deficit. Prince does not appear to notice her surprise and continues to explain his idea. However, in turn 8, the teacher stated, "He's got pxcor greater than negative five," attributing Prince's code to Sam. Before Prince could respond, Sam interrupted, pulling the teacher's attention away. This shift in attention away from Prince's idea was completely uncontested, a contrast with Prince's earlier responses, where being positioned as having less worthwhile ideas was something that he actively rejected.

Phase 3: Positioning accepted

As a final example, towards the end of the episode, Sam, gets frustrated with his code, not completely understanding what to do. He pushes the laptop back to Prince for the first time in around 30 minutes. After Prince explains an alternate approach, Sam asserts that he can do it faster.

1	S:	Is it make another square somewhere else? Or is it move that square?
2	P:	You wanna just… make another square? It didn't say it has to be a big square, it just has- it says make another square.
3	S:	Shut up!
4	P:	It just says make another square, so you can put, um… do the same code
5	S:	Let me show you
6	P:	No, do this code with a different, um, number.
7	S:	This number?
8	P:	Different number. Do that code, nonono, yeah yeah, but just put it with a different number
9	P:	But do the same thing you just did right there, but with a different number
10	S:	Nine, nine
11	P:	No no no, keep that, keep that right there, go right here and then change… copy and paste
12	S:	I hate when you're trying to tell me... you do it!
13	P:	Okay (*S: Growls*)
14	P:	So, copy…
15	S:	We jus- are we just gonna make another tiny square somewhere else?
16	P:	We're gonna do that and then we're gonna ask neighbors
17	S:	okay, so basically just make another tiny patch somewhere else?
18	P:	Yeah
19	S:	I could do it faster
20	P:	I know, I told you to do it
21	S:	Why? ... Nine-nine...

Despite the fact that turns 2-11 involved Prince proposing a solution that he was attempting to explain to Sam, Prince again was positioned as a less capable coder. Sam's frustration, which led him to turn the computer over to Prince, was immediately followed with his continued efforts to understand the proposed solutions. Once that had been accomplished, Sam made an immediate bid for his own greater competence, saying in turn 19 "I could do it faster." In previous interactions with Sam, Prince was more likely to defend himself from a positioning of being a less capable coder. In this moment, however, he conceded to Sam and affirmed him as the faster coder by saying "I know" in response on line 20.

Overall, Prince spent a total of 5 minutes on the laptop. Upon relinquishing it to Sam, Sam controlled the laptop and the thinking for the next 30 minutes, and the teacher will eventually write a solution for them. The group never returned to Prince's original idea, which would have resulted in the desired white square had an inequality symbol not been mixed up. This was a collective loss of knowledge not only for Sam and Prince, but for the rest of the class, as Prince had a unique solution.

Broader storylines: Resources tacitly accessed in interaction

The *Code Your Art* camp, in general, was a collaborative and creative environment where students were frequently sharing ideas and creating new things. However, the debugging activities were different in that there was a pre-defined goal for all students. Previous research on pair programming suggests that a focus on speed can create inequitable outcomes between group members (Lewis & Shah, 2015), and this activity's structure invited a familiar classroom storyline of competing to be the student who is first to get the right answer. There were many times when both boys, especially Sam, appeared to be working *against* each other, insofar as they compared their relative success and emphasized failing as something to be embarrassed about. This supported a competitive dynamic that became a resource for positioning; if we are competing, someone must by definition be better than someone else. This also connects with a broader narrative that failure in STEM is indicative of broader incompetence. This could possibly account for why Prince was quick to give up, as it is better to be caught not trying than to be caught making a mistake.

A key element of epistemic injustice is identity. Though there was never explicit mention of race in this episode, there were moments when it seemed that Prince's race was made visible. For example, when Prince first took control of the laptop, Sam reached out and squeezed Prince's hair. The hair touch draws upon a broader storyline of the exotification of Black people and Black features, such as Black hair. It appeared that Prince was further racialized by the teacher, during a period in which Prince put his head down. His teacher encouraged him to "make a rap about it," assuming that rap was the way to engage a Black student in coding, even though Prince had expressed a very high engagement with the debugging activity before being consistently undermined. These interactions suggest to us that race, and specifically, the idea that "Black students aren't good at STEM," was recruited as a storyline in these interactions. This storyline created tacit expectations of Prince, and then was used to make sense of Prince's behavior, specifically if he had a question or was simply quiet.

Discussion, conclusion, and implications

In this paper we used positioning theory to understand how and why Prince's participation appeared to change over time, ultimately resulting in what, to us, seems a clear case of testimonial injustice. The first-order positioning of Prince from the teacher, teaching assistant, and Sam all seem to assume that his ideas are unworthy of serious attention. These moments of established credibility deficit were initially challenged by Prince, but it took few repetitions for him to become increasingly silent and accepting of the position that was given to him. Though Prince's self-removal from the activity can be seen as an act of self-preservation, it also highlights his own apparent acceptance, or at least agreement, that his ideas are less valuable. Finally, these episodes of epistemic injustice resulted in real intellectual harm. Prince's idea to paint the top and the bottom of the strip blue, leaving a white square in the middle was an important contribution that, uniquely among other solutions, coordinated mathematics with programming. The idea would have worked, had it not been for a small coding error. However, the result was taken as a confirmation from both Sam and Prince that Prince's idea was not worthwhile. This ended the opportunity to investigate Prince's idea fully and resulted in a literal loss of knowledge about coding. We relate these moments of positioning of Prince in relation to his ability as a computer programmer to his racial identity through what seemed to be racially motivated comments. In this way, the broader storylines that were drawn on as resources in the interactions helped make the repeated assumption that the Black student in the pair was less likely to have a good idea, an assumption that was seemingly leveraged by everyone in the interaction.

Although we argue that Prince's race played a crucial role in his positioning, we also note that, consistent with the findings of Lewis & Shah (2015), the storyline of "competition" also offered an important resource that contributed to this interaction. This could have been mediated by explicit instruction about how students should work together, which did not happen before students began this activity. We know that creating group work without defined roles for each person, or without teaching groups how to work together is often ineffective (Cohen, 1994), and in fact, this lack of structure enabled all participants to recruit and use storylines that ultimately did harm. Still, we see this episode as representative of greater systemic trends in which Black students and their disciplinary contributions are regularly sidelined and ignored due to assumed creditability deficit based on their racial identity. The persistence of episodes like the one outlined here perpetuates the acceptance of Black learners' positioning as less capable and ultimately contributes to Black students' disengagement in disciplinary practices and in STEM fields more generally.

References

Anderson, K. T. (2009). Applying positioning theory to the analysis of classroom interactions: Mediating micro-identities, macro-kinds, and ideologies of knowing. Linguistics and Education, 20(4), 291-310.

Bills, T., & Hunter, R. (2015). The role of cultural capital in creating equity for pasifika learners in mathematics. *Mathematics Education Research Group of Australasia*.

Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of educational research*, *64*(1), 1-35.

Dumas, M. J. (2014). 'Losing an arm': Schooling as a site of black suffering. *Race Ethnicity and Education*, *17*(1), 1-29.

Fricker, M. (2007). *Epistemic injustice: Power and the ethics of knowing*. Oxford University Press.

Gresalfi, M.S., Brady, C., Knowe, M., & Steinberg, S. (2020). Engaging in a New Practice: What Are Students Doing When They Are "Doing" Debugging? In M.S. Gresalfi & L.S. Horn, (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 3. (pp. 199-206).* Nashville, TN: International Society of the Learning Sciences.

Hand, V., Penuel, W. R., & Gutiérrez, K. D. (2012). (Re) framing educational possibility: Attending to power and equity in shaping access to and within learning opportunities. Human Development, 55(5-6), 250-268.

Van Langenhove, L., & Harré, R. (1999). *Positioning theory: Moral contexts of intentional action*. Maiden, Mass: Blackwell.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lewis, C. M., & Shah, N. (2015, August). How equity and inequity can emerge in pair programming. In *Proceedings of the eleventh annual international conference on international computing education research* (pp. 41-50).

Leyva, L. A. (2017). Unpacking the male superiority myth and masculinization of mathematics at the intersections: A review of research on gender in mathematics education. *Journal for Research in Mathematics Education*, *48*(4), 397-433.

Martin, D. B. (2019). Equity, inclusion, and antiblackness in mathematics education. *Race Ethnicity and Education*, *22*(4), 459-478.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching*, *55*(7), 1053-1075.

Nasir, N. I. S., & Cooks, J. (2009). Becoming a hurdler: How learning settings afford identities. *Anthropology & Education Quarterly*, *40*(1), 41-61.

Rittberg, C. J., Tanswell, F. S., & Van Bendegem, J. P. (2018). Epistemic injustice in mathematics. *Synthese*, 1-30.

Ryoo, J. J., Tanksley, T., Estrada, C., & Margolis, J. (2020). Take space, make space: how students use computer science to disrupt and resist marginalization in schools. Computer Science Education, 1-25.

Tisue, S., & Wilensky, U. (2004, May). Netlogo: A simple environment for modeling complexity. In *International conference on complex systems* (Vol. 21, pp. 16-21).

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Aesthetics of Authenticity for Teachers' Data Set Preferences

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Abstract: This paper explores secondary school teachers' aesthetic judgments of data sets for prospective use to teach data science. Twelve teachers were interviewed and asked to examine and select from side-by-side data sets the one that would provide a more authentic experience for students. Situating our work in the "Knowledge in Pieces" epistemology, we drew upon diSessa's (1993) notion of an aesthetic – a knowledge system for appraisal and judgment. We examined what sensitivities were expressed and how judgments were made and supported. We observed that teachers drew upon at least three senses of authenticity to characterize and select data sets: authentic as messy, authentic as requiring more work, and authentic as involving computation. Identification of these ways of determining authenticity represents an initial step in better understanding how teachers appraise data that could be used in their teaching.

Introduction

In their review of how data are being used as part of investigations and inquiry experiences in middle and secondary classrooms, Lee & Wilkerson (2018) examined the current state of learning sciences research related to the use of curated and public data sets in classrooms. Specifically, they found substantially less guidance for how educators can best use these kinds of data, and they stressed that this was an area where more research and support was needed. As researchers in this space who expect that the design of rich data experiences will become a more persistent concern for the learning sciences, we are trying to address these gaps. We are imagining a future where teachers are able to obtain and introduce quantitative data sets into their classrooms much in the same way that a teacher might select and include what they consider to be a related or useful news article or website that they have discovered online as an instructional resource. In that scenario, some sets of data will be selected and be judged to be more or less useful in their teaching. We ask in this paper how those judgments get made.

Beyond being a relatively understudied area in the emerging space of pre-collegiate "data science education", we subscribe to a model of classroom instruction that involves teachers designing their own or adapting existing curricula (Brown & Edelson, 2003). This makes teacher selection of data sets one of the many design decisions that get made. However, in thinking about this design decision, it is unclear the process that teachers will go through in their decision making. We also have little existing research on which to base teacher learning experiences that will help teachers to be even more thoughtful and reflective of their data selection decisions. Rather, research on teachers and their thinking related to data sets focuses largely on their conceptual understandings (often presented as misunderstandings) of certain core topics involved in data analysis (Batanero, Burrill, & Reading, 2011).

As there are now growing calls to develop an area of data science education (Lee & Wilkerson, 2018) and for learning scientists to contribute to research and design supportive of it (Wilkerson & Polman, 2020), we believe some new work on teacher thinking about data sets is needed. To motivate this in terms that are more practice-oriented, we might imagine a situation where a high school teacher wants to bring in a real data set from professional research that relates to natural disasters. If they live in an area that is known to have major fault lines and seismic activity, then seismology data might be more desirable. However, if the teacher is working in an area where hurricanes and flooding are the major concern, then data on hurricanes might be more desirable. Decision making could be as simple as deciding what is more locally relatable, but there could still be a number of potential complicating factors. The quality or amount of data may differ, or the structuring of the data – such as using numbers on a logarithmic scale - may introduce challenges that lead teachers to be more reluctant to use them. Furthermore, a geography teacher may have different priorities than an Earth Science teacher, and they may have different priorities still from a mathematics teacher.

Regardless of whether teachers are doing the work of selecting data sets or whether curriculum or software designers have pre-selected data for them, some consideration of how teachers judge and appreciate data is needed. In this paper, we report on some initial efforts to examine that. Our focus is on data that is thought to be supportive of an authentic learning experience related to data science. The theoretical perspective we draw from is based in the "knowledge in pieces" epistemology (diSessa, 1988). In the section below, we discuss theoretical bases involving aesthetics and authenticity. Following that, we present some initial results in our efforts to understand teachers' aesthetics for authenticity.

Theoretical perspectives

Knowledge and aesthetics

This work is situated within what learning scientists refer to as the "Knowledge in Pieces" (KiP) epistemology (diSessa, 1988), which is most prominent in conceptual change research. It has also been recently used to model knowledge in interaction (diSessa, Levin, & Brown, 2016). As a theoretical perspective, KiP provides an alternative to descriptions of student knowledge that are critiqued for using imprecise, or arguably inaccurate, terminology (diSessa, Gillespie, & Esterly, 2004). A common use of KiP has been to challenge cognitive models of knowledge that make strong claims about context invariance. For instance, the claim that students come to instruction with rigid misconceptions that must be disproven is one that has come under critique from the KiP perspective. The proposed alternative to a misconceptions view is to think of student knowledge as involving more atomistic pieces of knowledge that are cued in response to contextual information (Smith, diSessa, & Roschelle, 1993). One interaction in which this has been made more apparent is in Piagetian-style clinical interviews. In such interviews, occasions where students seemingly contradict themselves or change their minds within minutes of having already given a seemingly confident and definitive explanation for a phenomenon are often cited as a demonstration of how a KiP perspective can be especially useful (Sherin, Krakowski, & Lee, 2012).

Some of the most prominent KiP work emphasizes the specification of certain kinds of cognitive resources that play key roles in dynamic reasoning processes (e.g., Hammer et al., 2005). Another related area of work within the KiP tradition is the identification and description of what diSessa calls *aesthetics* (diSessa, 1993). Aesthetics are "rich but structurally limited knowledge systems, which, notwithstanding their richness, appear fluid, data driven, and involve situation-specific reasoning…and idiosyncratic justification." (p. 187). As diSessa describes them, aesthetics provide judgments of similarity and preference. They also serve to provide hunches and intuitions with varying levels of confidence. Aesthetics are involved in a range of situations. One of the most well-known is the sense of mechanism that is invoked in commonsense physics reasoning. For instance, the sense of mechanism for physics helps students to predict behaviors of objects in motion or determine where forces are involved in a physical situation (diSessa & Sherin, 1998). Another aesthetic is the knowledge system that develops in order to recognize the law of large numbers within different probabilistic situations (Wagner, 2006). While these are mathematics and science-oriented examples, diSessa (1993) is explicit about stating that aesthetics are applicable to a range of domains. Knowledge about interpersonal relations is suspected to part of a social aesthetic. Indeed, this suspicion is explored and applied to a case of a teacher's ideological reasoning by Philip (2011). In that example, the aesthetic system serves to make judgments about students and explain why some students succeed or fail at being students.

One goal of the current paper is to provide some initial description of aesthetics involved in evaluating data sets. In particular, the aesthetics that are being considered are those of high school mathematics and statistics teachers. We selected these teachers because they were likely candidates for teaching data science as a standalone topic or course. While we focus on mathematics and statistics teachers, we do note that where and how data science should or eventually will be integrated into the curriculum is unsettled. Informally speaking, based on research workshops and summits, interest has been expressed from those in the computer science education, math & statistics education, and science education communities. Regardless, there are cases of standalone data science courses being deployed in large school systems (see Lee & Delaney, 2021) and being deemed eligible because they count as fulfilling the same requirements as that of a high school statistics course.

Authenticity

Learning sciences has often stressed authenticity as a valued priority in the design of learning experiences. Accessible, but authentic forms of scientific inquiry, are often pursued (Edelson & Reiser, 2006). This may involve supporting students in scientific modeling (Schwarz et al., 2009) or providing students access to scaffolded versions of professional tools like GIS systems (Edelson, 2004). In this treatment of authenticity, similarity or congruence with respect to professional practice are prioritized.

At the same time, research in the learning sciences has also treated community-based forms of knowing, understanding, and acting in the world as authentic, although those instantiations may not bear immediate resemblance to professional disciplinary practice. A well-known example comes from Lave and colleagues who documented how learning how to do solve mathematics problems to determine the best buy of a product in a traditional classroom can look quite different from what actually happens when one is determining best buy of a product while shopping in a real-world setting (Lave, Murtaugh, & de la Rocha, 1984).

That we can apply authenticity to these different situations suggests that there may be different frames of reference for what makes something authentic. Indeed, there is evidence for this in some of the psychology literature. In his summary of prior research on authenticity, Newman (2019) identified multiple ways by which we judge authenticity, at least with respect to objects. These include historical, categorical, and values authenticity. Historical authenticity implies a connection to a particular person, time, or place. An authentic Picasso painting would be one that was actually painted by Pablo Picasso. Categorical authenticity would match existing beliefs and requirements for a category to which the object belongs. Authentic Neopolitan pizza could be purchased and enjoyed outside of Naples provided that it was made with the correct ingredients and followed a specific preparation process. Values authenticity would involve consistency between internal state and external expression. While two politicians would say that they support racial justice, one might come under fire for being inauthentic whereas another might be seen as actually authentic.

It is unlikely that these treatments of authenticity are exhaustive, especially considering these were presented primarily with respect to objects. However, this illustrates that authenticity can be complex and subject to various evaluative criteria. In light of that, the question we examined was what data sets would our participating high school teachers deem as providing a more authentic experience for students. Our goal was to get some traction on understanding an authenticity aesthetic, as it relates to teaching high school data science.

Methods

Research participants

The participants in this study were 12 secondary school math and statistics teachers. These teachers were not recruited through a randomized process. Rather, they were solicited from existing contacts in schools and through snowball sampling. There were 6 men and 6 women who participated. These individuals had a range of 2 to 31 years of teaching experience, with the average being 13 years. These teachers came from a mix of public, private, and charter schools in the US, and some taught other courses, such as computer science, as well.

Procedure

The teachers participated in a videorecorded interview that lasted approximately one hour. These interviews were completed during the COVID-19 pandemic and thus were done via video communications (i.e., Zoom). The bulk of the interview involved the teachers being presented with two pairs of data sets as tables in CODAP, a free web-based educational tool for examining and visualizing data. During the interview, the teachers were provided a brief introduction to CODAP and shown what were its visualization capabilities using a data set that was provided in the software. Because these were done via Zoom, the interviewer explained that she would show the teachers the data sets as tables and at any time they could request that the view of the interviewer's shared screen be changed (e.g., scrolling) or that a data visualization be made. Surprisingly, very few teachers asked for visualizations to be made.

One pair of presented data sets were of passengers on the Titanic. Titanic data were selected as they are common in online and undergraduate data science courses and high school statistics courses. One Titanic data set ("Titanic A") came from the data website, Kaggle.com, which is used by data science enthusiasts, holds data sets on a wide range of topics, and hosts competitions for users. The other Titanic data set ("Titanic B") came from the *Introduction to Data Science* curriculum (Gould et al., 2018) used in a number of high schools in the United States. Titanic A had 891 cases, whereas Titanic B had 1000 cases.

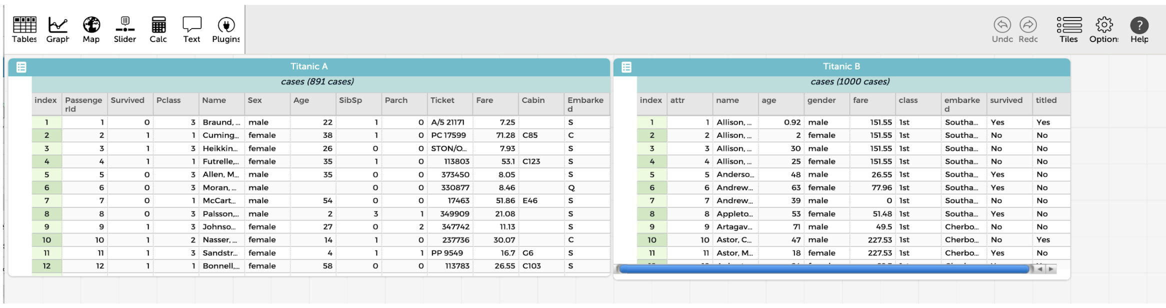

Figure 1. The Titanic A and Titanic B data sets.

The other pair were of popular movies and their box office revenue. One came from the *Bootstrap:Data Science* curriculum ("Movies A"). *Bootstrap:Data Science* is one of multiple *Bootstrap* curricular units that were developed to integrate computer science into curricula. The other movies data set ("Movies B") came from the above mentioned *IDS* curriculum. Movies B was much larger than Movies A in that it had 4935 cases while

Movies A had 100. These data sets were downloaded unaltered from their source curricula resource sites. While there was over an order of magnitude difference in the sizes of the two data sets, we chose to use them as they were because that was how they were made available in their respective curricula.

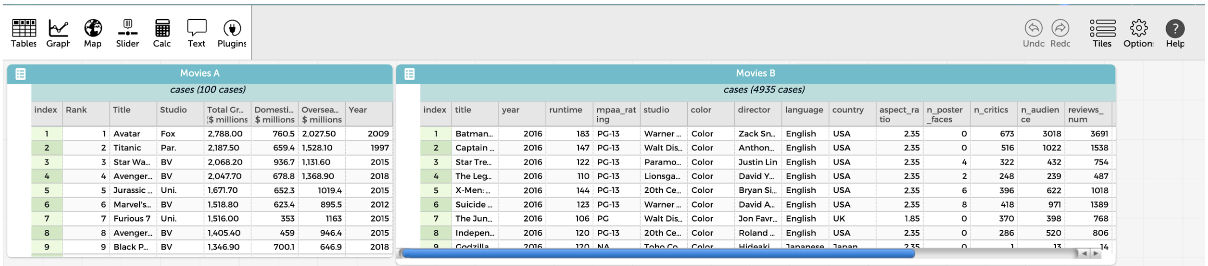

Figure 2. The Movies A and Movies B data sets.

We would also like to note that *B:DS* and *IDS* were selected because their development was funded by the United States' National Science Foundation, and they are among the only complete secondary data science curricula freely available online. In a separate paper (Lee & Delaney, 2021), we have reported on some content analyses of these two curricula and noted some differences between the two. Among those differences were in how large and how varied the data sets were used throughout each curriculum. Those differences motivated us to inquire about how teachers would judge these different data sets. At the same time, the data sets were different topically across the two units. Movies was one common topic, and Titanic was selected for the reasons stated above.

During the interview, the teachers were asked which data set will give students the most authentic experience of working with data in the context of a course they created that addressed data science. Those segments of the interview were our focus for this paper.

Analysis

The most common form of analysis for KiP oriented work is *knowledge analysis* (diSessa, Sherin, & Levin, 2016). Knowledge analysis typically involves video or audio capture of knowledge in use. For instance, interviews that involve participant sense-making about everyday activities in 'scientific' terms is one common interaction genre. Other approaches can involve paired problem-solving or work with a microworld.

Regardless of what type of interaction is recorded, those records are transcribed and then episodes are selected for iterative review and theory building. This may involve systematic and comprehensive coding, although when that is done, the goal of coding is to support theory building rather than emphasize frequency. Theory generation as part of knowledge analysis adheres to several core principles including a commitment to describing knowledge in terms of mental representations and fine grained and nuanced detail of those representations in action that is tightly connected to the presented data.

Reports of knowledge analysis tend to involve episodes of reasoning on the time scale of seconds to minutes with detailed description of knowledge elements at work. The reports are evaluated with respect to the adherence of theoretical claims about knowledge to the provided transcript excerpts and the potential for extending those claims to situations beyond those that are presented. Knowledge analysis reporting generally asks the reader to decide, assuming a KiP perspective, whether they are convinced of theoretical assertions that were motivated by the data.

For the current study, the interviews were transcribed and subject to multiple coding passes and joint interpretation sessions involving the authors. The coding passes varied from labeling content of what was discussed to what was being referenced within a data set to the sense of authenticity that was being evoked by the teacher. Some categorization of preferences was also done. Ten out of the twelve teachers picked Titanic A over Titanic B as providing a more authentic experience. For the Movies data sets, 11 picked Movies B.

Results

Authenticity as messy

Part of the aesthetic appeal for some of the teachers appeared to be based on the sense of authenticity as the data being 'messy'. To illustrate, we provide an excerpt from an interview with Kiera. The interviewer was trying to get clarification from Kiera as to why she had just picked Titanic A over Titanic B. Kiera began by talking about Titanic B.

Kiera: I was saying that B has exactly 1000 cases, which is just such a nice number, you could make percents out of that easier, but is that just a coincidence, or is that manipulated data, whereas A seems a little bit more raw, I guess. B seems a little more cleaned up. So I guess if we're talking about the word authentic, I guess A.

While Kiera had many points to make, the one that is most relevant currently is in the second half of her utterance. She described Titanic A as "a little bit more raw". In contrast, Titanic B could be "manipulated data". If it was not manipulated, then for it to have 1000 cases would have to be a "coincidence" rather than to be expected. Moreover, the number 1000 had the quality of being "nice". Given just this statement, it would be hard to ascertain with confidence. It could be that it has something to do with 1000 being a decade number (i.e., multiple of 10), which has familiarity in the number of fingers we have on two hands (Domahs et al., 2015), our monetary system, and in how we often count and compute numbers in many languages (Murata, 2004). Visually, it also has repetition of three zeroes, making it feel less random as too much repetition is seen as less likely in chance events (Nickerson, 2002). Regardless, the aesthetic system extracts the number of cases and infers that it is special and less probable, making Titanic A more authentic. This observation appeared for multiple teachers in our study.

Authenticity as messy also appeared in other forms. Don, quoted below, was sensitive to the presence of organization in Titanic B but not in Titanic A.

Don: Yeah, so, I think that-they [students] would find it challenging that it's-well B is now organized alphabetically…If I wanted to be authentic, I think that I would probably choose A, because the data-is not organized, it's a little bit less clear on what's happening there, some of-like, the cabin is only listed for some of the people-Like, that's the same way, in the real world, you can't just get the 300 million people in the United States and-and you chose 1,000, you won't reach the thousand.

In this initial part of this selection, Don was conveying that his appraisal was that Titanic A was "not organized", or as we characterize it, disordered. Part of this disorganization came as a contrast from alphabetical order he recognized in Titanic B from looking at the *Name* column. From there, he continued with other ways he sees disorder – namely, the presence of empty cells appearing in the *Cabin* column ("the cabin is only listed for some of the people"). This suggests that for Don, detecting incompleteness is part of authenticity. To support that, Don made an analogy to "the real world" where if one were tasked with contacting 1000 people in the United States as part of a data collection effort, the thousand could not be reached. Authentic data experiences should involve encounters with incomplete data. Contacting 1000 people and succeeding in reaching them had a feeling of being orderly, whereas not getting all information was more disordered and to be expected.

Authenticity as requiring more work

While we saw Don state that parts of Titanic A were "a bit less clear" to refer to disorder or messiness, this appeared to also be connected to an aesthetic judgment related needing to do more work with the data in order to make inferences from it. There are indications of some underlying resistance or additional work. This was elaborated in the same utterance, of which another excerpt is provided below.

Don: So I feel like A is more challenging to look at, for, it's labeled a little bit less clearly, organized a little less, a little more abstract, *survived* is numbers and the *Pclass*-but, I think that then the flip side to that, I guess, is that B is a little bit easier for kids to deal with. And then, they could still-A requires the challenge of figuring out what the heck is going on, and then doing the data analysis. Whereas B is slightly, but not perfectly, organized, in a way that the kids would be able to attack the learning objectives of the class a little bit easier. But A is closer to what real life data would actually look like.

In some way, Titanic A required that students work more and work harder. Evidence for this appeared with his comparative statement that "B is a little easier for kids to deal with" and "A requires the challenge of figuring out what the heck is going on". Part of the work to be done comes from understanding the header labels, as they had, such as *PClass*. (At a separate time, Don stated "*Pclass*, I'm guessing...three is the more expensive one, or, one is the more expensive one, I don't really know yet. I guess I could look at the *fare* and maybe figure it out."). Figuring out what *PClass* referred to and how the numbering system for it worked required additional steps to complete.

Authenticity as more work also appeared when Don was asked to select the Movies data set that would provide students with a more authentic experience.

Don: I would choose [Movies] B, because, it has data that is not necessarily necessary, which I think is-that's how you're going to get data, otherwise they're doing the work for you. Like if you ask your school principal, like hey, can I get some demographic data on the students at our school and the grades that they have? They're not going to just give you two columns, like race, GPA, maybe that's what you wanted to know, but they're not going to do that for you,

As Don described it, there is additional work to do with Movies B to discern what information (i.e., variables) is desirable in the first place. This is the result of having more columns than what is necessary. This implies some searching, selecting, or reducing must be done. Don illustrates this through an imagined scenario of asking the school principal for data. In this imagined scenario, he might want information related to two variables, race and GPA. Assuming the school principal were willing to share the data, "they're not going to just give you two columns". The school is "not going to do that [data reduction] work for you". That there is work that the school will not do implies that there is additional work.

A similar sentiment that authentic means additional work appeared in Roscoe's selection of Movies B as providing a more authentic experience.

Roscoe: I would choose B, mainly for the volume of data in it, the number of cases, and the fact that it has quite a few attributes, and you have to puzzle down which ones are the ones who want to look at. Also, it looks like there's... I see a couple of NAs in there, I don't see any of the others, I suspect there may be more missing data problems or... outliers or things that have weird attributes on them that you have to deal with, which is always a real problem with real data sets.

There were a few appraised qualities of the data that he noted that suggested more work. One was that there was abundance in the data (which we believe is likely its own aesthetic judgment that we do not detail here. In that aesthetic judgment, large sets are more authentic. Consistent with a KiP model, other knowledge can be cued. In Kiera's example above, 1000 cases in the Titanic B data was suspicious, meaning that a preference for B was superseded by the authenticity as messiness judgment). Abundance appeared in "the number of cases, and the fact that it has quite a few attributes [columns]". Here, the mention of attributes is of current interest. Because there were many attributes, students would have to do the work to "puzzle down".

Another quality of the data was the presence of NAs. These were values that acted comparable to the empty cells that Don noted above in Titanic A data, as this was described by Roscoe as a part of "missing data problems". These were grouped also with "outliers or things that have weird attributes on them that you have to deal with". In having to deal with them, there is added work, whether it is having to make additional decisions (such as whether to exclude those) or caveats (such as the outlier having an influence or inferences being based on less than the total number of cases).

Authenticity as involving computing

One other authenticity judgment we discuss came in the form of connection to computing. Data science was something virtually every teacher saw as involving computers and some amount of programming skill. For authentic experiences, some connection to computing seemed connected to a sense of authenticity. For example, Joan immediately noticed the presence of values of "0" and "1" and identified Titanic A as more authentic. She explicitly stated the following:

Joan: I guess as I teach computer science [in addition to other courses], I like the zeros and ones because it lets me have a conversation about bits and binary [in A].

The main connection Joan made was that it involved an encoding system (binary) that was connected to how computers store information. The presence of "1" and "0" values was mentioned by several teachers for Titanic A in the Survived column. Separate from being an encoding that was associated with computers, the binary values were also seen as being more easily used for computing values. Drake illustrated with the following rationale for choosing Titanic A.

Drake: I mean I think Titanic A would give them a more authentic experience. If I have to say why, it's that it's quantitative, and I think it's easier to work with quantitative values like, giving the values survived a value or 1 or 0 is much easier to work with than if it says yes or no, like they could much more easily figure out, okay well how many people survived? Well just add up.

Drake was drawn towards the values being quantitative, although there were quantitative values in all of the data sets. The quantitative values he focused on, however, were “1” and “0”. That encoding for survival would involve a simple matter of adding all values together. There would not be a need to transform written words into numbers that could be manipulated through calculation.

Another way that computing was implicated was in how computers would be necessary to do the work. Roscoe noticed features of the data related to the production of models for real-world phenomena. He elaborated on his noticing of data abundance in his choice of Movies B:

Roscoe: And like I say, Movies A is sort of light on the number of cases. Now, if I was just doing maybe a statistics class, and we weren't actually doing... I could imagine in statistics class, you might not do as much programming. And you know, you're not using it to try to train some model. It may be more appropriate to have fewer things there, that are less confusing and having less data available so that you can actually scan through it and see what the issues are, with, I guess 5,000, there's a chance, you can still stomach going through it, sort of scrolling through everything to see what's there. But definitely 100, people are going to go and look at the entire dataset.

The abundance of data, according to Ramsey, necessitates the use of computational tools and procedures central to data science. This was different from what he considered to be a statistics class where “you might not do as much programming” and the data are not being used “to train some model”. With the larger number of cases in Movies B, which also likely cued the “authenticity as more work” judgment, he suggested it was less likely that students would try to go through thousands of values. He expected that with just 100 data points (Movies A), students would just look at the entire data set to get the information they wanted rather than use computing tools.

Discussion

Thus far, we have examined high school math and statistics teachers’ aesthetic for data sets that support authenticity with data science work. These include sensing authenticity when the data was messy, when using the data required extra work, and when computing had some connection to the work that would be done with the data. These judgments are not exclusive. We suspect from our reviews of the transcripts that they may reinforce one another.

Looking at teachers’ sense of authenticity is consequential for a future where learning scientists will be participating in the work of designing data science educational experiences and for helping educators make judgments on how to provide students with high quality learning opportunities. Our current assumption as learning scientists is that authenticity is desirable. This paper is an initial effort to characterize what that could mean. Having made some observations about how teachers see authenticity in data sets for high school data science instruction, there must also be consideration of the extent to which authenticity is desirable by teachers. It may be that the authentic data sets involve work that the teachers appreciate but struggle to include given the constraints of existing school structures. For instance, data cleaning is a common data science activity and one that takes a substantial amount of data scientists’ time. However, just because it takes much of their time, it may not be something that educators feel is worth proportional instructional time. Indeed, we have begun to examine this in our data. At a later point, we asked teachers to select data sets based on what they thought would be best pedagogically. Of the ten teachers who selected Titanic A as more authentic, five of them said Titanic B would be a better choice pedagogically. However, for the Movies data, the same data set selected for authenticity was also selected by teachers for pedagogical considerations. Examining pedagogical aesthetics and how they complement or conflict with other aesthetics, such as authenticity, remains as work for us to do in the future.

References

Batanero, C., Burrill, G., & Reading, C. (Eds.). (2011). *Teaching statistics in school mathematics-challenges for teaching and teacher education* (Vol. 14). Dordrecht, Netherlands: Springer.

Brown, M., & Edelson, D. (2003). *Teaching as design: Can we better understand the ways in which teachers use materials so we can better design materials to support their change in practice?* Design Brief. Northwestern University. Evanston, IL.

diSessa, A. A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the computer age.* Hillsdale, N. J.: Lawrence Erlbaum.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10*(2&3), 105-225.

diSessa, A. A., Gillespie, N. M., & Esterly, J. B. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science, 28*, 843-900.

diSessa, A. A., Levin, M., & Brown, N. J. S. (Eds.). (2016). *Knowledge and Interaction: A Synthetic Agenda for the Learning Sciences*. New York, NY: Taylor & Francis.

diSessa, A. A., & Sherin, B. (1998). What changes in conceptual change? *International Journal of Science Education, 20*(10), 1155-1191.

diSessa, A. A., Sherin, B., & Levin, M. (2016). Knowledge Analysis: An Introduction. In A. A. diSessa, M. Levin, & N. J. S. Brown (Eds.), *Knowledge and Interaction: A Synthetic Agenda for the Learning Sciences* (pp. 30-61). New York, NY: Taylor & Francis.

Domahs, F., Moeller, K., Huber, S., Willmes, K., & Nuerk, H.-C. (2010). Embodied numerosity: Implicit hand-based representations influence symbolic number processing across cultures. *Cognition, 116*(2), 251-266. doi:https://doi.org/10.1016/j.cognition.2010.05.007

Edelson, D. C. (2004). My World: A case study in adapting scientists' tools for learners. In Y. Kafai, W. Sandoval, N. Enyedy, A. Nixon, & F. Herrera (Eds.), *Proceedings of the 6th international conference on Learning sciences*. Santa Monica, CA: Lawrence Erlbaum Associates.

Edelson, D. C., & Reiser, B. J. (2006). Making authentic practices accessible to learners: Design challenges and strategies. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 335-354). New York: Cambridge University Press.

Gould, R., Machado, S., Johnson, T. A., & Molynoux, J. (2018). *Introduction to Data Science v 5.0*. Los Angeles: UCLA Center X.

Hammer, D., Elby, A., Scherr, R. E., & Redish, E. F. (2005). Resources, framing, and transfer. In J. Mestre (Ed.), *Transfer of Learning from a Modern Multidisciplinary Perspective* (pp. 89-120). Greenwich, CT: Information Age Publishing.

Lave, J., Murtaugh, M., & de la Rocha, O. (1984). The dialectic of arithmetic in grocery shopping. In B. Rogoff & J. Lave (Eds.), *Everyday cognition: It's development in social context* (pp. 67-94). Cambridge, MA: Harvard University Press.

Lee, V. R., & Delaney, V. (2021). *What Is Being Covered in Standalone Secondary School Data Science Curricula?* Paper presented at the 2021 Annual Meeting of the American Educational Research Association. [Virtual]

Lee, V. R., & Wilkerson, M. (2018). *Data use by middle and secondary students in the digital age: A status report and future prospects*. Commissioned Paper for the National Academies of Sciences, Engineering, and Medicine, Board on Science Education, Committee on Science Investigations and Engineering Design for Grades 6-12. Washington, D.C.

Murata, A. (2004). Paths to Learning Ten-Structured Understandings of Teen Sums: Addition Solution Methods of Japanese Grade 1 Students. *Cognition and Instruction, 22*(2), 185-218. doi:10.1207/s1532690xci2202_2

Newman, G. E. (2019). The Psychology of Authenticity. *Review of General Psychology, 23*(1), 8-18. doi:10.1037/gpr0000158

Nickerson, R. S. (2002). The production and perception of randomness. *Psychological Review, 109*(2), 330-357. doi:10.1037/0033-295X.109.2.330

Philip, T. M. (2011). An "Ideology in Pieces" Approach to Studying Change in Teachers' Sensemaking About Race, Racism, and Racial Justice. *Cognition and Instruction, 29*(3), 297-329. doi:10.1080/07370008.2011.583369

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching, 46*(6), 632-654. doi:https://doi.org/10.1002/tea.20311

Sherin, B., Krakowski, M., & Lee, V. R. (2012). Some assembly required: How scientific explanations are constructed in clinical interviews. *Journal of Research in Science Teaching, 49*(2), 166-198. doi:10.1002/tea.20455

Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the learning sciences, 3*(2), 115-163.

Wagner, J. F. (2006). Transfer in pieces. *Cognition & Instruction, 24*(1), 1-71.

Wilkerson, M. H., & Polman, J. L. (2020). Situating Data Science: Exploring How Relationships to Data Shape Learning. *Journal of the learning sciences, 20*(1), 1-10. doi:10.1080/10508406.2019.1705664

International Society of the Learning Sciences

“That Was Mindblowing”: How Reading with a Social Robot Enhances Science Learning Experiences

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Abstract: Learning sciences research has demonstrated the importance of social interactions during learning to help promote deep and meaningful understanding through a process of co-constructing knowledge, but homework reading is typically done as an isolated exercise. We have developed a social robot to provide social interactions during reading activities with middle- school children, and in this study report on how interacting with the robot affected the learning experience. Our thematic analysis describes direct and indirect benefits from reading with the robot. We conclude with theoretical and practical implications of these results.

Introduction

Educational researchers and practitioners have increasingly called for a greater focus on students developing deep and interconnected understanding of content, rather than the memorization of facts and procedures. Learning sciences research has demonstrated the importance of social interactions during learning to promote this deeper learning through a process of co-constructing knowledge (Miyake & Kirschner, 2014). Yet, most homework assignments that ask students to read textbooks or other materials, used frequently in US education and in science curriculum, are typically done in isolation. Some approaches to supporting student learning at home include educational technologies that offer aids for comprehension and problem solving, but these too often focus on procedural learning and rarely include a social component. Computer supported collaborative learning (CSCL) technologies can effectively support social interactions during learning, but require coordination between learners when used at-home, that can be difficult for elementary or middle-school aged students. To benefit from social interactions while learning in homework reading scenarios, we need educational technologies capable of sharing the reading experience and providing critical social interactions during these learning opportunities when human-human social interaction is unavailable or limited. Our goal is to address this need by creating augmented science reading activities with a social robot that can provide knowledge supports through social interactions to promote deeper understanding of science content.

Theoretical framework

Our work is guided by a socially situated or sociocultural learning perspective (Vygotsky, 1978). Research on socially situated learning demonstrates how social interactions transform activities into collaborative experiences where knowledge is co-constructed with others. Social interactions encourage students to take an active role in their learning and engage in meaningful dialogue about content. These interactions also provide opportunities for scaffolded knowledge supports that simplify or make connections within and outside of the content (Hurst et al., 2013). While working together, learners build on and explore ideas with each other that helps to connect new concepts to other knowledge, and to summarize and synthesize what they are learning (Miyake & Kirschner, 2014). In this way, learners build rich and meaningful understanding, where they have grappled with concepts

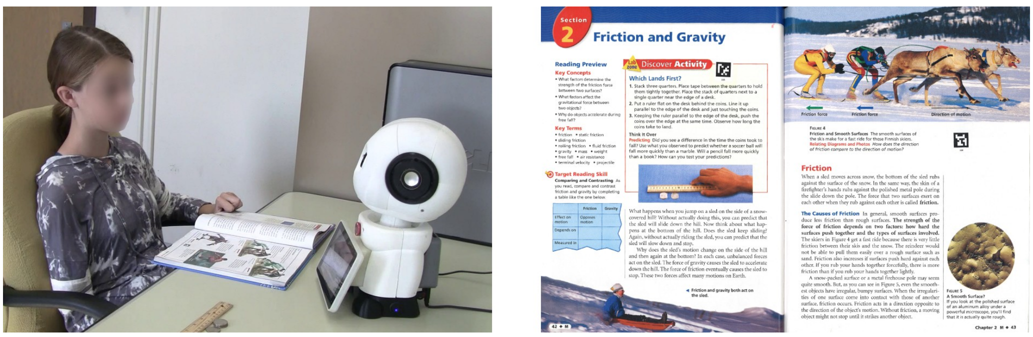

Figure 1. Child reading with Minnie (left). Textbook page with discover activity and AprilTags (right).

rather than simply tried to remember them. This social approach is underexplored in reading for learning, but some methods such as paired reading, have proven effective. Topping et al. (2011) demonstrate that paired reading, where students read out loud together on a regular basis, has long-term positive effects on reading ability that were highest for *near-peer* tutoring, where partners are close in age, and when reading pairs stopped to talk about the book every 5-7 minutes. These types of collaborative reading activities have also been found to promote greater reading comprehension in science and social studies content (Boardman et al., 2015), and can be seen as a template for creating socially situated reading experiences to improve learning.

The computer supported collaborative learning (CSCL) research community is a leader in designing technologies to support social interaction during learning (Kreijns et al., 2013). In these scenarios, the technologies, often web-based applications, are typically designed to facilitate collaboration between two or more learners, and are effective by supporting students in posing questions, exploring lines of inquiry together, practicing reciprocal teaching, and observing others learning (Stahl et al., 2014). In science learning, the collaborative supports can provide discussion boards, representational tools, or shared simulation space for learners, and can often take the form of scripts for students to guide effective interactions (Jeong et al., 2019). CSCL also has the potential to promote social interactions during reading activities. For example, elementary students participating in online collaborative readings with peers, improved reading comprehension when compared to individual reading (Vega et al., 2020), and scripted interactions between college students using an online CSCL tool enhanced their reading literacy in science content (Lee, 2015). While these technologies show promise, they require coordination between multiple learners, and therefore may not always be applied for reading activities at home and be difficult for younger learners to engage with outside of school.

In scenarios where human-human social interactions are difficult or not available, social robots have demonstrated a particularly powerful ability to make social connections with learners in ways that can improve learning (Belpaeme et al., 2018). Humans, especially children, seem to have reflexive and strong social responses to robots, where people apply and expect social norms during interactions (Ham et al., 2012). These strong social responses can be quite effective in learning environments, where robots build social connections with learners during activities (Michaelis & Mutlu, 2018), can provide meta-cognitive supports in stressful learning situations (Brown & Howard, 2014), and can inspire thinking and creativity (Gordon et al., 2015). The capacity for social robots to provide social interactions can be coupled with CSCL approaches to present socially situated learning supports. Social robots can effectively coordinate collaborative learning between human learners and can also act as collaborators themselves in learning interactions (Miyake & Okita, 2012). Social robots can act as less-able peers who need help from children to learn (Walker & Burleson, 2012), share in creating a story (Wong et al., 2016), or engage students in discussions about science (Shiomi et al., 2015). However, there is limited research on robots providing social interactions during reading activities, particularly for in-home settings.

In response to the need for work exploring the role of social robots for in-home learning, particularly as homework reading companions, we have begun a research program to explore the design of such a robot and understand the learner's experience during these socially interactive learning activities. Here we expand on findings from prior work to further our understanding of learning with a social robot during a shared science reading experience (Michaelis & Mutlu 2018, 2019). In this study, we ask the research question: *How do middle-school aged students experience learning while reading a science textbook with a social robot?*

Method

To explore the experience of reading with a social robot, we conducted a lab-based study where children read a science textbook chapter with "Minnie," a social robot programmed using design elements based on prior work (Michaelis & Mutlu, 2018). Here we report on the study procedure, materials, design of the robot's comments.

In a larger study, we recruited children from a mid-sized city in the Midwest for a randomized control trial testing the effectiveness of reading with a socially adept robot, compared to a robot without socially engaging features. Here, we examine the experience of the children in the socially-adept condition (N = 30). We chose to focus on this group since they received the maximized social interactions. Children in the study were aged 10-12 (18 male, 12 female) and had not yet started their 7th grade year. Study activities took place in a campus lab office after parent consent. Parents were compensated $25 USD for their child's participation, and study protocols were reviewed and approved by an institutional review board. Children completed a 30-minute reading session with the robot and were interviewed about their experience following the interaction. Several quantitative measures were also made during each session and are reported on elsewhere (Michaelis & Mutlu, 2019).

Minnie (See Figure 1, left) is based on an open-source 3D-printable tabletop robot, Maki, with servo-controlled head and eye movements (Hello Robo, 2020). We modified the Maki designs to add: a Rasperry Pi 3 microcontroller for enhanced computing power; a camera for image and facial recognition; and a seven-inch touchscreen display for user inputs. The robot's camera enables the use of facial recognition to track and look towards the child's face during reading, and to read scannable ID tags called AprilTags (APRIL Robotics Lab, 2020). The touchscreen display includes five buttons along the bottom, where children can select inputs for "yes" or "continue" (green button), "no" or "stop" (red button), "repeat" (blue button, "pause" (yellow button), and "help" (purple button; disabled for this study).

During the reading sessions, children read out-loud to the robot from a book with embedded AprilTags. When they encounter a tag, children hold the book to the robot's camera, and the robot responds with a pre-programmed *knowledge support comment*, that is a verbal utterance from the robot to highlight important material, summarize key points, make personal connections to the reading, or encourage children to complete activities in the book. The robot was designed to act as a *near-peer* that portrays an age and level of science understanding near the child's age and grade level. Therefore, the robot's comments were often framed as the robot wondering about a part of the book or summarizing its own understanding of what was just read. For example, after reading a section on diagramming forces, Minnie says, "Okay, I think I understand. Arrows show forces because the arrow points in the direction of the force, and a bigger arrow shows a stronger force."

Children begin by reading a custom-made introduction book that acclimates them to the reading process with the robot, and how to use the buttons and AprilTags while reading. After the introductory book, children are then asked to read a thirteen-page section, titled *The Nature of Forces*, in a middle-school level science textbook (Padilla et al., 2005) with content covering balanced and unbalanced forces and types of forces such as friction and gravity. We chose this book because it is at a reading level appropriate for our samples' age group and covers science related material typically encountered in 8th grade in U.S. middle school that our sample would likely not be overly familiar with. There were ten AprilTags placed in the reading with unique robot knowledge support comments that resulted from scanning each tag. Two of the tags were placed near two activities included in the book, and when scanned, the robot invited the child to complete the activity and say what they observed happening and why they think it happened. The first activity, the *at-home activity* had the child balance two playing cards against each other so they would stand, as in a house of cards, then exert a force on one of the cards, and explain the role of unbalanced forces in what happened. The second activity, the *discover activity* (See Figure 1) instructed children to push two different sized stacks of quarters off their table at the same time to observe which falls faster. Both stacks should fall at the same rate, and to ensure children saw this clearly, the robot is programmed to comment after the activity that both stacks of quarters fell at the same time. All activity materials were provided for the child, and they were allowed to complete the activity as they saw best.

Interviews (10-15 minutes in duration) were completed after the robot interaction, followed a semi-structure qualitative interview protocol (Blandford, 2013), were video recorded, and later transcribed verbatim. We then conducted a Thematic Analysis to analyze the data (Braun et al., 2018). Two researchers, including the first author, first familiarized themselves with the data where they reviewed and created notes from the videos. We then generated semantic codes closely related to the data using an inductive approach and organized the data within major categories based on these codes, including supporting knowledge, supporting interest, and social interactions. From these categories we then iteratively proposed, constructed, and refined emergent themes based on meaningful patterns in the data. The findings below are presented according to these themes.

Results

After several rounds of thematic analysis, we found that children felt the robot supported their learning and improved the depth of their understanding along three major themes, where the robot: (1) helped them slow down and focus on the reading, (2) provided summaries and guided attention to important parts, and (3) worked with them on the activities. Each theme is described below with quotes from participant interviews using participant IDs (e.g. R34). For clarity in reading quotes, ellipses were added to connect ideas in the responses, bracketed words indicate intended objects, and interjections were removed when not impacting the meaning.

Theme 1: Children slowed down their reading and focused more

Children felt that reading with the robot made them slow down and focus more on their reading in ways that helped them think more deeply about the content of the book chapter. In particular, children told us that reading to the robot helped them to slow down and focus so they could: (1) help the robot understand the content, and (2) think more deeply about what they read since they knew the robot would comment about it.

Children often said they learned more from reading out loud with the robot, because it slowed them down, and that slowdown helped them feel more focused on the reading. Most children directly related slowing down and focusing to the presence of the robot, as R36 told us, "If you were just reading aloud to yourself you might kind of slip over everything and say it fast." The idea of ordinarily skimming through textbook readings was brought up by several other children. For example, R2 told us that without the robot they “sometimes might skip a line”, R50 said “if I was reading it on my own I might have skimmed it and skipped over some important things,” and R64 told us, “when I’m reading alone, I normally just pretty much skim the concept.” Slowing down and not skimming the text was related to children feeling more focused on the reading. Children said the robot “focused me more” (R2), “helped [me] stay on task” (R10), helped them “concentrate” (R18), or that without the robot they “wouldn’t have paid much attention (R16).” R64 further explained that they didn’t skim with the robot, because, “if you’re reading to people, they would want you to slow down so I just kind of did that to the robot.”

These responses help us recognize that the robot’s presence and interactions seemed to drive children to read more slowly and focused in two ways. First, children told us they felt they should read clearly and thoughtfully so the robot could understand the content. For example, R64 said they slowed their reading down because they, “didn’t want to be confusing, and I wanted [the robot] to learn.” This slowing down for the benefit of the robot seemed to be linked to feeling that the robot was listening to them, as R50 illustrates by saying the robot is, “someone who seems like they are listening to you read it, so… it sort of depends on you that they can understand it.” Second, children seemed to anticipate the robot’s comments as a sort of query, that compelled them to spend more time focusing and thinking about what they read. Children felt they had to “think about what you were reading to respond to the robot (R14),” or that the “robot might ask me a question so I thought about it more (R16). Some children felt the robot would check on the child’s understanding, in ways that were also beneficial to the robot’s understanding – that the robot “sort of checked in for herself” (R50). Perceiving these interactions as ways to stop and think about what they were reading and to learn along with the robot appeared to drive a sense that they were understanding more, as R14 said it “makes you think deeper about the book.”

Theme 2: The robot provided summaries and guided attention

As part of the creation of our knowledge support comments, we intentionally created robot comments to correspond with challenging or important parts of the text, or that directed children to consider the figures and side-panels in the text that might otherwise be ignored. Almost every child in the study discussed these knowledge support comments as helpful for their understanding, and many suggested they felt the: (1) robot explained difficult ideas in the text, (2) comments often answered questions they had or gave them time to think about the reading, and (3) robot guided their attention to important parts of the reading.

Describing the robot comments as explanations or summaries was quite common. Children said the robot, “explains things you just read” (R4), “reviewed” (R28), gave a “reminder of what you just talked about (R48), “gave you a recap that sticks in your brain” (R20), or “makes sure you know and grasp the concept” (R64). Children revealed that they often faced challenges in understanding the concepts in the reading that the robot helped with, as R26 told us “I would read like two entire pages and then she’d say a quick summary and it helped me figure it out more easily, because sometimes I’d read this really in depth thing and then [feel] like ‘wait what just happened.’” R02 also added, “if I didn’t understand something, the robot would just break it down simply and that helped.” This was a very common response, where children felt that after reading the somewhat dense material in the textbook, they benefitted from the robot’s comments that explained the concepts.

They also felt that the robot’s knowledge support comments provided a summary or review of concepts that often served to answer questions they already had, or even “confirm your thinking was right (R10)”. R8 told us “it’s almost like you can ask questions, in a way, so it’s like she answers your questions.” R10 said, “sometimes it says something that you were kind of thinking in the back of your mind, but you weren’t really noticing it. And then [the robot] kind of helps you understand it a little better.” Through these explanations, the robot seemed to help clarify challenging ideas and bring the concepts to the forefront of their thinking. There was also evidence that children felt these knowledge support comments could either clarify or confirm their understanding and anticipate their questions, as R26 told us, “I had the question before the book asked the question, and I was like oh yeah I was thinking that too. And then [the robot] explains it.” Having the robot there to provide these supports appeared to be important to the children, as R44 summarized, “usually if something was hard in the book. . . you would have to figure it out by yourself but the robot… helped out.” There seemed to be something specifically important about the moment after each comment for the children to think about the material. They often described benefitting from thinking for a moment to absorb what the robot had said. R6 told us after the robot, “made a comment then [I] just paused and thought about what it said, and got more stuff,” and R8 said that when they were confused, “after a comment, you’re like ‘oh, hey, that’s how it works’.” R36 said, after a comment, “I thought about everything she said and then I could remember it more.” It appears that children experienced the robot comments not only as supportive information, but as targeted answers to questions and opportunities for thoughtful reflection.

Finally, some children suggested the comments guided their attention. R60 told us the, "robot pointed out things when they were saying something that I might have missed," and R58 felt the robot "pointed stuff out to me that I didn't really see." For R16 the robot drew their attention to figures in the book as ways of talking about real life examples. Specifically, R16 felt the robot used the example of racing reindeer in a book figure (See Figure 1, right) to explain how the "reindeer were a greater force than the friction, so they were moving." This comment from the robot was particularly helpful for the child since they had "just kind of glanced over [the figure], but then [the robot] mentioned it." R58 agreed that "the picture [of the reindeer] was a good example" of pointing things out. We were intentional in designing some of the robot comments to refer to figures in the book, and it seems that these references helped children who may have otherwise missed those pieces of the reading.

Theme 3: Working with the robot on book activities were powerful interactions

Another area where we deliberately designed comments to point out parts of the textbook reading to children, were the two activities contained in the book chapter. These seemed to be experienced by the children as opportunities to work with the robot on the content, and were appreciated as moments of interactive learning that they would have otherwise skipped – often resulting in powerful moments of understanding. Although the robot only made comments before and after the activities, children felt that these were interactive experiences. They felt that they were, "learning more," by "doing the tasks with [the robot] (R06)", and because they "actually have to interact with [the robot] (R64)." Doing these activities with the robot helped R14 "feel more involved." R64 said they had to "do little projects that you normally wouldn't do. . . you would talk to [the robot] and explain it." The notion that children might not ordinarily engage with the activities was also mentioned by R24, who said they "normally don't do the activities at home," but they "helped with being stumped." This interactivity appeared to help children feel they were working with someone else to make connections and think critically about the content in the text. R32 told us that when the robot's comment matched what they saw during the activity, they "understood it more and I felt like somebody else had the same opinion as me." The impact of these convergences of ideas was very clearly articulated by R20 in the following exchange about their experience doing the at-home activity in the book:

Researcher: I noticed that at the end of the book, when you started reading about air resistance. . . you said, 'Oh, that's why they fell at the same time,' and you went back, and kind of picked up the quarters and looked at them again. Can you tell me about that, like where that sort of connection came from?

R20: I thought that it was supposed to be connected because they did one and that [the quarters] fell at the same time and that they didn't do what I expected. It was, just mindblowing.

Researcher: Did you notice, did you see that they fell at the same time on your own? Or did you. . . because the robot also has a comment that sort of makes sure that you do see that they fall at the same time. Sometimes people sort of miss that. Did you figure that out on your own, or did the robot kind of help you see that, or did you remember that?

R20: I didn't and then I thought I did it wrong because you're not used to doing that, and so then I scanned the page and I did it one more time, I heard the robot's comment and then I'm like woah, that's actually what it's supposed to do and I'm like woah, that was mindblowing.

Here R20 demonstrates how they connected the comment the robot makes, explaining why objects with different masses fall at the same rate, to their experience with the at-home activity. The robot guided R20's understanding and strengthened this understanding with a later explanation. R20 described the robot making this connection as "mindblowing," that indicated help from the robot to connect ideas across the reading was very powerful. This exchange helps to summarize how children saw the benefit of their reading with the robot. The robot seemed to do more than simply provide supports for their reading, but rather provide a socially rich interaction.

Discussion

In this study, we sought to further our understanding of how children experience science learning with a reading companion robot. The results from our semi-structured interviews with children after reading with the robot demonstrate that the robot: (1) created a sense that the learning experience was for both the child and robot that helped focus the child's efforts; (2) provided targeted supports that anticipated the child's questions and guided their learning; and (3) participated in interactive knowledge building to help children think clearly and deeply about the content. Involving a social robot in science reading activities may be a powerful tool in re-imagining these reading activities as socially interactive rather than isolated. While there is evidence that children have strong social responses to robots (Ham et al., 2012) and that there are learning benefits to working with a robot (Belpaeme et al., 2018), there are currently no studies to examine how children experience reading science content with a robot. We believe evidence from our study suggests that the social presence of the robot transforms the reading experience into a shared knowledge building activity between the child and robot, that extends beyond the scripted knowledge support comments of the robot. Children found that the presence and demeanor of the robot encouraged them to utilize better reading habits (i.e. slowing down, focusing, and thinking) that benefitted their learning. They also described the reading as interactive, where they felt a constructive back and forth in grappling with the concepts in the book, particularly in completing the discovery and at-home activity in the book.

These findings provide a unique perspective on our understanding of child-robot learning interactions. To strengthen learning sciences theory, we provide demonstrate how children experience reading interactions with a robot, how knowledge can be co-created with an artificial partner, and how socially appropriate and meaningful interactions are key to creating powerful co-learning experiences. We believe our findings also illuminate practical implications for integrating these interactions into class and in-home learning experiences, and illustrate the aspects of the reading interactions that might best be leveraged for deepening science learning. Here, we discuss how our results support and expand prior work and share practical implications of science learning with a social robot.

Social robots provide socially rich experiences to scaffold and co-create knowledge

Empirical evidence from learning sciences research has demonstrated the benefits of social interactions during learning. Social interactions provide supports or scaffolds for learners that aid their understanding of concepts or that allow them to work on problems or material they might not otherwise be capable of doing alone (Vygotsky, 1978). Social engagement provides meaningful and natural interactions that promotes depth of thought about the content and builds deep and interconnected knowledge by co-constructing knowledge. The findings from this study demonstrate how the social presence of the robot directly and indirectly enhanced the learning experience.

Learning new concepts can be a tremendous task for novices, and these learners tend focus on the surface features and basic ideas they are grappling with, rather than complex or integrated knowledge we strive for in modern educational contexts. Our findings demonstrate that while children were reading the science textbook, they felt that their interactions with the robot allowed them to think more deeply and better understand what they read. For example, R10 told us the robot sometimes, “says something that you were kind of thinking in the back of your mind, but you weren’t really noticing it.” In this way, the robot’s comments helped children articulate and connect their ideas. While sharing this reading experience, children attended to new concepts, but often weren’t able to fully grasp the themes and bigger ideas of the reading. The robot provided summaries or pointed their attention to key aspects of the reading to aid their deeper thinking. The inability of learners to contend with the complexity of new content has been demonstrated in prior learning science research, and there is strong evidence that suggests learners benefit from social interactions in working on new material (Miyake & Kirschner, 2014). Our findings are in line with these theoretical perspectives, and add to this body of work, by demonstrating that children have a natural inclination to embrace a social robot as a near-peer, and that children feel these interactions are beneficial to their deeper understanding. Learning theory also suggests scaffolded supports can simplify or highlight connections and complexities within the content and relate new ideas to other knowledge and concepts (Puntambekar & Kolodner, 2005), We expand on this theory by demonstrating the benefit of providing these scaffolds in a social context. Our robot often used traditional scaffolding techniques, such as summarizing and guiding attention to a key figure, in a conversational way, within the social context of learning with the child. Scaffolds that summarized concepts were delivered as if the robot had just understood the material and was now summarizing their understanding, rather than presenting the summary as simply a fact for the child to absorb. We believe the robot’s social presence was key in providing direct supports for children.

The social presence of the robot also seemed to provide context for children to feel as if they were *learning with the robot*. Learning socially with the robot presented indirect benefits to the learning experience, where children slowed down their reading, focused more and read clearly so that they and the robot could better understand. At no point were children instructed to behave this way. Rather, our findings suggest these indirect effects came from children feeling that they were learning together with the robot, which seemed to cause them to subsequently change their typical reading habits to conform to the social context. This benefit is in line with prior work on the benefits of group learning to co-create knowledge (Miyake & Kirschner, 2014). One important element to induce the effect of learning together seemed to be that our robot’s personality was designed to be a near-peer (i.e. at just about the same ability level), rather than a tutor or teacher. Children felt the robot needed the child to help it learn, and wanted the child to think about the reading so the child could engage with the robot's comments (that were often seen as questions). That the robot could instill this sense of co-learning with such limited interactive capabilities demonstrates how willingly and naturally children embrace such a learning paradigm. We believe we provide evidence that the social presence of the robot had the indirect benefit of transforming the learning experience into a more meaningful and deep exchange of knowledge that stems from our natural ability to build on one anothers' ideas and work to achieve mutual understanding.

Practical implications: Augmenting learning using social robots

Our findings suggest that learning with a social robot can enhance the learning experience and transform a reading activity into a socially meaningful interaction. These findings have practical implications for learning with robots in both in-home and in-class settings, and offer some nuanced details of design and implementation decisions that can best facilitate the social learning experience. First, in creating direct learning supports, it appears that interactive activities interspersed throughout the reading may provide important learning opportunities, and also provide key moments for the robot to refer back to. Our reading included two such interactive activities, where children were asked to try balancing forces with playing cards (the at-home activity), and to observe the rate of falling for different masses with similar shapes (the discovery activity). In both of these activities, the robot asked the child to summarize their thinking and explain what they saw, which encourages the child to reason about these concepts. Since children often told us they would ordinarily skip these, the request from the robot seemed to be important to encourage them to engage in and think about the activity. The robot also referred back to these activities during the reading to help connect ideas, but also to enhance the importance of engaging in the activities. Second, the robot's design appeared to indirectly impact the learning experience by triggering social norms and expectations from children. The robot comments being interspersed throughout the reading seemed to emulate an interactive reading style that fostered the co-creation of knowledge, where children were compelled to focus, read carefully and take time to gather and synthesize their thoughts about the content. Our knowledge support comments did not deliberately ask children to slow down or think deeply, but there seemed to be an indirect effect of the social context that encouraged children to do so. The near-peer perspective of the robot may have enhanced this effect as children attributed the robot's need for understanding as a reason they read more carefully. We also found many children thought the robot anticipated their questions or was even asking them questions, as the robot provided comments that related closely to challenging aspects of the text. Our robot was not technically capable of such enhanced interactions, but the child still felt they needed to read more carefully to engage with the robot. These observations show how social supports enhance the experience, but improvements to the interactive capability of the robot, including asking and responding to questions may also be required.

In summary, based on our observations of the benefits to the student's learning experience, to promote deeper thinking while engaging in science reading we suggest designing robot interactions that: (1) provide opportunities for interactive activities during science reading, (2) allow time for the child's thoughtful reflection, (3) include robot references back to joint activities and previous learning, (4) utilize a near-peer perspective for the robot, and (5) closely tie robot comments to critical and complex parts of the reading. These supports can benefit in-class activities, where a robot might guide individuals or a small group, as well as in-home learning, where a robot can become a homework companion that encourages active engagement with content. The positive effects of these designs can be achieved with a relatively low-tech robot, but sustaining positive interactions over time may require enhanced capabilities such as posing and responding to questions.

Conclusion

In this study, we explore children's experience of reading with a social robot, and these experiences inform designing learning technologies. This approach limits the scope of our interpretation, in that we cannot report causal effects between these experiences and learning. We are also limited in that we do not include a comparison to other learning technologies or to reading on their own, and therefore cannot determine the scale of the effect of reading with a social robot. Finally, the short duration of the reading limits understanding how these interactions may change over time. For future work, we plan to examine science reading with a social robot in the context of school-based homework, over time and compared to other interactive learning technologies. During these studies we will conduct quantifiable measures of learning and estimates of changes in interest over time.

In summary, these findings demonstrate reading with a social robot creates a social learning experience that children feel encourages them to think deeply and engage meaningfully with science content. These findings support the growing belief that social robots can be a powerful tool for learning, and the social nature of the interactions can enhance student learning in tasks, such as reading, that may otherwise be isolated.

References

APRIL Robotics Lab. (2020). AprilTag. https://april.eecs.umich.edu/software/apriltag

Belpaeme, T., Kennedy, J., Ramachandran, A., Scassellati, B., & Tanaka, F. (2018). Social robots for education: A review. *Science Robotics, 2(3)*, eaat5954.

Blandford, A. E. (2013). Semi-structured qualitative studies. *In M. Soegaard & R. Dam (Eds.), The Encyclopedia of Human-Computer Interaction*. Interaction Design Foundation.

Boardman, A. G., Klingner, J. K., Buckley, P., Annamma, S., & Lasser, C. J. (2015). The efficacy of Collaborative Strategic Reading in middle school science and social studies classes. *Reading and Writing, 28(9)*, 1257-1283.

Braun, V., Clarke, V., Hayfield, N., & Terry, G. (2018). Thematic Analysis. In P. Liamputtong (Ed.), *Handbook of research methods in health social sciences (pp. 843–860).* Springer.

Brown, L. N., & Howard, A. M. (2014). The positive effects of verbal encouragement in mathematics education using a social robot. *2014 IEEE Integrated STEM Education Conference*, 1–5.

Gordon, G., Breazeal, C., & Engel, S. (2015). Can Children Catch Curiosity from a Social Robot? *In ACM/IEEE International Conference on Human-Robot Interaction* (HRI), 91–98.

Ham, J., van Esch, M., Limpens, Y., de Pee, J., Cabibihan, J.-J., & Ge, S. S. (2012). The Automaticity of Social Behavior towards Robots: The Influence of Cognitive Load on Interpersonal Distance to Approachable versus Less Approachable Robots. *In S. S. Ge, O. Khatib, J.-J. Cabibihan, R. Simmons, & M.-A. Williams (Eds.) International Conference on Social Robotics* (pp. 15–34). Springer Berlin Heidelberg.

Hello Robo. (2020). Maki. https://www.hello-robo.com/maki

Hurst, B., Wallace, R., & Nixon, S. B. (2013). The Impact of Social Interaction on Student Learning. *Reading Horizons*, *52*(4), 375–400.

Jeong, H., Hmelo-Silver, C. E., & Jo, K. (2019). Ten years of Computer-Supported Collaborative Learning: A meta-analysis of CSCL in STEM education during 2005–2014. *Educational Research Review*, *28*.

Kreijns, K., Kirschner, P. A., & Vermeulen, M. (2013). Social Aspects of CSCL Environments: A Research Framework. *Educational Psychologist*, *48*(4).

Lee, Y.-H. (2015). Facilitating critical thinking using the C-QRAC collaboration script: Enhancing science reading literacy in a computer-supported collaborative learning environment. *Computers & Education*, *88*, 182.

Michaelis, J. E., & Mutlu, B. (2018). Reading socially: Transforming the in-home reading experience with a learning-companion robot. *Science Robotics*, *3*(21).

Michaelis, J. E., & Mutlu, B. (2019, June). *Supporting interest development in science learning with a social robot.* ACM Interaction Design and Children Conference. Boise, Idaho.

Miyake, N., & Okita, S. Y. (2012). Robot Facilitation as Dynamic Support for Collaborative Learning. In J. Aalst, K. Thompson, M. J. Jacobson, & P. Reimann (Eds.) International Conference of the Learning Sciences. Sydney.

Miyake, N., & Kirschner, P. A. (2014). The social and interactive dimensions of collaborative learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of The Learning Sciences* (2nd ed., pp. 418–438). Cambridge.

Padilla, M. J., Cyr, M., Miaoulis, I., & Jones, T. G. (2005). *Motion, Forces, and Energy*. Pearson Prentice Hall.

Shiomi, M., Kanda, T., Howley, I., Hayashi, K., & Hagita, N. (2015). Can a Social Robot Stimulate Science Curiosity in Classrooms? *International Journal of Social Robotics*, *7*(5), 641–652.

Stahl, G., Koschmann, T., & Suthers, D. (2014). Computer supported collaborative learning. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 479–501). Cambridge Press.

Topping, K., Miller, D., Thurston, A., McGavock, K., & Conlin, N. (2011). Peer tutoring in reading in Scotland: Thinking big. *Literacy*, *45*(1), 3–9.

Vega, N., Stanfield, J., & Mitra, S. (2020). Investigating the impact of Computer Supported Collaborative Learning (CSCL) to help improve reading comprehension in low performing urban elementary schools. *Education and Information Technologies*, *25*(3), 1571–1584.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological process*. Harvard Press.

Walker, E., & Burleson, W. (2012). User-Centered Design of a Teachable Robot. In S. A. Cerri, W. J. Clancey, G. Papadourakis, & K. Panourgia (Eds.), *Intelligent Tutoring Systems* (243–249). Springer.

Wong, C. J., Tay, Y. L., Wang, R., & Wu, Y. (2016). Human-robot partnership: A study on collaborative storytelling. *ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, 535–536.

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Distributed Argumentation for Politicization in an Activist Campaign

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Abstract: The paper analyzes the emergent practice of *distributed argumentation* in an environmentalist campaign. I argue that distributed argumentation was a sense-making process spread across participants as they iteratively, interactively articulated political rationales, with speakers alternating and building on their colleague's contributions. This practice emerged as both a collaborative practice of intentionally supporting colleagues' concept development, as well as an oppositional practice that sought to combat more conservative colleagues by affirming peers they identified with and expanding on their argument. Theorizing distributed argumentation contributes to studies of democratic education and argumentation by exploring the interactional learning that happens beyond classrooms to build skill in engaging in democratic debate and politicization

Argument is a pervading activity as I write, with the ongoing public and private debates of US partisan politics, appropriate approaches to pandemic management, racial justice, climate change, and the list goes on. There is much to debate and, in North America (as elsewhere) an increasingly polarized context where finding common ground can seem nearly impossible, and often unpalatable. Yet in the learning sciences, discussions of debate and deliberation rarely reflect the kinds of real world intensity and consequences that many of us face in debate. In the literature, debate and discussion are highlighted as important aspects of democratic engagement, rather than as toxic spaces where some people's humanity is devalued. For the last years, I have worked as an activist scholar alongside the RadLab, a group of youth climate activist researchers, to understand the ways that sense is made around politics, and a recurring theme we encounter has been that of debate and argumentation—how it happens, who it serves, and how norms around expertise get reified and mobilized to undermine Black and/or Indigenous people and people of colour's (BIPOC) participation in environmentalist spaces, as well as that of white women, though differently. In this paper I seek to complicate ideas of argumentation, drawing on a non-school, activist context where young adults engaged in consequential argumentation, and I show how the argumentation practices evolved to address dominant masculine and white practices of power in the group. I argue that distributed argumentation was an emergent strategy that BIPOC and white women participants mobilized to make space for themselves and to enable their own politicization.

In this paper, I explore how activists engage in political concept development through argumentation. I ask what practices enabled student activists engaged in the Fossil Fuel Divestment Campaign at the University of Toronto. I examined the emergent practice of distributed argumentation, where participants in the campaign interlaced bids at argumentation with their colleagues in order to collaboratively develop political ideas. In distributed argumentation sequences, I examined activists' attempts to articulate an emergent politics without yet knowing what they were arguing, making connections on the fly, and building on their colleagues' ideas iteratively. I argue that distributed argumentation allowed participants to build on each other's ideas, build confidence, and expand their learning beyond what any participants might generate alone. I highlight how relationships of politicized trust made it possible for distributed argumentation to evolve as a practice, and how distributed argumentation built politicized trust and shared identity through politicization.

Context

Fossil Free UofT was a youth climate activist group that worked for over two years to get the University of Toronto to withdraw its endowment's holdings from the 200 fossil fuel companies with the largest fuel reserves. Student activists, including undergraduate and graduate students met weekly to plan outreach activities, to strategize around persuading the university administration, and to coordinate retreats, rallies, and other demonstrations to help them win their goals. In this campaign, a highly racialized and gendered pattern of turn-taking emerged (Curnow & Chan, 2016), where white men dominated the talk, and where these white men advanced a more conservative set of politics which centred technocratic analysis of climate change rather than anti-colonial and antiracist perspectives (Curnow, et al., 2019). Over the course of the campaign, these different political ideas and the turn-taking dynamics which made them difficult to override/challenge/contest became highly contentious ground, politicizing many members of the group and polarizing the dynamics.

As the group became increasingly polarized, two strategies emerged which enabled white women and BIPOC members of all genders to disrupt the turn-taking. First, they organized formal and informal meeting spaces outside of the large group meetings (Curnow, et al., 2020). This created space for them to debrief the dynamics of the large group and to create their own norms around participation, where their voices were heard and acknowledged, and their political development was fostered. Second, they innovated with practices which made it harder for a few white men to dominate discussion (Curnow, et al., 2019). It is these practices of resistance that I examine here, to see how they emerged, what they enabled, and how they contributed to the politicization of non-dominant participants. These approaches to argumentation extend the literature on debate and argument, in that they highlight an emergent practice of argumentation that worked against the marginalization of BIPOC and white women speakers, and which extended the political analysis that was being centred in the discussions.

Perspectives

To understand the phenomena of distributed argumentation, I look to work on argumentation and sense-making in the learning sciences. Studies of democratic education have argued that debate and argumentation are a core practice of democracy that can be learned and practiced in schools (Mirza & Perret-Clermont, 2009). These studies often examine teachers introducing artificial debate and managing student participation. In recent years, learning scientists have examined argumentation practices among school children, arguing for sociocultural analysis that attend to participation in debate (Asterhan & Schwarz, 2016; Kolikant & Pollack, 2009), and suggesting that argumentation practices are necessary for students to expand their learning into critical analysis (Schwarz, et al., 2016). Little has been written to explore how democratic debate learning among adults, or how argumentation links to political development, and so our work extends the school-based literature, challenging the boundaries of teacher-structured debate. My work looks at the consequentiality of argumentation when the stakes are real and highly salient, particularly for non-dominant participants from BIPOC communities, the queer community, etc.

To contextualize argumentation within relations of power and politics, I look to the expanding learning sciences research oriented to questions of how learning is always already political (Politics of Learning Collective, McKinney de Roysten & Sengupta-Irving, 2020), as well as how people learn politics (Curnow, Davis & Asher, 2019; Philip, et al. 2017, Vea, 2020), become activists (Curnow 2013r; Kirshner, 2008; Uttamchandani, 2020), and create change at scale (Jurow & Shea, 2015). This work makes clear that learning ecologies, including argumentation spaces, are not neutral, but are embedded in the dominant relations of our societies, and that "our theories of learning are theories of society" (Philip & Sengupta, 2020). Through this lens, scholars have to attend to the ways that dominant social relations shape the field of learning and the practices that unfold within them, and problematize the ways that they are implicated in the reproduction of inequality.

In this context, the RadLab has examined the longitudinal and micro-interactional practices through which activists become politicized—shifting their political analysis, their ways of knowing, their practices, and their identities (Curnow, Davis & Asher, 2019) and attending to the ways that sociohistoric relations of difference, including racialization, gender, and class, shape who becomes politicized in under which conditions. Our analysis of distributed argumentation carries that work forward, examining the micro-interactional practices that created space for some activists to develop new orientations to radical politics.

In addition to our work on politicization which helps us to theorize the interrelated learning process that unfolded within FossilFree UofT, I also look to recent work on politicized trust (Vakil & McKinney de Roysten, 2019; Vakil, et al. 2016) relations of confianza (Teeters & Jurow, 2018), and educational intimacy (Uttamchandani, 2020). In different ways, these papers highlight how spaces of solidarity are constructed and enable politicized learning among non-dominant participants. These papers stress the agency of non-dominant learners, as well as the significance of trust rooted in a shared experience and analysis of dominant power relationships in making space for resistance, resilience, and revolution. These relationships of solidarity were also scaffolded through processes of guided emotion participation (Vea, 2020), where the emotion practices of participants shaped the sense-making among BIPOC and white women participants, as their feelings were simultaneously shaped the sense-that-was made of relations in the group (Curnow & Vea, 2020). This work lays out the importance of relationality, solidarity, and shared emotional sense-making in the context of contentious politics, and enables us to analyze the ways that distributed argumentation practices relied on and built politicized trust through shared emotional and politicizing processes.

For studies of argumentation, centring politicization, politicized trust, and emotionality in the context of sociohistoric relations of power recentres our analysis away from ideas that debate and deliberation are neutral, social goods, and helps us to instead see how argumentation strategies can enable political learning, but at a cost.

Methods

This project emerges from a long-term collaboration with youth climate activists involved in Fossil Fuel Divestment. Through a participant action research process (Maguire, 1987), the RadLab asked questions about when and how environmental activists became radicalized around racial and gender justice. Orienting to militant ethnographic principles (Scheper-Hughes, 1995), our team is made up of activists from the group, who collectively designed questions, analyzed the video data, and wrote up findings. The strength of this approach is in our deep relationship to the context, where our immersion in the group allowed for activist researchers to theorize the consequentiality of distributed argumentation in alternative spaces and how they travelled to the meetings, and then rely on video data to evaluate the extent to which the pattern was sustained in the data, and if/how it changed the dynamics of Fossil Free UofT.

We analyzed this process of emergent distributed argumentation within the context of a campus-based environmentalist campaign as part of a larger project analyzing politicization processes. From September 2014 to April 2016, Fossil Free UofT met weekly to plan events and coordinate strategy. Meetings lasted two to three hours, with facilitation responsibilities rotating between members. Participants engaged in activist work on campus, including recruiting, event planning, coordinating rallies, and meeting with the administration. Many students came into the organization as a-political or as moderate, yet many became politicized through their engagement.

Through interaction analysis of over 10,000 minutes of multi-camera video data (Derry, et al., 2010; Heath, Hindmarsh & Luff, 2010) of large group meetings, actions, and the Women's Caucus, as well as Stimulated Recall Interviews (SRIs) (Dookie, 2015; Lyle, 2003), we examined different practices that supported political concept development. After content-logging and preliminary coding, our participatory action research team collectively iteratively coded for interaction (Jordan & Henderson, 1995; Angelillo, Rogoff, & Chavajay, 2007). We identified conflict, naming, jumping scale, and distributed argumentation as recurring themes in our data that enabled participants to participate in argumentation around radical politics. We then coded video from the most contentious meetings which we identified through a collaboratively constructed and coded timeline, identified by focal participants as generative and politicizing, for instances of these codes. Two aspects of distributed argumentation became salient, those behind the scenes, and those we traced in coding the videos of conflict. In addition to content logging and coding, we also transcribed subsets of the data, which are excerpted here. Because the phenomena of distributed argumentation is often spread over significant amounts of talk, these transcripts are not shared in full here, but are paraphrased and then highlighted to identify the kinds of convergence we found through distributed argumentation. To analyze the learning behind the scenes, which was often not recorded, we draw on field notes, SRI content, and journals from the time. While RadLab members jointly analyzed the data and co-drafted earlier versions of writing on distributed argumentation, they were unavailable to co-author this paper, but have been shared on drafts and provided feedback on the presentation of data, which has been integrated as part of the process of member checking and relational accountability.

Findings

In this section I outline two distinct, but related, practices of argumentation.. In the first, distributed argumentation occurred in spaces outside the main meetings, especially the women's caucus, people of colour caucus, and the equity committee. These spaces were more politically radical, but also did not include campaign members who opposed radical political ideas, thus these spaces allowed for a different environment for developing ideas. In the alternative spaces, we see equity-oriented participants collaboratively construct arguments. Participants extended their own learning by building on arguments that were still embryonic, based on their sense of allegiance and identity. In the second, we see this practice travel to the large group, but shift purposes; rather than intentionally helping participants to articulate concepts for themselves and others, the distributed argumentation practices in the large group was a strategy of disrupting toxic argumentation practices, resisting domination, and contesting dominant, and more conservative, narratives. In this context, distributed argumentation was used to contest the opposition and to build on arguments that were emergent. We saw distributed argumentation emerge as a strategic intervention that allowed people of colour and women to vocalize their experiences of marginalization in the Fossil Free UofT meeting. Where participants said that the first context felt more comfortable and invited them to explore and develop ideas, the second context served a similar purpose, putting participants in a defensive position in which they built on others ideas based on identity and alignment. In our analysis, RadLab members identified these practices as related, where the alternative space collaboration enabled them to develop the muscle of iterating on each others' ideas based in trust and identity, and they credited those spaces with enabling the contestation and learning in-real-time that unfolded in the large group.Through both contexts we see distributed argumentation opening up and expanding new political concepts and reshaping activists' engagement with radical politics.

Alternative spaces

As space was foreclosed across the large group meetings, BIPOC members and some white women increasingly sought and created "alternative spaces" for themselves, where their ideas could be heard and developed in a supportive, rather than combative space, and where an environment of solidarity and politicized trust emerged. distributed argumentation in these settings is very much about individual participants being encouraged to articulate political ideas for themselves, and for others. It has both a sense of talking it through for oneself (in some instances) and a pedagogical feeling of modeling for others. In some of the instances, the talk here is doing the piecing together—sensemaking in real time. And it is affirmation seeking, and responds (in most, but not all cases) to the feedback, correction, and sculpting of other speakers— we can see how the ideas become shared products, and how they emerge again in later meetings and talk.

In the Women's Caucus, where women met to discuss their shared experiences of gender, the kind of collaborative sense-making that underpinned distributed argumentation flourished. We see instances of distributed argumentation as participants named the problematic turn taking dynamics (Curnow, et al., 2020), as they identified emotional labour as a gendered phenomenon (Curnow & Vea, 2020), and as participants linked experiences of gendered marginalization to other sociohistoric forms of oppression. For example, when presented with the initial data around turn-taking, the sense-making unfolded in real time:

Tresanne:	A lot of like- it was really sad to read all the things that I know. But then, but then to read it all together…
Lila:	[…] It's weird because at the time I didn't think of those things as problematic, at all. Part of that was that it was earlier, so I wasn't thinking critically about it. […]
Sydney:	I catch the blatant things, but not everything,
Heather:	I don't have much experience, but I thought [the turn-taking report] was really interesting, I'd never seen gendered conversation quantified, so I was kinda like, whoooaaa. And now looking for it, I've been looking around more, which is cool.
Jody:	Through the process of writing, I kinda felt like it was validating, like internal feelings, where otherwise I have a tendency to be like, oh maybe I was like looking for it and projected things that weren't actually there, or maybe I'm being too, like, I don't know what the word is. But like questioning myself, questioning whatever my feelings are, like feeling dismissed, or feeling invisible, so like that was kinda nice, in like a twisted way. Like, oh, it's nice, I really am, I really do never participate, and I think I don't. And also the fact that it was really messed up. It was worse than I expected, but also not surprising?

This exchange reflects a number of key practices in the alternative spaces. First, we see widespread engagement, in ways that are unique from the large group spaces. In this instance both Jody and Heather speak, which almost never happens in the large group, and which we interpret as an indication of some level of trust/comfort, or at least space to do so which is unique from regular meetings. Second, we see participants building on each other's ideas, and in the larger context that this is excerpted from (for space), we see consistent cross-referencing each others' contributions. We also see the kind of real–time sense-making as they collectively construct grievances around the gendered turn-taking practices, and begin to identify their own experiences as valid sources of knowledge which they had often dismissed (or had dismissed by others). In the larger transcript, we see this shared experience building a sense of camaraderie, and creating an environment that was filled with enthusiasm and, in some spaces, joy (Curnow, et al. 2020), where the sense of shared marginalization and the de-individualization of their marginalization created the kind of politicized trust that enabled them to build on one another's ideas, to joke and tease, and to push each other into deeper forms of cognitive analysis.

In another instance of distributed argumentation in alternative spaces, Lila reflected on her learning and planning process as she and Sinead designed a workshop on the root causes of climate change for the retreat in spring of year 2. Their planning came amidst two related processes that made the process significant: first, Lila and Sinead, and the other Equity committee members increasingly saw themselves as radical, and while many of the cognitive analytic links between colonialism, capitalism, patriarchy, and the environment were not yet clear to them, they spent significant time trying to read and theorize those links together, and they trusted they were there. Second, the large group was increasingly polarized, and Lila and Sinead envisioned the workshop as an opportunity to convince the more conservative members of the group through an evidence-based, well-facilitated process. In the planning process, Lila and Sinead spent hours designing a process meant to uncover the layers of interconnection between racialization, settler colonialism, and climate justice (something that had been litigated in the group in fleeting ways for over a year, but never been intentionally explained). In a journal reflection as part of the RadLab writing process, Lila reflected

> Thinking through things with Sinéad was a lot better than just thinking it through by myself because we were able to answer each other's questions and push back on things that we got to too fast, and make sure that we really had a good grasp on it. It wasn't distributed argument the way it was in larger groups, because there were only two of us, and we had more time to go back and revise, but it was still really good to like build the argument together. It helped me fill in the gaps in my explanation so I felt more confident believing this and explaining it to other people.

This kind of collaborative work was more common in the Equity Committee spaces, but not in the large group, and played a role in extending the cognitive analysis of climate justice that Lila and Sinéad were working toward, but had not articulated for themselves, or been in spaces where those critiques were made explicit. Lila describes how when one person made a statement and received push back they would try to build on each others' ideas and defend the position, even when they weren't confident about the specific logic. In this way, their planning process enabled them to extend the argument they were attempting to make around the dialectical relationships between race, colonialism, and climate change, building their own capacity to articulate the politics, and then also discovering a logic, making it more scientific, rather than an intuitive thing that they trusted but did not feel that they could explain publicly or go to bat for in the conflictual spaces of the large group meetings. Neither Lila nor Sinead was more capable and positioned as a mentor or teacher; instead they oriented to each other as resources and accomplices in their purposeful work as they collaboratively built something new to both of them. This collaboration space was an important space for cognition, but it's important to note that it was only available to them because the identity pieces were already in place—they already believed that there were core connections within the political analysis that they just needed to unpack. They assumed they were there, that they were correct, and that the two of them were capable of theorizing those relations and teaching them to the larger group through a shared process.

Throughout these alternative spaces, we see relations of politicized trust forming in real time and shaping the sense that was made of the dynamics in the large group. Distributed argumentation advanced this process by creating space for participants to work through their ideas-in-process. As Lila noted, the collaboration between herself and Sinead enabled them to extend their thinking beyond what either was individually capable of. It also created a sense of solidarity in the shared project of articulating a politics and in being ready to share that with the larger group.

Travel to large group meetings

Distributed argumentation looked quite different in the large group settings, where because a few white men spoke so frequently, it was deployed as a resistance strategy, an educational strategy, and an expression of politicized trust between equity committee members. In these spaces, distributed argumentation was identified as multiple turns spread across speakers which built on previous speakers. These turns almost always alternated with one of the dominant white men speakers' turns (ie: Amil (equity speaker), Graham (non-equity speaker), Lila (equity speaker), Graham, Sydney (equity speaker). In these conflict-oriented settings where turn-taking dynamics skewed toward a few white men who dominated the talk and argued for more conservative politics, distributed argumentation emerged as a practice of disruption and validation. It seemed to emerge as a way of backing other speakers up, affirming them. Often we saw interesting things happen in these turns where embryonic ideas got adopted by other speakers, and got expanded by different speakers in the process. This is one of the organic sense-making that we found in the data set of people talking through and making connections, and our interpretation is that this was driven by allegiance and also politicized trust.

In a September 2015 meeting, we see an interesting expression of distributed argumentation. The context of the debate was that in response to the brief submitted to the university president, FFUofT received a casual request to define "social injury", the defining criteria for divesting according to the university policy, more narrowly, and in relationship to other divestment campaigns on campus (Black Liberation Collective's campaign to divest from US private prisons and the Boycott, Divest, and Sanction campaign against Israeli apartheid). This argument unfolded over 40 minutes (because of the length, transcript is not provided here), pivoting around the questions of: 1. If climate change represented a more serious social injury than racialized and settler colonial harm in the other campaigns and 2. If FFUofT should do the "dirty work" for the university in establishing why our campaign was more deserving than the others. In this instance, we see the normalized patterns of speaking hold, with 11 minutes of talk spread out between three white men. After a brief interruption, we then see another 10 minutes of discussion by the same 3 white men. At this point, Lila interrupted the exclusive talk and asked for a go-around where all meeting participants could speak. What ensued was a discussion that hinged on larger contestation about the role of fossil fuel divestment as a campaign, and the tactics of the environmental movement more broadly. While the 3 white men who speak most frequently argue for a narrowly-framed approach to divestment and social injury, we see a series of BIPOC speakers and white women speakers who try to reframe against, arguing that solidarity with other campaigns should be the goal. The full transcript shows the interventions that are made in response to the white men speakers, but in the interest of space, because these turns are relatively long, I highlight here a selection of the responses which demonstrate the subsequent building on previous equity speakers' ideas..

Sydney: It's super important- like if we accomplish our goals, while disadvantaging other movements, I don't think we're actually accomplishing anything. I think it's really important the way that we frame this and the way that we- and the way we present our arguments, is not that ours is the exception. Because I think that, y'know what I'm saying? I think that if anything, we should be showing solidarity with other movements that are trying to work on divestment. (Minute 68)

Amil: My thinking are along the same lines of Sydney and Lila, I really don't want to handicap other campaigns. I know this is how, sort of , legal cases play out, but I'm not into law at all, and I just think that, ethically or morally speaking, saying that you don't want to divest from, sort of like, these shitty institutions because it will open the door to divesting from other shitty institutions, is a messed up argument to make. (Minute 74)

Jade: I agree. I don't want to shut anyone else down. I think there's a way of wording things where we can make our argument sound very convincing without being like, look how different we are, compared to other things happening now. (Minute 75)

Cricket: Building on what these people said, fossil fuel divestment only matters to a small number of people on this campus. UofT is not a very sustainable university compared to UBC where there's an institutional commitment to sustainability. Divestment is just a small drop in the bucket. And I don't think, for lack of another word, trampling on another campaign to get ours up, in the bigger picture, will accomplish much more for this campaign. Even if UofT does divest, there's still miles and miles and miles to go, and I don't want to see this campaign… which in the bigger picture, when it's just a small drop in the bucket, achieve its goals by putting another group down, cuz at the end of the day, our work is not the end of what UofT needs to do. (Minute 87)

Across these turns, speakers make a number of moves that are significant. They are consistently cross referencing each others' talk—other speakers cite other equity speakers, saying "Just going off what Sydney said…", and I agree with what was just said", and "building on what these people said…". They also use the same language-- the idea of not "handicapping other campaigns" comes up repeatedly by three different speakers subsequent to Amil's use. There's a travel of the major idea of solidarity and contestation of the idea that fossil fuel divestment is the most important issue on campus, and travel of the idea that justice work is linked. For members like Cricket, who was relatively new, this is a significant moment in articulating fossil fuel divestment in the context of larger movements for social and environmental justice.

A few aspects of distributed argumentation stand out here: first, we notice the diversity of participation (with 15 people speaking, including 10 BIPOC and white women) in comparison to the exclusive talk between three white men speakers making frequent and long turns. Second, we note the ways in which ideas of solidarity are being expanded in real time, by different people, as a way of contesting the white men's assertions. The idea of solidarity travels across speakers and expands into new directions of argument that attend to the assertions of the white men, but which also attempt to reframe the debate. Third, we can see how the relations of trust and identity emerge in this series. The sides of the debate are clearly delineated, and when BIPOC speakers and white women speakers take their turns, they orient to the substance of previous BIPOC & white women speakers. In some cases they explicitly bridge, while in other instances the bridging is suggested through similar discourse or extending the previous argument to respond to the critiques directed at that person. Even when this bridging does not happen, we interpret the continued turns in favour of similar ideas as a reflection of a shared politics rooted in politicized trust: they are extending each others' arguments as an expression of faith in their colleagues' analysis, as well as of identity.

Other examples from our data set include extended turns where, for the first time in the large group, BIPOC people named the racialized dynamics that were normalized in the group. Over a series of turns spread out across multiple speakers during a go-around where each speaker had a turn, BIPOC participants built on each others' contributions and extended the critique that the Women's Caucus centred, through which gender was the primary lens of analyzing the participation dynamics in the group. The sequence of distributed argumentation drew speakers in who almost never spoke in the large group, and explained the racialized marginalization that they experience in the group on the regular. We saw a similar phenomena when the Women's Caucus brought their concerns to the large group meeting. Spread across a group of women, we saw consecutive contributions which built on the contributions of colleagues and anticipated the critiques white men would bring to bear (see Curnow, et al, 2020).

Significance

Our analysis shows ways that activists were collectively engaging in sense-making practices, and moves discussions of democratic education and learning beyond the classroom and the controlled context of teacher-moderated debate. We show how activists learned to take up the ideas of colleagues and extend them, contributing to studies of learning in social movements, and contributing to new theorizations of political learning. This work is significant micro-interactionally and politically for the field of the learning sciences.

Micro-interactionally, this study reveals useful patterns around how embryonic politicization was fostered through turn-taking dynamics which required speakers to extend their learning beyond what had been articulated and fully made sense of in the moment as a way of asserting identity claims and contesting what were understood as racist, colonial, homophobic, and misogynist claims. This reveals an interesting process of sense-making in moment to moment interaction, where cognition followed the identity and epistemological development of participants, and was made possible through emergent practices designed to reclaim space. This complements Vygotskian work on sense-making, while drawing our attention to the ways that identity can be a central driver in which peers are oriented to as more-knowledgeable others, which ideas are extended as valuable and relevant contributions, and when these ideas and practices will be advanced by learners as they navigate new political terrain.

This analysis shifts the attention of work on argumentation, looking at the real world debates that are extremely common in today's contentious political field. This matters because it helps learning scientists to theorize ways that non-dominant people strategize and practice resistance in debates which too often de-legitimize and discount their existence. Too much of the scholarly debate around argumentation treats the parties of debate as false equivalents, where it is desirable, or at least permissible, for both sides of the debate to receive air time and be heard, acknowledged, and learned from (Sfard, 2020). This argument is dangerous and detrimental to the well-being of non-dominant participants, who are so often forced to engage with ideas, practices, and ways of knowing and being that fundamentally undermine and seek to degrade their humanity, their civil and human rights, and their ability to participate fully in the world. Rather than accept the norms of democratic debate un-problematically, this analysis shows the agentic interventions that radical activists coordinated collectively to resist and undermine their de-humanization and] assert agency, grow their political analysis, and shift the overall politics of the community of practice.

References

Angelillo, C., Rogoff, B., & Chavajay, P. (2007). Examining shared endeavors by abstracting video coding schemes with fidelity to cases. *Video research in the learning sciences*, 189-206.

Asterhan, C. S., & Schwarz, B. B. (2016). Argumentation for learning: Well-trodden paths and unexplored territories. *Educational Psychologist*, *51*(2), 164-187.

Curnow, J. & Chan, J.R. (2016). Becoming an "Expert": Gendered Positioning, Praise, and Participation in an Activist Community.In Looi, C. K., Polman, J. L., Cress, U., & Reimann, P. (Eds.). (2016). *Transforming Learning, Empowering Learners: The International Conference of the Learning Sciences2016, Volume 1*(pp. 146-153). Singapore: International Society of the Learning Sciences.

Curnow, J., Davis, A., & Asher, L. (2019). Politicization in Process:Developing Political Concepts, Practices, Epistemologies, and Identities Through Activist Engagement. *American Educational Research Journal. 56*(3*)* 716-752.

Curnow, J., Fernandes, T., Dunphy, S., & Asher, L. (2020).Pedagogies of Snark: Learning through Righteous, Riotous Anger in the Youth Climate Movement. *Gender & Education.*

Curnow, J. & Vea, T. (2020).Emotional Configurations of Politicization in Social Justice Movements. *Information and Learning Sciences.*

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., ... & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences*, *19*(1), 3-53.

Dookie, L. (2015). *Examining marginalizing acts of social positioning in mathematical group work: Towards a better understanding of how microaggressions and stereotype threat unfold in intergroup interactions* (Doctoral dissertation, University of Toronto).

Goldberg, T., Schwarz, B. B., & Porat, D. (2011). "Could they do it differently?": Narrative and argumentative changes in students' writing following discussion of "hot" historical issues. *Cognition and Instruction*, *29*(2), 185-217.

Heath, C., Hindmarsh, J., & Luff, P. (2010). *Video in qualitative research*. Sage Publications.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences*, *4*(1), 39-103.

Jurow, A. S., & Shea, M. (2015). Learning in equity-oriented scale-making projects. *The Journal of the Learning Sciences*, 24(2), 286-307.

Kirshner, B. (2008). Guided participation in three youth activism organizations: Facilitation, apprenticeship, and joint work. *The Journal of the Learning Sciences*, 17(1), 60-101.

Kolikant, Y. B. D., & Pollack, S. (2009). The asymmetrical influence of identity: A triadic interaction among Israeli Jews, Israeli Arabs, and historical texts. *Journal of Curriculum Studies*, *41*(5), 651-677.

Maguire, P. (1987). *Doing participatory research: A feminist approach*. Amherst: University of Massachusetts.

Mirza, N. M., & Perret-Clermont, A. N. (Eds.). (2009). *Argumentation and education: Theoretical foundations and practices.* Springer Science & Business Media.

Philip, T. M., Gupta, A., Elby, A., & Turpen, C. (2018). Why ideology matters for learning: A case of ideological convergence in an engineering ethics classroom discussion on drone warfare. *Journal of the Learning Sciences, 27*(2), 183-223.

Philip, T. M., & Sengupta, P. (2020). Theories of Learning as Theories of Society: A Contrapuntal Approach to Expanding Disciplinary Authenticity in Computing. *Journal of the Learning Sciences*,

Scheper-Hughes, N. (1995). The primacy of the ethical: propositions for a militant anthropology. *Current anthropology*, *36*(3), 409-440.

Sfard, A. (2020). Lost and Found in Dialogue: Embracing the Promises of Interdiscursivity and Diminishing Its Risks. Keynote, International Conference of the Learning Sciences, Nashville, TN.

Schwarz, B., Rajala, A., Rosé, C. P., Clarke, S., Fynes-Clinton, E., Renshaw, P., Solli, A., Hillman, T., Mäkitalo, Å., Goldberg, T., Tammi, T., & Wegerif, R. (2016). Fostering Deliberative Discourse in Schools Towards the Constitution of a Deliberative Democracy In Looi, C. K., Polman, J. L., Cress, U., and Reimann, P. (Eds.). Transforming Learning, Empowering Learners: The International Conference of the Learning Sciences (ICLS) 2016, Volume 2. Singapore: International Society of the Learning Sciences.

Teeters, L. A., & Jurow, A. S. (2018). Relationships de Confianza and the organisation of collective social action. *Ethnography and Education*, *13(*1), 84-99.

The Politics of Learning Writing Collective (2017). The Learning Sciences in a new era of US nationalism. *Cognition and Instruction, 35*(2), 91-102.

Uttamchandani, S. (2020). Educational intimacy: Learning, prefiguration, and relationships in an LGBTQ+ youth group's advocacy efforts. *Journal of the Learning Sciences*, 1-24.

Vakil, S., & McKinney de Royston, M. (2019). Exploring politicized trust in a racially diverse computer science classroom. *Race Ethnicity and Education*, *22*(4), 545-567.

Vakil, S., McKinney de Royston, M., Suad Nasir, N. I., & Kirshner, B. (2016). Rethinking race and power in design-based research: Reflections from the field. *Cognition and Instruction*, *34*(3), 194-209.

Vea, T. (2020). The learning of emotion in/as sociocultural practice: The case of animal rights activism. *Journal of the Learning Sciences*, 1-36.

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Adapting a Choice-based STEAM Learning Program to Remote Learning: Barriers, Competing Priorities, and Design Considerations

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Abstract: In response to the outbreak of COVID-19, schools and educational designers have been forced to adapt quickly to remote or hybrid instruction. This presents us with a critical need and unique opportunity to understand how to adapt teaching and learning to a remote format, the barriers and competing priorities that educators and designers have experienced in attempting this adaptation, and the impact that these adaptations have had on student experiences. Here, we examine these questions in the context of one choice-based, interest-driven STEAM (science, technology, engineering, arts, and math) learning program called FUSE Studios, by examining survey and interview data collected with educators and students who participated in this program remotely during Spring 2020. We also discuss design iterations our team implemented, in response to research findings.

Introduction

In response to the outbreak of COVID-19, schools and educational designers have been forced to adapt quickly to remote or hybrid instruction. It is unclear how long this will last and what long-term impact it will have on K-12 teaching and learning. This presents us with a critical need to understand how to adapt teaching and learning to a remote format. It also presents us with a unique opportunity to understand the barriers and competing priorities that educators and designers have experienced in attempting this adaptation. In this paper we investigate these issues by drawing on remote interviews conducted during Spring 2020 with teachers and students participating in a choice-based, interest-driven STEAM (science, technology, engineering, arts, and math) learning program called FUSE Studios (Stevens et al., 2016). We also describe professional development and design iterations that the FUSE team enacted in response to the data we collected with teachers and students.

FUSE is typically an in-person learning experience in which students choose STEAM challenges of interest. While the menu of challenges and challenge instructions is housed on the FUSE website, students complete challenges collaboratively in a classroom, using a suite of digital and tangible tools. As a result, our prior research has shown in-person FUSE to be an engaging experience for students (Stevens & Ramey, 2020) that helps them explore and cultivate STEAM interests (Ramey & Stevens, 2019). However, this research has also shown that peer helping and collaboration over shared materials and representations are core features of the FUSE experience (e.g., Stevens et al., 2016). This Spring, as schools went remote, this left us with open questions regarding how or whether FUSE would be adaptable to a remote learning context. On the one hand, we might expect that FUSE challenges being housed on a website would make them easily accessible at home. Similarly, FUSE being choice- and interest-based might make it well-suited to students working at home, where interest and motivation are typically allowed to and therefore play a larger role in engagement and learning than they do within classrooms (e.g., Ito et al., 2010). On the other hand, it was unclear whether the collaboration and sense of community we've observed in in-person FUSE studios could be replicated (or even approximated) in a remote context. Similarly, while many of the FUSE challenges use free, web-based applications or materials that students would have access to at home (paper, cardboard, spaghetti, marshmallows), other challenges require technology tools, such as 3D printers and breadboards that would likely not be available during remote instruction, thus limiting the number and types of FUSE challenges that students could choose to work on.

Consequently, we launched an investigation into how teachers were adapting FUSE to remote learning and what aspects of it were being retained or lost as a result of this adaptation. We focused this investigation on three specific research questions: (1) 'How have educators adapted FUSE to remote learning?'; (2) 'What barriers and competing priorities have they experienced in doing so?'; and (3) 'What impact have these adaptations had on student experiences?' This investigation was part of a larger inquiry into the ways in which our education partners have adapted FUSE (and the effect of those adaptations on students' experiences), as the program has scaled up from a handful of after school programs in one suburban Midwestern school district, in 2012, to over 200, primarily in-school implementations across the United States, in 2020. Therefore, our findings will also speak to the larger question of how/whether educators adopt and adapt educational innovations, particularly in times of crisis, and how educational designers might adapt to educators' needs.

Reasoning and innovation in times of crisis

One body of literature that informed our investigation of the ways in which educators did or did not adapt FUSE to a remote learning context was studies of reasoning and the fate of innovations in times of crisis. For example, in an experimental, decision-making study, Ben Zur and Breznitz (1981) found that when put under time-pressure, individuals tended toward conservative rather than risky choices. Similarly, research on business innovations suggests that during times of crisis (i.e., economic recessions or depressions), new or persistent innovation is the exception rather than the rule (e.g., Antonioli & Montresor, 2018; Holl & Rama, 2016).

Therefore, we might expect that, given the stress that the global pandemic put on educators (and everyone else), educational innovations might be deprioritized, and adaptations might be modest and limited to things viewed as essential. This would be consistent with narratives of remote learning during Spring 2020 as a poor approximation of school-based learning (Hobbs & Hawkins, 2020; Jacobson, 2020), rather than an experience which took advantage of this unique moment to reimagine what teaching and learning could and should be. But it also raises the question of what *was* adapted and how, as well as what reasons or motivations led to those adaptations. For example, did educators react to this stressful time by falling back on familiar or comfortable patterns of behavior or did they feel pressure to rapidly adapt or innovate to meet the new demands of remote teaching? If the latter, what types of adaptations did they focus on and why? These questions are important to answer, as they will inform our understandings of what is likely or possible during future periods of crisis.

Conceptual framework

In framing our investigation, we drew on prior work studying educational leadership, policy, and innovation from a distributed perspective (e.g., Fenwick, 2011; Spillane, 2006; Stevens et al., 2018). We conceptualize schools as distributed assemblies of people and things, and therefore, argue that understanding how such organizations adapt to new circumstances involves understanding how individual human and nonhuman actors come into and out of association with one another over time, forming and reforming different networks (e.g., Latour, 2005).

We further drew on work by Coburn (2001), which emphasizes the importance of examining how educators make sense of programs or policies, in order to understand how they are adapted and implemented. We believe that this perspective is particularly important to understanding remote learning adaptations that took place during Spring 2020, as teachers were required to make sense of and implement a series of rapidly changing policies, often without thoughtful, comprehensive, top-down guidance. As a result, we suspect that teachers may have had more agency than usual in interpreting policy and adapting (or not) their own teaching practice.

Finally, in working with our partner educators to adapt FUSE to their remote teaching needs, we drew on design-based research (Design-Based Research Collective, 2003) and design-based implementation research approaches (Penuel, Fishman, Cheng, & Sabelli, 2011). These approaches shaped our framing of implementation as an integral part of design, not a phase that follows it, and drove us to be responsive in using the data we collected to design new challenges, web tools, and professional development to support educators and students.

Methods

To examine how FUSE students and teachers have adapted to remote learning and what challenges or successes they have experienced in doing so, we collected three types of data. First, we sent out a survey in late March to all our partner schools to find out how and whether they were implementing FUSE during Spring 2020. We received responses from 43 of our partner schools. Second, we followed up with partners at nine focal schools where we had previously conducted interviews and observations, as part of our broader study of the spread of FUSE. We chose to focus on these schools, because we had the most complete understanding of what they were adapting from, as they moved into remote instruction. With our partner teachers and/or administrators at these focal schools, we conducted remote, semi-structured interviews via videoconference. These interviews focused on understanding whether and how they were adapting FUSE specifically and instruction generally to remote learning and any successes or challenges they'd experienced in doing so. We also conducted remote, semi-structured interviews via videoconference with four focal students at one of our case study schools. These students were selected in collaboration with our partner teacher at that school, in order to represent a cross-section of student perspectives and experiences on FUSE and remote learning. The interviews focused both on how students were experiencing remote instruction broadly and specifically on their experiences doing FUSE remotely.

Findings

Survey responses and interviews with educators at our partner schools showed that many of them were using FUSE during the period of remote instruction and also adapting it in a variety of ways. For example, of the 43 survey responses we received, partners at 13 schools reported that they were still offering FUSE as a required course remotely. Another 25 reported that FUSE participation was optional for students. Only two said that FUSE wasn't being offered at all, and two said that they hadn't decided yet. In describing the format of instruction, 26 school partners reported that FUSE and other classes were being offered asynchronously, 2 reported that they would be engaging students in synchronous instruction, and 13 reported that they would be doing both.

Our interviews with school partners provided a more detailed picture of adaptations, as well as the barriers and competing priorities educators were responding to in adapting FUSE. For example, through iterative rounds of inductive coding, we identified two specific barriers that educators (and students) experienced: (1) access to technology; and (2) competing home and school interests and responsibilities. In attempting to adapt FUSE to overcome these barriers, our partner educators also described being faced with competing priorities. The three sets of competing priorities that we identified were: (1) foregrounding required subject matter content versus foregrounding student engagement, (2) prioritizing choice versus prioritizing accountability, and (3) promoting online safety versus promoting unrestricted, open collaboration. Sometimes these competing priorities were both held by the same individual (e.g., the FUSE teacher), who had to figure out how to balance them in adapting to remote instruction. Other times, they were held by different individuals at different organizational levels (e.g., the FUSE teacher vs. building or district level administrators). However, in all cases, we argue that how teachers navigated these competing priorities decisively shaped both how they adapted FUSE to remote learning and how students experienced FUSE remotely. In the sections that follow, we will discuss each barrier and set of competing priorities in greater detail. We will then close by explaining how our design team responded to educator needs.

Barriers to remote teaching and learning

Unsurprisingly, the first barrier that educators cited to remote learning (including but not limited to FUSE) was lack of access to technology. For example, of the 43 educators that we surveyed, 11 said that all of their students had access to the necessary online platforms for remote learning; 21 said that most (75-100%) had access; 6 said that many (25-75%) had access; 3 said that some (1-25%) had access, and one didn't know. Similarly, 10 said that all students had access to video-conferencing; 20 said that most (75-100%) had access; 6 said that many (25-75%) had access; 4 said that some (1-25%) had access, and one didn't know. When asked what kind of devices students were using to access online content from home, 16 said that students were using Chromebooks, one said they were using iPads, 3 said they were using laptop or desktop computers, 21 said they were using some combination of these devices and other smartphones or tablets, and one was unsure. Finally, in describing students' sharing of these devices, 26 educators said that students had their own devices (either issued by school or owned by student), while 26 said that some/all students had to share a device with others, and three were unsure.

These data show that access to necessary technology (a critical non-human actor for remote learning) was far from universal both within and across schools. This is to be expected, as many of our partner educators came from under-resourced schools serving populations that are majority low-income. However, for the most part, our education partners positioned this as a surmountable barrier and had identified solutions for addressing it. For example, many schools sent home laptops, iPads, or Chromebooks owned by the school (either one per student, one per family, or one only to each student/family who needed it). To provide WiFi to those students (and teachers) who needed it, some districts worked with local cable companies or sought donations from local businesses to provide WiFi hotspots for families in need. However, needs-based computer and WiFi distribution programs were dependent upon parents reaching out and requesting the needed technology, which didn't always happen, creating ongoing barriers to e-learning for a small number of students.

In addition to these general technology barriers, affecting all remote learning, in facilitating FUSE remotely, teachers and students faced an additional, more unique, technology barrier: access to specific software and physical tools and kit materials needed to do some of the challenges. As of March 2020, there were five FUSE challenges that could be completed entirely with open-source, web-based applications and therefore could be easily done at home. There were an additional five that involved online 3D design followed by 3D printing of the designed object. For these challenges, everything but 3D printing could also be easily done at home. There were two challenges that could be completed at home using cheap, everyday materials: *Spaghetti Structures* (which required spaghetti and marshmallows) and *Slow Your Roll* (which required paper or cardboard, tape, and a marble or other small ball), and there were two challenges that used software that was free but could only be downloaded on a desktop or laptop computer (not on an iPad or Chromebook). So these two challenges could be done at home, but only if students had the right type of device and the appropriate administrative access to download software (not always the case, particularly on school-issued devices). The other 17 FUSE challenges were designed to be done using kit-based materials (or a combination of digital tools and kit-based materials), which students did not have access to during spring remote learning. Therefore, they could not be completed remotely. So, while roughly half of FUSE challenges were available to students in some form while they worked remotely, the other half were not, and even those that were available were in some cases only available to some students (software challenges) or were only partially completable by all students (3D printing challenges). As a result, the primary way that educators said the FUSE team could help support them in implementing FUSE remotely was to design more challenges that could be done with the tools and materials students could access from home.

The second barrier to participation in both school broadly and FUSE specifically, described by both teachers and students, was the problem of competing home and school interests and responsibilities. Regarding competing interests, one student, 'Jackson', talked about feeling distracted by other activities at home and having a hard time focusing on schoolwork, saying, "It's tough to like stay focused on the tasks…like every time I try to like work on something, I get like off task, to like music or like video games or something. And that's, uh, it's been leading me to like, not do some of the work. So like, it's kind of hard for me to pay attention." He elaborated further, saying, "[I]t's just a cluster of tabs on my computer. And sometimes I don't know the question or the answer, or uh, a word or a question. So I have to like search it up and then I just have like 20 tabs open on like Google, trying to explain the one topic that I, I was trying to explain myself." Importantly, while Jackson described having difficulty focusing on schoolwork during remote learning (both in and out of FUSE), he said that in his free time, he was pursuing a wide range of learning activities related to his interest in a career as an astronomer or aerospace engineer, including watching National Geographic, Bill Nye the Science Guy, Iron Man, and other Marvel movies; playing video games, such as No Man's Sky and Space Engineers; coding in AI and Brainwaves; and solving a complex math equation for fun.

Home responsibilities also competed for students' time and attention. For example, we heard from educators that middle and high school students were being tasked with watching younger siblings while parents worked or were themselves working in essential jobs to help the family (in some cases because their parents had lost their jobs). For example, one high school teacher shared some of the students' stories she'd heard, in response to the question, "With all that is going on, what have you struggled with during this time?", saying,

> [M]ost of the answers are heartbreaking. Parents lost jobs, student still works an essential job. So they're working to pay the bills now and save up for that car they wanted, the other stuff. An aunt passed away, not COVID-related. Working all day, getting schoolwork done late at night. 'Parents still work, but I'm the teacher now and have to take care of my siblings and make sure they're learning and getting work done for them and bathe them. Then I get my schoolwork done when my parents get home.' 'My parents still work, but I'm an only child, so I'm home alone all day, until 7:00 PM at night, and I feel lonely.'

As a result, many students either didn't do schoolwork at all or were doing schoolwork and sending questions to teachers in the middle of the night, because that was the only time they were able to do it. For example, the same high school teacher said, "One girl messaged me. She got into FUSE and she was having a question. Well, she messaged my Google voice number at three in the morning."

While this problem was not unique to FUSE, neither was FUSE exempt from having to compete (and often losing out) to students' other interests and responsibilities at home. Our interview with Jackson shed some light on why FUSE may not have been as successful at holding students' interest and attention at home as our prior research suggests that it has been at school. He explained that during in-person FUSE, he enjoyed working with friends and preferred working on hands-on, kit-based challenges, such as those involving Arduino breadboards or building a solar car. At home, the collaboration piece was missing for him, as was access to these kit-based challenges. He described working solely on the computer as more distracting, saying "[I]t's easy to be distracted while building, but still be able to build and work on it. But on computers, I just get fully distracted and I take my mind off of the thing I'm working on."

Competing priorities in adapting instruction to a remote context

Teachers adapted to these two barriers to remote learning in different ways. How they adapted to them was decisively shaped by how they made sense of and navigated a series of competing priorities with regard to remote teaching and learning. First, in order to overcome the barrier of competing interests and responsibilities, educators had to negotiate a tension between two competing priorities: Is it better to foreground traditional subject matter content or foreground engagement? Some teachers and administrators believed that since students (and teachers) had limited time and attention to dedicate to remote learning, perhaps it was most important to prioritize covering core subjects, material that met standards, or things that might later be covered on standardized tests. For example, one teacher explained that even though standardized testing had been suspended during the pandemic shut-down, her administration's priority was still on math and reading – the things that would later be covered on standardized tests. In contrast, other teachers and administrators prioritized students' socio-emotional well-being and promoted activities that were fun and engaging, to motivate students to want to engage more in remote learning.

How educators balanced these competing priorities had implications for FUSE implementation. The schools that chose to foreground traditional subject matter coverage over engagement either didn't do FUSE or made it an optional extra, rather than an emphasized or required part of the remote learning curriculum. For example, an educator from one school that decided not to do FUSE remotely explained the reasoning behind that decision, saying, "[T]he challenge is trying to actually reach the students, for their normal…what is typically normal academics and trying to actually get over the hurdles of…reaching them with distance learning. So we've had so many challenges on that with that regard that unfortunately FUSE has actually taken a back seat." In contrast, those education partners who foregrounded engagement tended to include FUSE as part of remote learning. In some cases, the negotiation between these competing priorities was a negotiation between the FUSE teacher and their administration. For example, one teacher explained that although her administration's priority for remote learning was on math and reading, she decided to do FUSE anyway, because she wanted to make sure that her kids were "emotionally okay" and wanted to "give them fun things to do."

A second, related set of competing priorities that educators experienced in dealing with both the technology barrier and the competing interests and responsibilities barrier was a negotiation between prioritizing choice or prioritizing accountability. Because not everyone had access to technology or was interested/able to engage in remote learning, most educators decided to prioritize flexibility and choice and decrease accountability (both to increase engagement and address equity concerns). However, some educators had the opposite response, opting to increase accountability and decrease choice, to make up for having less contact with students and being unable to monitor their progress in the usual, more informal ways (e.g., walking around the classroom). For example, one teacher said that her administration had laid out three guiding principles for remote learning – "flexibility, grace, patience", which she had tried to incorporate into her remote teaching. However, she expressed frustration with colleagues who had failed to put these principles into practice by assigning as much or more work than they would in person, prioritizing accountability and resiliency, rather than flexibility and choice.

In FUSE, this meant that some educators retained or even expanded the choice aspect of FUSE (a core feature of FUSE in its typical implementation in schools). For example, one teacher talked about how his administration had encouraged expanding the number of choices available to students within FUSE and expanded the choice aspect of FUSE to other subjects during remote learning, saying, "[W]e have choice boards, which…we have to create by department for all the departments…and then the students are supposed to choose the activities that they're going to work on…or there might be options on how they're going to do it. With STEAM [FUSE]…we have nine choices on there [each week]." This meant that, in addition to regular FUSE challenges, the FUSE teachers also designed additional, related STEAM activities for students to choose from, organized around weekly themes (e.g., Star Wars projects for May the Fourth, Earth Day projects, and healthcare worker appreciation projects). In contrast, other FUSE facilitators eliminated choice by assigning one activity per week (either a FUSE challenge or a STEAM activity of their own design), in order to increase accountability.

Those facilitators that assigned weekly challenges tended to also layer in additional elements of accountability, such as requiring the completion of one challenge/activity per week or requiring written reflections after challenge completion. While some of our partner educators had implemented these sorts of accountability measures prior to the pandemic, most had not, and we spoke with specific partners who explicitly discussed newly implementing them during the pandemic, to increase accountability. This trend was interesting, because it existed in tension with the fact that, during remote learning, grades were largely eliminated or assigned as "pass-fail", a practice which was common in many FUSE classrooms previously but uncommon in schools broadly.

A third major decision that educators had to make in implementing remote instruction generally was how they were going to use available technology, particularly video-conferencing. When we surveyed our education partners on whether they were using video-conferencing during remote learning, eight said no, 20 said yes, it's optional, and 13 said yes, it's required. On one level, this decision hinged on which of the two barriers to participation in remote learning educators viewed as more problematic, interest/engagement or equitable access to technology and time to participate synchronously in instruction. If educators were more concerned with equity issues, they de-emphasized video-conferencing, but if they were more concerned with interest/engagement they incorporated more video-conferencing. On another level, this decision was shaped by a tension between a desire to enforce online safety and a desire to allow open collaboration or other forms of interaction. For example, one teacher explained why her administration had banned video-conferencing with students, saying,

> [W]e were instructed not to do live instruction for the legality of it, so liability of it, but also [it's] very difficult to pin point, because we have run the gamut, as we just discussed, of, socioeconomics, to pinpoint a child to a specific time to sit down in front of a computer. It seems all well and good that, yeah, well, they go to school from eight to three, just pick a time between eight and three, but we know that that's not the normal schedule right now for families.

> So we have been, we've been told we can do phone calls. We can do video calls without the video, just the audio. We can record ourselves instructing and post that, but no live instruction.

Other teachers did incorporate some synchronous video-conferencing into their remote instruction. However, almost universally, educators at our partner schools had decided that video-conference collaboration had to be monitored by an adult (i.e., students couldn't be on a video-conference call without an adult present). In some cases, a teacher also could not be alone on a call with a student. The reason cited for both of these decisions was a fear of someone doing or saying something inappropriate. This same reasoning also extended to asynchronous forms of collaboration. For example, many of our partner educators used tools like Google Classroom that would have allowed for peer to peer text chatting or commenting on work, but they specifically disabled these features, in order to avoid inappropriate comments and/or to not have to monitor for the (in)appropriateness of comments.

For an environment like FUSE, which typically relies heavily on peer collaboration in pairs or small groups, this proved problematic. Typically, during in-person FUSE, we see students going to peers or the FUSE website for help first, then, only as a last resort, going to teachers. Our interviews with teachers and students this Spring show what happened when peers were removed as accessible help resources in FUSE. For example, one of the students we interviewed, Kayla, from a class that didn't use any synchronous videoconferencing during FUSE, emphasized how much she missed the collaborative aspect of FUSE, saying "[During in-school FUSE] you would figure things out and collaborate. And that's one thing I definitely miss about FUSE and STEAM in the classroom, because [at home] you're like…collaboration, you're lacking that, you're totally self-taught. And it's just FUSE is there to help and guide you, but it's just a lot different from like a normal classroom."

She elaborated on the ways in which she thought FUSE did support her in working remotely, saying, "I really don't think there's much you could do to make it any better for FUSE at home…it's an online teacher that helps us tremendously, especially while we're at home and we don't have, you know, that teacher that we could access by crossing the room." In these words, we see two broader trends in our data reflected. First, in the absence of opportunities to collaborate and seek out help from peers, students were more likely to seek out help from teachers, but second, because teachers were also less easily accessible, students were largely forced to solve problems independently, relying mostly on resources on the FUSE website. One of the teachers we talked to reflected on this dilemma. When we asked her what the primary barrier was to her students doing FUSE at home, she said, "For some of them it's lack of access to the materials…for others, it's lack of access to me…You know, when one of my eighth graders, you know, had said to his mother, he says, you know, if we were just in school, I could just ask [teacher's name] and she could show me how to do it, and it would be okay." Other teachers elaborated on this theme, explaining that often, during remote learning, when students did reach out with questions via email, text, or direct message, by the time the teacher got around to responding, the student had either figured it out themselves and moved on or they'd gotten frustrated and given up.

Meanwhile, while technically, students could have independently collaborated with peers on FUSE, by hopping on a phone call, video call, or text chat, on their own, using an outside device or platform, we did not hear of any instances of students doing this, unless they were explicitly encouraged or required to do so by teachers. For example, one exception to this was when a teacher assigned a group project, called a "together apart challenge", where one student was expected to start the challenge, then pass it to another person to do the next part, etc. The only other examples of collaboration that we heard about were collaborations between siblings in the same house. As a result, collaboration was the number one thing that students and teachers reported as missing while implementing FUSE remotely and reported that they wanted to find ways to improve.

Design adaptations

In order to respond to the barriers and competing sets of priorities experienced by our partner educators and students, the FUSE design and implementation team focused their energy during Spring and Summer 2020 in three specific areas: new challenge development, the development of new tools and resources on the FUSE website, and virtual professional development workshops on remote teaching and learning.

In order to address lack of access to kit-based challenge materials, preserve the choice aspect of FUSE, and keep students engaged, the first thing that our design team worked on this spring was designing additional challenges that could be done at home. For the team, this meant focusing development on two types of challenges: (1) "DIY kit challenges" – hands on challenges using everyday household objects; and (2) digital only challenges – challenges that could be done from home using only free, online applications that are accessible across platforms (iPad, Chromebook, Mac, PC). The first DIY kit challenge that our team developed in Spring 2020 was, *Look No Hands*, which asked students to use household objects to create a Rube Goldberg machine. The second challenge, developed in Summer, was *Video Magic Tricks*, a videography and special effects challenge that uses a free, online application that is compatible across platforms. In Fall 2020, our team began redesigning two of our existing challenges that previously required software downloads, so that they use free online applications instead.

To support students and teachers in implementing FUSE remotely, our team has also added a number of new features to the FUSE website. First, to help facilitators support students remotely, our team created several, additional student-facing help videos for the FUSE website, including: "How to FUSE", "How do I choose a challenge?", and "Try Something New!" Second, we introduced a virtual whiteboard called "Studio Notes" – a space where facilitators could post announcements or pin important information for their students, just like they would do on a real whiteboard, in their physical classrooms. Third, to address the need for more and better remote collaboration, our team developed a new tool called "Help Finder". This tool was based on representations that teachers had previously created for their in-person FUSE studios, such as the "Boss Board" or "Star Board" (Ramey & Stevens, 2020a) and was designed to facilitate, in the digital space, some of the collaborative practices typically observed in a FUSE studio. For example, in a typical, in-person FUSE studio, because students work on different challenges in different orders, relative experts in different tools and challenges emerge (Stevens et al., 2016). Students then seek help from these relative experts when they have questions on those challenges. Students also frequently choose challenges based what other students in the room are doing and choose to collaborate with others based on shared interest in a particular challenge. "Help Finder" is designed to facilitate these practices in the digital space, by allowing students to see which of their classmates have previously completed or are currently working on different challenges, and who is actively available online (perhaps at 3:00 AM) to answer questions or work together in real time. However, this tool still has to be used in conjunction with other online collaboration tools such as discussion boards or video-conferencing, which brings us to our last area of development.

In order to share insights from our team and our community of FUSE facilitators on how to use new and existing tools to best adapt FUSE to remote learning, we developed a series of professional development resources and workshops. In Spring 2020, we sent out two memos highlighting new tools and suggesting practices educators might engage in to support students doing FUSE remotely. During summer 2020, we ran professional development workshops for new and returning FUSE facilitators. For returning facilitators, this took the form of a one-hour webinar, focused on adapting FUSE to a remote context. This included reminding facilitators of the core design features of FUSE (choice, engagement, collaboration) and providing simple recommendations for how to use internal (Help Finder, new challenges) and external tools (video-conferencing, Google Slides, Google Classroom, Padlets) to facilitate these features of FUSE remotely. For new facilitators, this same content was incorporated into a larger, two-day professional development workshop, conducted via video-conference.

Discussion

The findings presented here show how educators have adapted the FUSE learning environment to remote teaching and learning and highlight specific barriers and competing priorities that they faced in doing so. Specifically, we found that most of our partner educators continued offering FUSE remotely but, in doing so, faced barriers related to students' access to technology and competing interests and responsibilities at home (i.e., changes in the network of humans and nonhumans involved in teaching and learning). These changes had implications for student engagement and experiences. For example, Jackson reported being less engaged in FUSE, because he didn't have access to kit-based challenges, couldn't collaborate, and found working on the computer at home distracting. Similarly, Kayla reported missing the collaborative aspect of in-person FUSE but said that the FUSE website provided significant support when working remotely.

In addressing these barriers, educators had to make sense of and navigate three sets of competing priorities, including: (1) foregrounding required subject-matter versus foregrounding engagement; (2) prioritizing choice versus prioritizing accountability; and (3) promoting online safety versus promoting unrestricted, open collaboration. In some cases, teacher-facilitators themselves felt a commitment to both competing priorities. In other cases, these sets of competing priorities were being negotiated across organizational levels (e.g., between teachers and administrators). In both cases, how educators navigated these sets of competing priorities determined how they adapted FUSE (and other instruction) to remote learning. These adaptations, in turn, shaped how students experienced FUSE. For example, while students reported that the resources on the FUSE website were helpful in supporting their remote work, limits on free collaboration in the virtual space and lack of synchronous access to teachers and peers meant that students missed teacher and peer support.

Our findings also speak to the larger question of how/whether educators adopt and adapt educational innovations, particularly in times of crisis, and how educational designers might support them. For example, consistent with findings from prior research (e.g., Antonioli & Montresor, 2018; Ben Zur & Breznitz, 1981; Holl & Rama, 2016) we found that educators largely lacked the time, energy, and interest to engage in substantial redesigns of existing curricula or pedagogy, and in some cases, chose to shelve innovative, enrichment programming like FUSE entirely, in favor of core subjects. However, preliminary data collection during Fall 2020 has shown a potential shift in this pattern, with educators incorporating more innovations and innovative curricula into remote teaching and learning. It has also shown the impact of our team's design interventions, as we have seen significant uptake of the new challenges, tools, and instructional strategies created or suggested by our team and related increases in student engagement and collaboration.

As we continue collecting interview and survey data over the 2020-21 school year, the approach and findings provided here suggest questions for further investigation regarding the role of different human actors (e.g., teachers, administrators, students) and nonhuman actors (technology, building materials, ideas) in shaping how a program like FUSE (or teaching and learning broadly) is adapted to a remote context. For example, 'Which things are dependent on technology?', 'Which decisions are getting made at or negotiated between which organizational levels?' and 'How much agency do students or teachers have in decision-making around teaching and learning remotely (relative to in schools)?'

References

Antonioli, D. & Montresor, S. (2018). Persistence of innovation in times of crisis: An analysis of Italian firms.

Ben Zur, H. & Breznitz, S. J. (1981). The effect of time pressure on risky choice behavior. *Acta Psychologica, 47*, 89-104.

Coburn, C. E. (2001). Collective sensemaking about reading: How teachers mediate policy in their professional communities. *Educational Evaluation and Policy Analysis, 23*(2), 145-170.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher, 32*(1), 5-8, 35-37.

Fenwick, T. (2011). Reading educational reform with Actor Network Theory: Fluid spaces, otherings, and ambivalences. *Educational Philosophy and Theory*, 43(S1).

Hobbs, T. D. and Hawkins, L. (2020). The results are in for remote learning: It didn't work. *The Wall Street Journal*. Available online at https://www.wsj.com/articles/schools-coronavirus-remote-learning-lockdown-tech-11591375078

Holl, A. & Rama, R. (2016). Persistence of innovative activities in times of crisis: The case of the Basque Country. *European Planning Studies, 24*(10), 1863-1883.

Ito, M., Baumer, S., Bittanti, M., Boyd, D., Cody, R., Herr-Stephenson, B., . . . Yardi, S. (2010). *Hanging out, messing around, and geeking out: Kids living and learning with new media.* Cambridge: MIT Press.

Jacobson, L. (2020). Students on remote learning: More creativity, interaction needed. *Education dive.* Available online at: https://www.educationdive.com/news/students-have-to-be-creative-with-the-way-they-learn/576370/

Latour, B. (2005). *Reassembling the social: An introduction to Actor-Network-Theory.* London: Oxford University Press.

Penuel, W. R., Fishman, B. J., Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher, 40*(7), 331-337.

Ramey, K. E. & Stevens, R. (2019). Interest development and learning in choice-based, in school, making activities: The case of a 3D printer. *Learning, Culture, and Social Interaction, 23.*

Ramey, K. E. & Stevens, R. (2020a). Best Practices for Facilitation in a Choice-based, Peer Learning Environment: Lessons from the Field. Proceedings of the 14th International Conference of the Learning Sciences, Nashville, TN.

Spillane, J. P. (2006). *Distributed leadership*. San Francisco, CA: Jossey-Bass.

Stevens, R., Jona, K., Penney, L., Champion, D., Ramey, K. E., Hilppö, J., Echevarria, R., & Penuel, W. (2016). FUSE: An alternative infrastructure for empowering learners in schools. Proceedings of the 12th International Conference of the Learning Sciences, Singapore, SG, Volume 2, 1025-1032.

Stevens, R. & Ramey, K. E. (2020). What kind of place is school to learn? A comparative perspective from students on the question. Proceedings of the 14th International Conference of the Learning Sciences, Nashville, TN.

Stevens, R., Ramey, K., Hilppö, J., Kumpulainen, K., Kajamaa, A., Rajala, A., Meyerhoff, P., & Halverson, R. (2018). Exploring the adoption, spread, and sustainability of an informal STEAM learning innovation in schools. Proceedings of the 13th International Conference of the Learning Sciences, London, UK.

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Students' Conceptualizations of the Role of Evidence in Modeling

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Abstract: Modeling is a central scientific practice and is important for students to engage in and understand. Middle school students are able to identify scientifically appropriate criteria for evaluating model goodness, but struggle to prioritize a key criterion: fit with evidence. Although many studies have explored students' use of evidence, less is known about how students conceptualize the role of evidence in modeling, or reason about the importance of fit with evidence compared to other criteria. In this study we explored students' conceptualizations of the relationship between evidence and models by analyzing students' reasoning about criteria for good models. The results suggest that students conceptualize evidence in three ways: as a communication tool, as a way to determine accuracy, and as a way to determine accuracy mediated through inference. These findings can guide educators to facilitate classroom discussions that develop students' understanding about the epistemic nature of evidence.

Introduction

Modeling is a central scientific practice, and scientists across disciplines use models as a tool both for developing their understanding and for representing or explaining complex systems and phenomena in the world (e.g., Giere, 1988, 1999; Godfrey-Smith, 2006; Gouvea & Passmore, 2017; Schwarz et al., 2009). Scientists use epistemic criteria to guide them when constructing, evaluating, and revising scientific models (Hogan & Maglienti, 2001; Passmore & Svoboda, 2012). These epistemic criteria include that models are good when they *are explanatory*, *have an appropriate level of detail*, or *show a mechanism* (e.g., Pluta et al., 2011). Several educational guidelines and standards support giving students opportunities to engage with and reflect on scientific practices and their underlying epistemic commitments, such as criteria for evaluating epistemic products such as models (NGSS, 2013; NRC, 2012). In particular, these guidelines advocate for supporting students to develop their understanding of evidence, including the criterion that good models need to *fit with evidence*, in scientific knowledge building. For example, students need opportunities to reason about how data can be interpreted to draw conclusions, and how conclusions from larger a body of evidence can be used to determine the validity of models (Duncan et al., 2018). A number of researchers have echoed this support, noting the importance of helping students develop facility using evidence, and understanding importance of fit with evidence as a criterion for evaluating scientific knowledge and products (Duncan et al., 2018; McNeill & Berland, 2017).

In prior work we found that middle school students were able to identify a variety of scientifically appropriate criteria for good models even prior to an intervention (Av-Shalom et al., 2018; Pluta et al., 2011). However, students struggled to prioritize fit with evidence (Pluta et al., 2011). After an inquiry intervention over several months, students in Av-Shalom et al.'s (2018) study showed improvement both in using evidence and invoking fit with evidence as a criterion when evaluating competing models. However, many students still had difficulties using evidence productively. Although it is encouraging to see that students are able to develop facility using and discussing evidence, to further develop students' skills more research is needed to understand how students make sense of the role of evidence in knowledge building.

A number of studies have investigated how students develop scientific models and claims with evidence (e.g., Driver et al., 1996; Kelly & Takao, 2002; Passmore & Svoboda, 2012; Novak & Treagust, 2018). Other studies have explored how students reason about certain types of evidence (Lehrer & Schauble, 2017) or about evidence in certain contexts or used by different people, such as in science class or by scientists (McNeill, 2011). However, more research is needed to understand how students conceptualize the role of evidence in the development of scientific knowledge and the practice of using evidence to develop models. Further, little research has investigated whether students prioritize fit with evidence over other epistemic criteria for good models, or how students reason about the importance of fit with evidence. Scientists use evidence to guide them as they answer scientific questions and build scientific models (e.g., NGSS, 2013). To be able to participate in and understand knowledge building processes in science, students need to develop a sophisticated understanding of the role of evidence in model development and evaluation.

In this paper we explore whether younger students (fourth and fifth grade) are able to identify scientifically appropriate criteria for good models prior to an intervention, and how their individual lists compare to their shared consensus list. We then discuss an analysis of interviews of the same students after they participated in a short intervention, conducted as an after-school science club. In this analysis we explored how students reason about the criterion of fit with evidence and about the role of evidence in modeling. Thus, in this study we wanted to understand:

1. Which epistemic criteria do students in late elementary school (4-5th grade) generate prior to an intervention? Further, do students identify fit with evidence as a criterion and, if so, how do they prioritize it?
2. How do students conceptualize the role of evidence in scientific modeling after an intervention?
3. How do students reason about the relative importance of the criterion of fit with evidence compared with other criteria?

Theoretical framework

A central epistemic criterion in science is fit with evidence. That is, scientists use fit with evidence to guide their knowledge production and to determine the veracity of scientific knowledge products, such as models. Given its importance in science, several studies have investigated how students use or reason about scientific evidence when engaging with a scientific problem (e.g., Lehrer & Schauble, 2017; Manz, 2016) and whether they can differentiate evidence from hypotheses or claims (e.g., Ruffman et al., 1993; Sodian et al., 1991). In McNeill's (2011) study she found that fifth grade students were often able to identify that evidence is used by scientists to figure out what is true or find the answer to a question. However, in other contexts, such as when used in science class or in everyday life, students often conceptualized evidence as being for communicative purposes, such as convincing somebody or winning a debate, rather than for the purpose of answering a question or figuring something out.

Several studies have found that students of varying ages have difficulty connecting evidence with explanations (Driver et al., 1996; Sandoval & Millwood, 2006) and adjusting claims given new evidence (Novak & Treagust, 2018). Novak and Treagust (2018) suggested that some students do not change their claims in light of new evidence because they ignore the evidence, or because they do not conceptualize evidence as guiding the development of scientific knowledge. Other students do not synthesize discrete ideas from multiple pieces of evidence into a single claim, suggesting that they may not yet be proficient in looking across a body of evidence or understand the importance of doing so (Novak & Treagust, 2018). Although these are plausible reasons, further research is needed to understand precisely why students struggle to connect models with evidence and claims.

Further, despite agreement between researchers and standards documents about the importance of evidence, the concept of evidence remains underspecified in science education practice and research (Duncan et al., 2018; McNeill & Berland, 2017): In the research community and in standards documents, evidence is used at different times to mean empirical data, theories, personal experiences, data from simulations, science reports in news or other media, and others. Further, in traditional science classrooms students are often presented only with very simple evidence and do not have opportunities to engage with the complex nature of evidence, nor to discuss the epistemology of evidence and its role in scientific knowledge building. For example, traditional science classrooms often present evidence as strictly factual, rather than guiding students to understand that evidence is collected, constructed, and interpreted by people (McNeill & Berland, 2017), and that there may be multiple legitimate interpretations. Thus, in order to leverage and develop students' skills, it is necessary to identify students' epistemologies about evidence and evidence-theory relationships. This can also guide researchers and educators in clarifying the construct of evidence as it pertains to science education practice. Researchers and educators will then be able to improve methods to support students in forming a more robust understanding to ground their engagement with evidence.

To address these challenges, in this study we explored students' conceptualizations of evidence. First, we expanded on our prior research on students' metacognitive understanding of epistemic criteria (Av-Shalom et al., 2018; Pluta et al., 2011); our previous research focused on middle school students (seventh grade, ages 12-13), but in the current study our participants were younger students, in elementary school (fourth and fifth grades, ages 9-11). We explored whether students at this age were already able to identify fit with evidence as an important criterion for good models. Following this, we focused on two interrelated components of the criterion of fit with evidence: how students conceptualized the relationship between evidence and models, and how students prioritized fit with evidence in relation to other criteria that they identified for evaluating scientific models.

Method

Research context and participants

The participants in the study were students in upper elementary school (grades 4-5; ages approximately 9-11), who were participating in an after-school science club (n=20) at a charter school in northeastern United States. Based on the state report card, 21.3% of students in the school were Asian, 8.6% Black or African American, 7.2% Hispanic, 60.1% White, and 2.9% were of two or more races. Also, 12.9% of students had disabilities and 4.7% were considered economically disadvantaged. The school performance was above average, ranked in the top 2% of public schools in the state. The science club ran once a week for six weeks, for 1.5 hours each session.

During session 1 of the club, students engaged in a task to introduce scientific models. In this study we chose to focus on explanatory models which provide a causal account of the mechanism underlying a phenomenon, in line with others in the field (e.g., Windschitl et al., 2008). During the task, students saw six sets of two to three models, each about the same topic, and were asked which model was better. These sets were designed to highlight different epistemic criteria. One of the five sets that the students saw is shown in Figure 1. Students were asked, "Which model best explains how plants get their food and energy to grow?" The model on the left includes a clear mechanism. In contrast, the model on the right has pictures, which may be attractive to students, but explains less about the mechanism, and includes extraneous and confusing elements (e.g., the person letting out air). This set highlights the criterion of *showing a mechanism* and calls into question the importance of *having pictures or visuals*. Students looked at these models in pairs, and later discussed them with the whole group. Students were not told a "correct" answer, nor were they told which criteria to attend to. After looking at the model, students developed individual lists of criteria for what makes a good model, and later had a whole-group discussion to develop a "club list" of criteria.

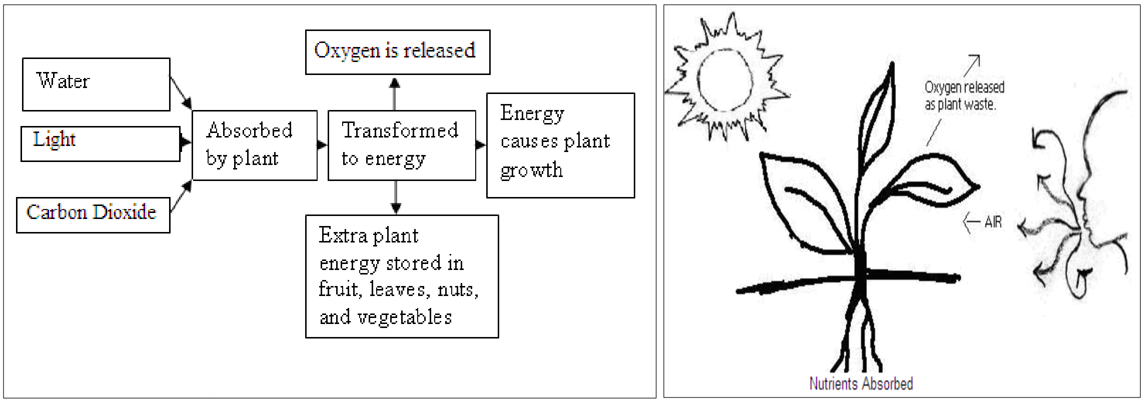

Figure 1. Set of models that students were shown.

In sessions 2-5 of the club, students were presented with a "mystery" to solve, in the form of a story. In this story a child added several fish to a fish tank, but after some time the fish died. In order to figure out what happened, students explored a variety of resources, including NetLogo agent-based computer simulations (Wilensky, 1999) and empirical research, primarily in the form of text-based reports (Rinehart et al., 2016). These resources were developed by the research team and designed to teach students about the broader biological context of carrying capacity. The range of resources was designed to align with the diversity of resources used by scientists when developing their understanding of phenomena. Students used these resources to construct, evaluate, and revise scientific models in small groups (3-4 students) and as a whole club.

In session 5, students revised their club criteria for good models and discussed the differences between the two types of resources that they engaged with. In sessions 5 and 6, small groups (2-3 students) were interviewed for 15-20 minute. We chose to interview students in small groups rather than individually so that they would feel more comfortable to share their thinking, and so that they could have discussions together and build and elaborate on each other's ideas. The interviews were open ended, guided by prompts, about topics pertaining to club activities including the relationship between fit with evidence and other criteria discussed in the club in determining model quality.

Data analysis

The data sources included videos of all the club sessions, screen captures of sessions in which students were using computers, and student artifacts. In this study, we focused on students' written work, club criteria list, and videos of their interviews. To identify the epistemic criteria that students generated prior to an intervention we analyzed students' personal criteria lists, developed on the first day. On this day, 17 students attended, and we collected all of their lists and categorized the criteria that they included. The categories were adapted from coding schemes used by Av-Shalom et al. (2018) and Pluta et al. (2011) to categorize students' model-quality criteria. The findings were supported by comparing with the club criteria list that students agreed upon following a discussion.

We also did an exploratory analysis of students' interviews to investigate students' conceptualizations of the relationship of evidence to models, particularly contrasting with two other criteria: accuracy and understandability. We focused on interviews in which students were asked at least one of the following five questions: 1) Is it possible for a good model to have accurate information but not fit the evidence?, 2) Is it possible for a good model to fit the evidence but not have accurate information? (asked as a follow-up to question 1), 3) How do you determine accuracy? 4) What's more important: being understandable or fitting the evidence?, or 5) Students were given a scenario in which a town experienced a problem, and two people developed models to explain it, one model being clear and easy to understand, but not fitting the evidence, and the other fitting the evidence but being more complex and harder to understand. They were then asked which of the two models would be better (asked as a follow-up to question 4).

In their criteria lists and group discussions, students used a number of terms which seemed somewhat conflated with evidence, such as "accuracy," "true facts," and "accurate information." In designing our research questions, we intentionally used similar language with the assumption that there was some shared understanding and norms of usage of these terms between students. We also wanted to see whether and how students would elaborate on and compare the terms when answering the questions.

Students in five interview groups were asked at least one of the prior questions. One group was not included in the present analysis because their interview was cut off prior to the students being able to say enough to establish a clear conceptualization from any of the students. The four remaining groups consisted of nine students (three pairs and one trio). All students were interviewed during the last session (week 6) of the club.

Results and discussion

Criteria lists

At the beginning of the science club, students individually developed lists of criteria for good models. Table 1 shows the criteria listed by three or more students. The frequencies show that many students were able to identify scientifically appropriate criteria, such as good models being explanatory and fitting with evidence. The students were allowed to talk with their peers while developing their criteria lists, and criteria lists of students sharing a table tended to have high overlap. Thus, the frequencies likely do not fully reflect what would be seen if students had developed the lists individually, which may explain why the frequencies of certain criteria such as *evidence* are present more frequently than we have found in previous work, when students did not collaborate (e.g., Pluta et al., 2011).

Table 1: Criteria raised by three or more students on their individual criteria lists.

Criterion	Number of students
Labels	14
Facts (including real facts, true facts, accurate facts, and true information)	12
Details	10
Explanations / Explains	9
Evidence (includes one instance of "proof")	9
Picture/Diagram	8

Criterion	Number of students
Sequence	8
Reasons	6
Clarity	5
On topic	4
Convincing	3
Understandable	3

After developing their individual lists, students had a whole-group discussion in which they agreed on a shared list for the club. Their list included six ranked criteria (1 being most important, 2 second-most, etc.) and six unranked, supplementary criteria (Table 2). It is notable that despite being on more than half of the students' personal criteria lists evidence was only added as a supplementary criterion in their shared club list, not as one of the six "most important" criteria. Also, on their shared list students prioritized "true facts" over "evidence." These findings suggest that although students may be familiar with the need for evidence, they may not yet understand that "facts" or claims need to be supported by evidence. That is, that fit with evidence is the primary way to determine "truth" or accuracy.

Table 2: Students' shared criteria list

Ranking	Ranked Criteria
1	Based on true facts
2	On topic (stay focused on the thing we want to explain)
3	Includes an explanation (explains)

Supplementary Criteria
Is clear and organized
Is coherent (makes sense)
Includes examples

4	Description & details	Evidence that supports the model
5	Has labels	Convinces the person that is reviewing it (is convincing)
6	Shows sequence/steps	Includes pictures

Conceptualizations of evidence

The students' individual and club criteria lists suggested that they may not fully understand fit with evidence as a key criterion to determine the validity of models. To shed light on how students conceptualized the role of evidence in modeling, we analyzed students' interviews. In this process, three conceptualizations of evidence emerged, evidence as (1) a communication tool, (2) a factual determiner of accuracy, and (3) a determiner of accuracy *as mediated by inferences*. Each will be discussed in turn.

Evidence as a communication tool

In their interviews, several students' responses suggested that they considered evidence to be a tool for supporting their ideas after the ideas had been established, usually for persuading or clarifying for others. In this view, a model is developed by identifying accurate claims and then, if necessary, choosing supporting evidence. As Kyle (all student names are pseudonyms) said, "if you don't have accurate facts there's no need for evidence at all. And if you have accurate facts but no evidence that's still a little enough to persuade the person." Later in the interview he added, "evidence is something that supports your facts." In this case, Kyle seems to be using "facts" to refer to his claims. According to his conceptualization, a person first needs to identify accurate or true claims before deciding whether supporting evidence is necessary or available.

When discussing what people should do if they found evidence that contradicted their model, Arun said, "You can change your claim or change the evidence." In general, students with this conceptualization of evidence said that depending on the situation a person could choose to change your model or to change or discard the contradictory evidence. Their choice could be based on which was easier to do, or else based on your own ideas or on your review of the model (without using evidence). When discussing whether to keep or discard contradictory evidence, Tegan elaborated on how a person would know which pieces of evidence were important, saying, "Because if you have true and accurate facts that are clear you could find the correct evidence. First, you could find evidence that supports your theory or hypothesis. Then you learn the true and accurate facts. Then you see which evidence supports which, and if you don't need any evidence, you don't need it."

Students who conceptualized evidence as a communication tool all seemed to understand that evidence is important in scientific practice; for example, that evidence is useful to "prove" an idea. Further, these students preferred models which were complex and difficult to understand but fit the evidence versus models which were simpler but did not fit the evidence. However, they shared a misconception about the connection between evidence and models. Canonically, evidence is a key arbiter of scientific models and claims. Scientists construct, evaluate, and revise models and claims based on evidence, and it is the model, not the evidence, which must be changed in response to incongruencies with the evidence. Students with this conceptualization of evidence expressed that it was more or equally appropriate to fit the evidence to the model than to fit the model to the evidence.

Initially, some students with this conceptualization of evidence appeared to develop a more canonical view of evidence with only slight guidance. In the excerpt in Table 3, the interviewer probed Arun about his idea that he would have made an accurate model prior to choosing evidence, and he changed his mind, saying that evidence was in fact necessary. Several times after this, Arun's statements such as, "if the evidence is wrong then the whole model will be wrong," suggested that he now understood that evidence was the arbiter of accuracy. However, later in the interview he was asked whether a model needed to fit with all of the evidence or just some. He argued for all, saying "… it [the model] needs to support all the evidence 'cause your evidence needs to prove the whole claim. You can change your claim or change the evidence." This excerpt shows that he still did not have a clear understanding that evidence supports models, instead saying that the model needed to support the evidence. Furthermore, he returned to his original position that when faced with contradicting evidence a person can choose whether to change the claim or the evidence. Like other students who conceptualized evidence as a communication tool, Arun's understanding seemed to be that when developing models a person must determine accurate claims or "true facts" first, and that identifying supporting evidence can be identified afterwards.

Table 3: A student changes his mind.

Interviewer	What I'm hearing you [Arun] say is that it's important for it to be accurate but you're already assuming that it [the model] fits the evidence and the evidence is correct.
Arun	Yeah, evidence should be correct. No, you like, first it has to be accurate before you choose your evidence.
Interviewer	But what do you mean *choose* your evidence?
Arun	Before you have the evidence, you need your claim or whatever you're saying to be correct.

Interviewer	So how are you going to know if it's correct if you haven't looked at evidence?
Arun	Oh yeah, you need evidence, yeah… so yeah you need evidence. Yeah, I changed what I was saying.
Interviewer	So you're saying evidence is more important?
Arun	Evidence is more important.
James	Yeah because the evidence um, like, wouldn't always be right, so you need to get the right evidence for the information to be accurate.
Arun	I agree with James.

Evidence as a determiner of accuracy

Students who had this conceptualization stated that evidence helps a person know or prove what is true or whether a model or claim is accurate. During Michael and Adam's interview, Michael noted that it was impossible for a good model to fit the evidence but not have accurate information, saying, "If you have evidence and not true information then there's no point in the evidence because it's not true anyway." The students were then asked whether it was possible for a good model to have accurate information but not fit the evidence (Table 4).

Table 4: Student discussion about the connection between fit with evidence and accuracy

Interviewer	So is it possible for a good model to have *accurate* information but not fit the evidence.
Adam	*No*
Michael	Well, it can be okay, but it can't be very good.
Adam	Well, let's say the model has no evidence, but it's true. It's still *true*, except-- I agree with Michael, it's at least better than the non-true evidence.
Michael	Yeah
Interviewer	Now, how would you know if it's true?
Michael	Because um… you wouldn't. You wouldn't know unless there's any references or anything like that…

In this excerpt, the students concluded that although models can be true even without supporting evidence, it will be impossible to tell without additional information. Note that Adam's response in this excerpt, "let's say the model has no evidence," suggests that he interpreted "not fit with evidence" to mean *not be supported by evidence* rather than *be contradicted by evidence*; that is, these students likely understood that a model would not be "true" if there was contradictory evidence. This is supported by their other statements. For example, the two later agreed that the purpose of having evidence is, as Michael said, "to make sure if it's [the model is] true."

Overall, students with this conceptualization argued that evidence is necessary to determine accuracy. Some students further elaborated by saying that an absence of evidence means that it is impossible to determine accuracy. Students were also able to articulate that contradictory evidence is usually an indication of inaccuracy and said that when confronted with contradictory evidence people need to change their claims or models.

Students with this conceptualization also reasoned about the relevance of evidence to models when presenting the model to others. Michael and Adam also stated that in some cases it may not be necessary for models to fit all available evidence (Table 5). He then added that a person needs to tailor the amount of evidence presented to the background knowledge and interest of the audience.

Students with this conceptualization reasoned about the relevance of evidence to models when presenting the model to others. Michael and Adam also stated that in some cases it may not be necessary for models to fit all available evidence (Table 5). When they were then asked about a person should do in response to contradictory evidence, Adam responded, "Well, you can *fix* it." He and Michael then added that even though supporting evidence is important, a person needs to tailor the amount of evidence presented to the background knowledge and interest of the audience. They then discussed that if there is too much information "sometimes your brain just can't hold it," and adding that in those situations "you probably know it, and there's no point reading" and that "then you're missing all the information." In conclusion, Adam noted that when presenting a model, you should only include "the evidence that is most important and most needing to know [sic]."

Table 5: Students discussing whether a model needs to fit all of the evidence or only some of it.

Michael	It's better to make all of it, but you don't have to, 'cause you might know some of the stuff, but I mean the author sometimes doesn't put *all* the evidence because sometimes you just know, it's obvious to everyone.
Adam	We don't *need* all the evidence, but it would be more helpful if someone just got on this topic to have all the evidence out for them, and to know that this test actually…
Michael	Yeah, so you know for sure that everything you're reading is true and you're learning something.

Evidence as the determiner of accuracy as mediated by inferences

Students with this conceptualization of evidence are consistent with the prior group in that they understand that using evidence is necessary to determine accuracy, and prioritize fit with evidence over other criteria. Ajay argued that fitting with evidence was more important than being understandable "because then if you put the evidence but it's not a good claim then it doesn't even matter because you don't have the right stuff." Cooper also said that she would "rather read something that's very complex and that doesn't make sense to me the first time and read it a few times over than read something that's perfectly understandable to me but has no right information."

However, students with this conceptualization also expressed that people needed to use evidence appropriately and skillfully in order to reach accurate conclusions. In one interview, Emily gave an example explaining how it is possible for a good model to fit the evidence but not have accurate information, "So, for example, you have evidence that Raj's fish was in a clean tank, alright? But your information is that Raj's clean tank stayed clean, because it started in a clean tank. So, you have the evidence that Raj's fish started out in a clean tank, but your conclusion from it is not accurate." Raj was the main character of the mystery that students were trying to resolve, and Emily's example highlighted that students could draw incorrect inferences from the evidence that was available. In this view, their model might fit with the evidence, but still be inaccurate. Cooper later added that "you can have a reason and have it explain the evidence but also have that reasoning be wrong."

In another interview, Ajay argued that a model could have accurate information but not fit real evidence, "Yes, because it can prove a different topic, maybe not that topic but it can be a different topic." He added that in some cases a model could fit the evidence but not have accurate information if it included a "fake claim."

Conclusion and contribution

This research shows that, prior to an intervention, students as young as fourth and fifth grade can generate productive criteria for good models. Moreover, both their individual lists and their shared consensus list included a variety of scientifically appropriate criteria, such as good models needing explanations and a sequence. However, the findings suggested that some students may not yet have understood that evidence determines accuracy, which may explain why students across studies have struggled to prioritize using fit with evidence to evaluate and revise knowledge products, such as scientific models.

In the analysis of student interviews after the intervention, we found that students had three different conceptualizations of evidence. Two of them, evidence as a communication tool and evidence as the determiner of accuracy, align with McNeill's (2011) findings that in some contexts students said that the purpose of evidence was to convince or in other ways communicate ideas to others, whereas in other contexts they said that evidence was the way to determine truth. However, in our study we found that some students were also beginning to develop a more epistemically sophisticated conceptualization of evidence, that its meaning is inferred by people. However, these students still did not demonstrate an understanding that there can be multiple legitimate interpretations.

Importantly, the findings also indicate that students as young as 9 to 11 years old can articulate their conceptualizations about the role of evidence in evaluating and revising models, and some may already understand that fit with evidence is used to determine accuracy. However, students' responses in this context suggested that they may need scaffolding to reach more sophisticated understandings of evidence as constructed and open to multiple interpretations. This study was conducted in a high performing school (see section on participants), so the results may not reflect how all children at this age range perform on these tasks. Even so, the results further our understanding of the different ways in which students may interpret the role of evidence in science.

The findings also suggest that short prompts to reflect on evidence may help students who view the role of evidence to be for communication purposes move towards a more sophisticated understanding of evidence as way to determine truth, but that more scaffolding may be necessary to sustain that understanding. Further research is needed to identify the best strategies for promoting epistemic growth in this area.

Students in this study included several criteria on their criteria lists and in their whole-group discussions which may seem conflated with evidence, such as "facts," "true facts," and "accurate information." We intentionally used similar terms in the interviews with the hope that students would elaborate on and compare the terms when answering the questions. Thus, they could express their ideas in ways that helped us understand how they understood them to be related. Students' usage did bring up some important insights, such as that students seemed to conceptualize evidence as disconnected from "true and accurate facts." Such conceptualizations may in turn affect students' ability to value evidence and evaluate models based on evidentiary fit.

Understanding students' conceptualizations may guide researchers in clarifying the construct of evidence as it pertains to student understanding in the classroom. Educators may also be able to leverage the range conceptualizations of evidence seen in their classrooms in order to promote dialogue between students about the epistemic nature of evidence that will help students develop and refine their understanding.

References

Av-Shalom, N. Y., El-Moslimany, H., Duncan, R. G., & Chinn, C. A. (2018). Changes in Students' Use of Epistemic Criteria in Model Evaluation. In J. Kay & R. Luckin (Eds.), Rethinking Learning in the Digital Age: Making the Learning Sciences Count: The International Conference of the Learning Sciences (ICLS) 2018 (Part 2, pp. 768-775). London, England: International Society of the Learning Sciences.

Driver, R., Leach, J., & Millar, R. (1996). *Young people's images of science*. McGraw-Hill Education (UK).

Duncan, R. G., Chinn, C. A., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching*, *55*(7), 907-937.

Giere, R. N. (1988). Explaining science: A cognitive approach. University of Chicago Press.

Giere, R. N. (1999). Using models to represent reality. In *Model-based reasoning in scientific discovery* (pp. 41-57). Springer, Boston, MA.

Godfrey-Smith, P. (2006). The strategy of model-based science. *Biology and philosophy*, *21(5)*, 725-740.

Gouvea, J., & Passmore, C. (2017). 'Models of' versus 'Models for'. *Science & Education*, *26*(1-2), 49-63.

Hogan, K., & Maglienti, M. (2001). Comparing the epistemological underpinnings of students' and scientists' reasoning about conclusions. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *38*(6), 663-687.

Kelly, G. J., & Takao, A. (2002). Epistemic levels in argument: An analysis of university oceanography students' use of evidence in writing. *Science education*, *86*(3), 314-342.

Lehrer, R., & Schauble, L. (2017). Children's conceptions of sampling in local ecosystems investigations. *Science Education*, *101*(6), 968-984.

Manz, E. (2016). Examining evidence construction as the transformation of the material world into community knowledge. *Journal of Research in Science Teaching*, *53*(7), 1113-1140.

McNeill, K. L. (2011). Elementary students' views of explanation, argumentation, and evidence, and their abilities to construct arguments over the school year. *Journal of Research in Science Teaching*, *48*(7), 793-823.

McNeill, K. L., & Berland, L. (2017). What is (or should be) scientific evidence use in k-12 classrooms?. *Journal of Research in Science Teaching*, *54*(5), 672-689.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

Novak, A. M., & Treagust, D. F. (2018). Adjusting claims as new evidence emerges: Do students incorporate new evidence into their scientific explanations?. *Journal of Research in Science Teaching*, *55*(4), 526-549.

Passmore, C. M., & Svoboda, J. (2012). Exploring opportunities for argumentation in modelling classrooms. *International Journal of Science Education*, *34*(10), 1535-1554.

Pluta, W. J., Chinn, C. A., & Duncan, R. G. (2011). Learners' epistemic criteria for good scientific models. *Journal of Research in Science Teaching*, *48*(5), 486-511.

Rinehart, R., Duncan, R., Chinn, C., Atkins, T., & DiBenedetti, J. (2016). Critical design decisions for successful model-based inquiry in science classrooms. *International Journal of Designs for Learning*, *7*(2).

Ruffman, T., Perner, J., Olson, D. R., & Doherty, M. (1993). Reflecting on scientific thinking: Children's understanding of the hypothesis-evidence relation. *Child Development*, *64*(6), 1617-1636.

Sandoval, W. A., & Millwood, K. A. (2005). The quality of students' use of evidence in written scientific explanations. *Cognition and instruction*, *23*(1), 23-55.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., ... & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *46*(6), 632-654.

Sodian, B., Zaitchik, D., & Carey, S. (1991). Young children's differentiation of hypothetical beliefs from evidence. *Child development*, *62*(4), 753-766.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science education*, *92*(5), 941-967.

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Mathematical Physical Research: Mathematical agency in the practices of professional dancers

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Abstract: Research in embodied mathematics has shown that the body is fundamental to understanding mathematics, yet how to support learners in seeing and leveraging these connections remains an open question. This paper explores how bodies, a vital resource for intuitive sensemaking, can be leveraged to support agentic forms of mathematics learning that foregrounds the interpersonal relationships learners cultivate. To do this I studied professional dancers who used their embodied practices to explore and choreograph mathematical ideas. I traced these dancers' practice, *physical research,* from the dance studio to their participation in a double stimulation experiment in which they were asked to reenact mathematically salient choreography from a large-scale ensemble performance. This paper takes up recent methodological calls in the learning sciences to use the relational histories of learners in their embodied practices of disciplinary learning.

Although mathematics is commonly understood as a disembodied, Platonic discipline, scholars in mathematics education have argued for the importance of recovering the body for mathematics learning (Hall & Nemirovsky, 2012; Stevens, 2012). Lakoff and Núñez (2000) traced the discipline of mathematics backwards to embodied semantic primitives. By linking the form of the human body to the mathematics that we have today, Lakoff & Núñez argued that embodied resources for sensemaking were fundamental to the historical development of mathematics, even if not to contemporary mathematics teaching or learning. An entrenched history in math education has positioned the body as a container, with the sole purpose of transporting a thinking brain, which means that inviting learners to ground their mathematical sensemaking in their bodies is not always an invitation that is accepted, taken up, or trusted. While the body is an omnipresent resource for learners in all contexts, it is commonly dismissed or erased in formal learning environments, as learners routinely do not see their everyday embodied activities as mathematically relevant (Moschkovich, 2002; Nasir et al., 2008). Thus, it is insufficient to invite learners to use their bodies for mathematical sensemaking without better understanding culturally and historically laden practices that foreground the body as the primary site for sensemaking. As more research explores the multimodal and embodied ways learners can make sense of disciplinary ideas (Hall & Nemirovsky, 2012; Ma, 2017; Marin et al, 2020), a question remains: how can we design math learning activities in which learners have reason to trust their bodies as resources? In this paper I propose that looking to the practice of professional dancers may provide answers, as their sensemaking centers on embodied forms of collective noticing as ever present and crucial to exploring how they can express and make sense of mathematical entities.

Motivation

A group of four 8th grade girls were participating in an exploratory mathematics activity: I asked them to reenact a moment from the opening ceremony of the 2016 Rio Olympics in which performers folded large flexible silver squares into triangles. The girls folded their own similar square prop into a triangle, but disagreed about what kind of a triangle they had folded. They placed their large triangle on the ground and engaged in an enthusiastic debate as to whether it was a right triangle (with a 90 degree angle) or an isosceles triangle (in which two edges have equal length). Ava started the debate standing fixed at one edge of their triangle, "IN MATH [...] you're not going to turn the math book and say it's a right triangle, you're gonna say that's an isosceles." Octavia supported Ava's argument for team isosceles, "when they give it to you they don't put the 90 up there ((pointed to the angle on the floor Tracy argued was 90 degrees)) [...] They don't put the 90 up there. THEY DO NOT DO THAT in books."

Here, Ava and Octavia (all names used in this paper are pseudonyms) used school-based mathematical epistemologies cultivated from paper-scale geometry to reason about their large, walking-scale triangle, deferring to a fixed understanding of what "they" do "in math." This was perfectly reasonable. The implicit norms in mathematics textbooks correlate orientation with geometric properties by deferring authority to the invisible authors of these books, allowing for quick recognition. These sensemaking resources employed "in math," however, limited the girls' engagement with the mathematical properties being discussed, as they accepted a static, decontextualized understanding of mathematical rules, even for a mathematical object they had made by moving together at walking scale (Vogelstein, Brady, & Hall, 2019). The moment these girls labeled their activity as "math," they turned away from their embodied sensemaking resources both within themselves and each other.

The ubiquity of our bodies, as inseparable from our existence, makes them a fundamental resource for how we make sense of the world around us. Thus, if we want to ground mathematics learning with these powerful resources, we must leverage the body as a powerful source of reasoning which is not a trivial task. In this paper I examine a contrasting case to the one described above to show how professional dancers' in the company, Novel Tectonics, engaged in this same activity in a way that linked their mathematical reasoning to their embodied practice called "physical research," building mathematical discoveries from agentic and embodied forms of reasoning. By engaging in their practice of physical research, these dancers took up mathematical reasoning in expansive ways. The 8th grade girls wanted to do this, but did not have a toolkit to support this kind of reasoning and thus were far more constrained. The practice of physical research has important structures to support collective mathematical sensemaking that links embodied noticings to ensemble mathematical learning in a way that foregrounds participants' individual and collective creativity and agency.

In this paper I analyze the response of professional dancers (in conversation with 8th grade students' response) to an embodied mathematical activity I created to intentionally support learners' recruitment of everyday, embodied reasoning. This activity was presented in a double stimulation interview (Engeström, 2007) in which participants were presented with novel tools (large prop and video recording from Rio) to accomplish a task (reenact folding choreography from the 2016 Rio Olympic Opening Ceremony), designed to provoke observably creative solutions for study (Vogelstein et al., 2019). Building mathematical learning from intuitive sensemaking means that learners see these forms of reasoning as valuable and part of their everyday lives and not stuck in the isolated context of mathematics (Hall & Jurow, 2015; Nasir et al., 2008). In contrast to the episode of 8th grade girls' reasoning about their mathematical choreography, professional dancers framed their engagement in this context as a practice of inquiry, flexibly leveraging embodied sensemaking resources to explore what was expressively possible within the people-plus-prop system. Instead of reaching a solution quickly (inverting the relationship between speed and intelligence), these dancers slowly created new possibilities and ideas together. The dancers referred to this practice as *physical research*, recruiting how they participate in a dance environment to this hybrid movement and mathematics context. In physical research participants explore their unknown expressive potential as an ensemble through an iterative process of creating and responding to collective, full-body movement. This foregrounds artistic agency and collective persistent inquiry (Lerman, 2014; Sengupta-Irving & Agarwal, 2017). The dancers' engagement in mathematical physical research in the interview points to new possibilities for expansive mathematics learning through their embodied mathematical sensemaking. To that end I explore how the practices of professional dancers can broaden our conceptualizations of epistemic mathematical practices by asking the following research questions:

1. How did dancers engage in processes of physical research in their professional context and what forms of participation did this support?
2. How did dancers engage in physical research to support mathematics reasoning in the context of the Rio interview and what forms of participation did this support?

I address these questions by using an ethnographic study (Lave, 2011) to trace the cultural practice of physical research from the dance studio to the double stimulation interview (Engeström, 2007). Use of physical research in the interview setting shows how dancers leveraged this practice for mathematics learning. I operationalize learning as a socially distributed process of changes to participation in a community of practice (Lave & Wenger, 2011) and directly take up recent methodological calls in the learning sciences to contextualize analyses of disciplinary learning in the history of participants' relations as mediated by embodied practices (Gutéirrez & Rogoff, 2003; Vossoughi et al., 2020). Dancers' use of mathematical physical research offers a new way to think about the designs for mathematics teaching and learning that place everyday resources of the body on par with symbolic or graphical resources in conventional approaches to mathematics education (Gerofsky, 2010).

Theoretical framework

Ensemble learning

Ensemble learning (Ma & Hall, 2018) references activities that are done with others that cannot be learned alone. These activities are necessarily a collective endeavor in which participants recognize the need to learn as a group, such as a high school marching band preparing for a competition or professional dancers engaging in an exploratory choreographic process where the group explores what they can express collectively (Lerman, 2014). Analytically, this necessitates a shift in the unit of analysis from the individual to the ensemble. This does not mean that individuals and their contributions are erased; rather, this shift contextualizes individual contributions in how they inform the group's work together and highlights the coordinated efforts of distributed learning (Danish et al., 2020; Ma, 2017).

Ensemble mathematical activity can expand *what* is possible to learn in mathematics contexts by changing the scale and modality of geometric objects, thus re-scaling the body's relationship to geometric figures and changing the modality of engagement. In traditional paper-scale geometry, learners maintain a bird's eye view and an authoritarian relationship to manipulating small objects. The representational infrastructure of mathematics changes when the scale and materiality of geometric objects change (e.g. 7' x 7' shiny silver Mylar square) so that manipulating geometric objects now requires the participation of a group. This disrupts canonical embodied routines and creates new possibilities for modal engagements, understanding, and participation in mathematics learning (Hall, et al., 2014; Ma, 2016; Vogelstein et al., 2017 & 2019). For example, in the Rio interview, dancers choreographed a way to find the midpoint of one edge of the prop by having two people hold adjacent corners with one hand to create a taut edge for their other hand to slide along. When the two hands met they were in the middle of the edge and had found the midpoint. This is an excellent example of how modalities of engagement shifted from using a ruler to first measure the entire length and then divide it in two, to two hands sliding towards each other. This led to a conceptualization of midpoint that highlighted the relationship between the defining points, enacting the same travel time from end points to midpoint. This relational understanding of a mathematical concept was built from the coordination of moving bodies and perspectives.

Embodied mathematics

Ensemble activity foregrounds the importance and necessity of *doing* things together since these activities cannot be done by someone on their own, which highlights the body as a central to learning. How the body is used in learning processes (embodied learning), however, has been theorized differently by many scholars. Stevens (2012) outlined two theoretical perspectives characterizing the majority of embodied mathematics literature: conceptualist and interactionist. He argued that the conceptualist stance positions the body as revealing cognition in the brain (Alibali & Nathan, 2012; Lakoff & Núñez, 2000) and the interactionist position commits to seeing cognition in interaction (Goodwin, 2000; Nemirovsky et al., 2012). I take an interactionist perspective which aligns with Kirsh's (2010) notion of physical thinking, in which studying a choreographer revealed how physically enacting movements affords opportunities for observations and actions that could not be accessed through simulation or without direct participation. Notably, becoming mathematical entities through exploratory dance research can bring relations into existence in meaningful ways (Kremling et al., 2018).

When geometric figures are re-scaled and necessarily manipulated by an ensemble, noticings while moving become consequential for learning as learners gain an intrinsic perspective of the object they constitute together. For example, when the dancers slid their hands towards each other to find their midpoint, they began to notice how this action leveraged the midpoint as an anchor for the folding sequence that followed. Coordinating both intrinsic and extrinsic perspectives adds to the depth of mathematics learning in these environments by emphasizing how components coordinated together constitute complex mathematical objects. Embodiment constituted *in* the movement of ensembles shows how being immersed inside and outside of mathematical phenomena supports the coordination of multiple perspectives which leads to new forms of engagement and sensemaking that positions learners as agentic and actionable mathematics thinkers..

Intercorporeality and relationality

Expanding possibilities in mathematics education through studying ensemble learning from an interactionist and embodied perspective highlights how individuals' movements are understood in relation to the whole group composition. Participants gain a view of mathematical structures from their intrinsic perspective, while also engaging in mathematical sensemaking with others as they are forced to coordinate distributed perspectives and participation to create objects together. Thus, how groups learn to reason as a group through the development of new relations is foregrounded in these learning environments (Sengupta-Irving & Agarwal, 2017).

Leading work in the learning sciences has called for research that values new forms of relationality as outcomes of learning (DiGiacomo & Kris D. Gutiérrez, 2016; Vossoughi et al., 2020), expanding what it means to take changes in participation as evidence of learning (Lave & Wenger, 1991). As an intimately connected practice enacted with an ensemble, physical research supports the development of *intercorporeality* (Meyer et al., 2017), or a sense of withness. Hahn and Jordan (2017) argued that evidence of intercorporeality is a change in participants' identities from I's to we. Embodied anticipations begin to stabilize as reciprocal responsibility develops, which also supports empathy and *intercorporeal trust*. Empathy and trust are important sensibilities to cultivate in learning environments, and are commonly absent from mathematics contexts (Cooper, 2010).

Tracing the practice of physical research over the years has shown deep reciprocal relations between these dancers, foregrounding intercorporeal trust as a fundamental aspect of their practice. Thus, when these dancers entered into the Rio interview they were able to draw upon well-established relations of trust in each other to both explain what the Rio dancers did and to create new performance elements. Analysis of the dancers' developed sense of withness, and a substantial repertoire of language and body practices for engaging with this mathematical task importantly expands understandings of what mathematics learning can look like and result in.

Methods

This paper traces the practice of physical research through ethnography and a double stimulation interview. The 90-minute interview was designed as a Vygotskian double stimulation experiment (Engeström, 2007), which allows researchers to observe participants' inventions in response to novel situations such as choreographing geometric transformations with a large Mylar square. Initial analysis of professional dancers engaging in this interview prompted two years of ongoing ethnographic observations to better understand the practice of physical research in the context of the dance studio and how the dancers leveraged it in the interview.

Participants and research context

The primary participants consisted of 10 professional dancers and the artistic director, Clarke, of a contemporary dance company, Novel Tectonics, located in a mid-sized city in the American Southeast. Almost all of the dancers moved from all over the country to work in the artistic "research lab" Clarke created where dancers explored how they could collectively embody new ideas. While foregrounding the exploratory nature of dance is not unique to Novel Tectonics, it is noteworthy that these dancers moved to a new city for a job that was not enough to make ends meet. Clarke described this artistic community as follows: "We are Black, White, Latinx. We are gay, straight, bisexual, Christian, Jewish, believers in science, and atheists." The dancers' diversity was reflected in physical research by leveraging bold movement proposals that reflected their unique perspectives. Dancers have expressed that leveraging their artistic agency and allowing them to express possibilities they could not explore on their own drew them to this community (Vogelstein, 2020).

Data sources and analysis

Ethnographic data

Novel Tectonics rehearsed 3 hours a day, 5 days a week from September to May. During the 2017-2018 & 2018-2019 seasons, I observed 1-2 rehearsals a week for a total of 50 observed rehearsals. Data collected during rehearsals included field notes that describe observations of how these dancers engaged in cycles of physical research as well as video recordings of their work. Field notes were collected as a means to capture events and impressions from being present as an observer, supplementing the inherently limited view of the camera lens, while video recordings captured the fast moving bodies of the dancers to allow for micro-ethnographic Interaction Analysis (IA) of how multimodal aspects of gaze, gesture, and coordinated movements were used in interaction (Hall & Stevens, 2015).

Double stimulation interview data

The Rio interview was designed as a double stimulation experiment (Engeström, 2007) in which participants were presented with a primary stimuli (the Rio Olympic reenactment task) to make their uptake of a secondary stimuli, representational supports or tools (large square Mylar prop and video recording from Rio), observable. As a whole, the interview consisted (1) of showing a group of 4 people a performance from the 2016 Rio Olympic opening ceremony, (2) asking them to reenact parts of the performance using a similar prop, (3) having them discuss the relevance of mathematics in this activity, and (4) allowing participants to choreograph their own performance with the prop. 4 cameras recorded the interview (2 cameras on adjacent walls, 1 on the ceiling, and 1 on the table), approximating the different angles used in the viewed recording of the Rio performance. Analysis of the dancers' participation in this interview shows how they leveraged consequential embodied sensemaking resources by engaging in physical research.

Findings

How these dancers engaged in physical research professionally

This analysis demonstrates how engaging in the practice of physical research allowed the dances to collectively engage in expansive, agentic mathematical sensemaking in which, unlike the 8th grade girls, mathematical authority resided in their own seemingly simple observations. Analyses of the first year of ethnographic data illuminated the basic structure of physical research in practice (Vogelstein, 2020) across multiple contexts. In the rehearsal studio, cycles of physical research were enacted through making and responding to physical proposals between the choreographer and dancers to develop "movement vocabularies" and then "sculpt" them through proposals to change what had been established. Framing any movement enacted as a proposal meant that movements were always thought of as something that could be responded to, ideas that others could and should build off of. Choreographic proposals for sculpting existing movements were generally verbal prompts to alter what the dancers had created (e.g. enact these moments but in a diagonal formation) from an extrinsic perspective, to which the dancers used their bodies to respond to these new arrangements by making new proposals and responding to each other physically from an intrinsic perspective until something had formed, a referenceable movement vocabulary, that the choreographer could continue to sculpt (Figure 1).

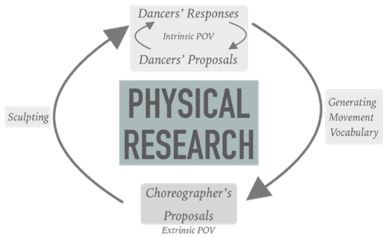

Figure 1. Model of physical research

This model of physical research helps illuminate how these dancers participated in this practice, proposing ideas with their bodies that they responded to until something had solidified that could be observed and then sculpted. As they engaged in this practice year-in and year-out, their ability to work together as an ensemble also developed as proposals and responses blended into trusting movements together:

> I feel like it happens physically because […] there is also like a trust that like the body like has some understanding of what's happening just by the person in the room being in the room. You know, I feel like there's something that is exchanged in that, that chain of sharing that is more than verbal. […] Maybe it's the way that Maddie makes a proposal and I then, you know, follow up. […] It's still improvisational but there's still a sense of knowing. You know, like if I end up behind Maddie and my arms are in front of her then she knows that if she wanted to she could like thrust all of her weight back and I could fall safely. […] And it's through the doing and the redoing I think too (Darius, Interview March, 2019).

Committed to the notion that people's physical presence affects what is possible, Darius described physical research as a process developed by moving in response to and with others. He linked this to the relationships with his colleagues, where trust supported them to exchange ideas and move in new ways together without words. He emphasized, "doing and redoing," in which long-term trajectories of participation support the development of intercorporeal trust as an innate part of physical research. In the next section I use this ethnographically-grounded model of physical research to analyze these dancers' collective mathematical sensemaking in the Rio interview to show how physical research can support agentic forms of mathematical reasoning that can also foster new forms of relationality through trust as a valued outcome of learning.

How these dancers engaged mathematics in physical research in the interview

In this episode, four dancers from Novel Tectonics (Cathy, Darius, Faith, & Maddie), participated in an experimental hybrid movement and mathematics activity in which they were working on reenacting choreography from the opening ceremony of the 2016 Rio Olympics that involved a quartet folding a large silver flexible square sheet of plastic into a triangle. Over the course of a 20-minute process of physical research, the dancers iteratively refined their understanding of the referent choreography by exploring together what was visible in the video record and what was possible to create with the prop together.

By engaging in this mathematical activity through their collective practice of physical research, the dancers continuously explored possibilities with the people-plus-prop system (quartet and square prop), making new discoveries until they were "satisfied" and stopped. Framing their activity as physical research meant that the dancers continued to redefine how they could fold the prop into the desired shape. Their engagement focused on exploring possibilities rather than perfecting the execution of a set sequence of movements, remaining open to opportunities for changes through new proposals. In the following analysis I outline the dancers' physical research trajectory as it led them to discover three different embodied understandings of the concept of midpoint and how the resources involved in cycles of physical research supported this engagement.

Physical research of a triangle: Three different ensemble coordinations used to find a midpoint

Noticings from the video record became crucial to the ensemble's engagement in physical research as they coordinated their extrinsic perspective of the performance from re-watching the video with their intrinsic perspective as a part of a group manipulating a similar prop. These intuitive sensemaking resources, comparing observable configurations, were easily taken up in their inquiry. For example, early on the group identified that the camera angle used to broadcast the performance captured observable triangles with one 90-degree angle and three sides of different lengths (a right scalene triangle). The dancers proceeded to fold the square prop on the floor to prove that creating the desired triangle was possible. On the floor, the first proposed movement was a grab at the midpoint of one edge, to which another dancer responded by using this as a fulcrum to fold her corner up and over across the midline of the object, this was the first way they found this midpoint together.

In addition to coordinating observations from the video with their own roles in the choreography, the dancers also responded to how they manipulated the prop together, engaging with it as a fifth member of the group that needed to be supported. Once they had folded a right scalene triangle on the floor, they transitioned to a standing up configuration, sculpting their movement vocabulary. Once they stood up, the dancers quickly discovered that they needed to actively pull corners to tighten edges in order to make folds along the same lines as they had on the floor, reconfiguring the supports the floor had passively provided. However, now that active force was needed at the corners of the square, nobody could reach to grab a midpoint. Cathy and Faith creatively slid their hands along the taut edge between them using the symmetry of their movements and the length of their wingspans to find the midpoint between them. This second movement vocabulary for establishing a midpoint was found by responding to the new configurations and movement vocabulary they continuously developed.

After choreographing a triangle-folding pattern standing up, utilizing points that created tension to fold across straight edges, the dancers had solidified a new movement vocabulary but some were still not satisfied. Faith and Maddie made a proposal to sculpt this vocabulary by incorporating a visual formation the Rio performers' "hit" in the video that they had not yet created. Faith's proposal to sculpt, "Yeah let's do the dumpling airbag," (Figure 2A) came from an extrinsic perspective on the choreography, positioning Faith as the choreographer in this moment. The "dumpling-airbag" referred to a formation where all four performers started with their prop extended as a square and all walked to the center together, puffing the prop into a dumpling-like shape below their waists. Observing and naming this formation allowed the movement to be referenced and reenacted as a group. Maddie led the group in enacting this formation, coordinating their movements with a verbal cue, "So, dumpling," (Figure 2B). Creating the dumpling formation was the group's response to Faith's sculpting proposal and once formed, Cathy's new intrinsic perspective led to a new way to find the midpoint, "oh and then find our edge here," (Figure 2C & D) as opposed to pulling it tight as they had before. The dumpling folded the prop without a need to stretch edges taut and in fact folded each edge in half so that the midpoints between corners now puffed out between members, making it easy to grab as the edges collapsed in half. Confirming the utility of this formation, Faith followed up by announcing to the group, "this is how they do it," (Figure 2E). This comment solidified the generation of a new movement vocabulary, setting the group up for another process of sculpting as they continued in their cycles of physical research.

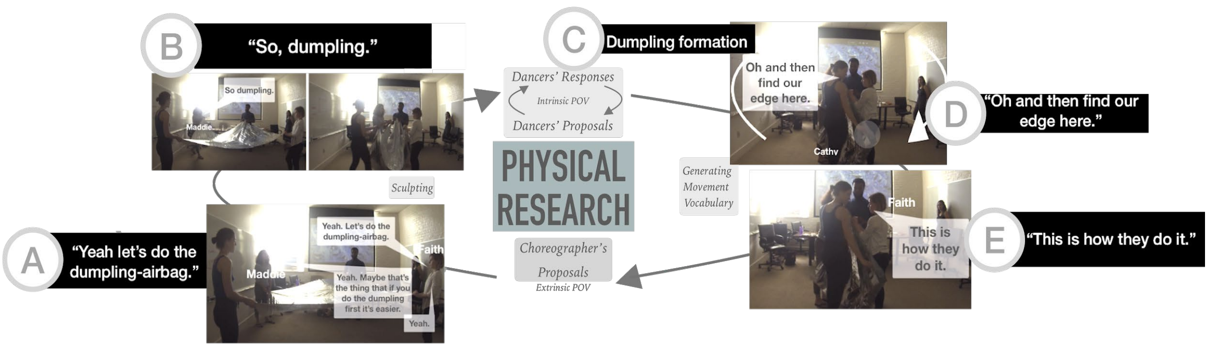

Figure 2. Mapping the dancers' mathematical discovery that midpoints can emerge through symmetric movements onto the preliminary analytic model of physical research

This example of the development of finding the midpoint of an edge, distributed amongst the dancers, shows how engaging in cycles of physical research structured participation so as to make small, intuitive noticings (e.g. all of the Rio performers gathered together at one point) about the aesthetics of movements consequential and productive for inquiry. One small proposal became important as it was amplified by seeding responses from other members distributed in the group as individual wonderings became whole group enactments (from I's to we's). The relations of trust enabled deeper understandings of what can be done and at the same time the relational structure of the mathematical object (the multiple ways the prop could be folded across a midpoint). These forms of reasoning are typically not available when this sort of mathematics is engaged with at paper-scale under circumstances in which individuals manipulate entire geometric figures on their own, foregrounding the resultant state and not relations and pathways in movement. It is also important to note that proposals to sculpt in this process of physical research supported a process of mathematical engagement in which discoveries were being made, even 17 minutes into a 20-minute inquiry process, constantly fueling new ideas, formations, and understandings from the dancers.

This analysis demonstrates how these dancers' engagement in physical research in the Rio interview supported the use of everyday sensemaking resources for agentic mathematical reasoning. Simple noticings of measurement, orientation, and configurations led to the development of complex embodiments of three different ways midpoints could be found and used as anchors for symmetric transformations. Additionally, this analysis shows how physical research structured the use of these sensemaking practices to support new relations between learners because as the dancers engaged in this activity their fluency in responding to each others' movement proposals increased through the development of intercorporeal relationality and trust.

Discussion and significance

To concretize the importance of this paper, I return to the opening example. Although Ava and Octavia's intuition when folding the prop into a triangle was to recruit disembodied forms of reasoning used, "in math," their eagerness to engage in an extended debate about the properties of a triangle and resultant conclusion. Eventually Tracy persuaded Ava by showing that in the creation of the triangle one of the corners came from a square and since it was not altered in the process of folding, it must have remained 90 degrees. Tracy's insistence and Ava's change in reasoning points to students' willingness to engage their intuitive, embodied sensemaking skills, although not always right away. Imagine what kind of mathematical participation these girls could have engaged in if they had exercised their agentic forms of embodied sensemaking from the beginning as physical research supported the dancers' mathematical reasoning or had trusted each other and built off of each others' proposals, as the triangle in question was actually both right *and* isosceles.

This paper contributes to work in mathematics education to better understand practices (such as physical research) that support embodied, everyday sensemaking resources learners already possess as relevant to mathematics inquiry. The observations the dancers made and acted on utilized basic embodied sensemaking resources (e.g. mirroring slow movements, noticing visible differences in formations) that the 8th graders could have enacted, yet it was engaging in the practice of physical research, a practice that had cultivated their ability to work as a collective, that enabled these dancers to engage in such deep and generative mathematical inquiry.

Studying these dancers' engagement in physical research, both in the dance studio and in the interview, shows the development of a responsive collective agency through the making and responding to proposals as an ensemble. This enactment of agency shifted the relations between the dancers, supporting collective and embodied forms of mathematical inquiry and imagining. By illuminating the structures of activity that supported physical research over time, this analysis both challenges normative conceptions of mathematical learning as mediated primarily with pencil-and-paper and illuminates possibilities to guide current and future designs of innovative and inclusive embodied mathematics learning environments. Questions about how to design to support these collective practices so that learners see their everyday, embodied sensemaking resources as mathematically relevant remain. Drawing from these initial findings, I have begun the next phases of this work, co-designing and co-analyzing mathematics activities with the dancers of Novel Tectonics, using their practice of physical research to structure forms of participation for students that are promising in initial analyses.

References

Alibali, M. W. and Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the Learning Sciences*, 21: 247–286.

Cooper, B. (2010). In search of profound empathy in learning relationships: Understanding the mathematics of moral learning environments. *Journal of Moral Education*, *39*(1), 79-99.

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: a sociocultural framework for embodied cognition. *Int. J. Comput. Support. Collab. Learn.*, *15*(1), 49-87.

DiGiacomo, D. K., & Gutiérrez, K. D. (2016). Relational equity as a design tool within making and tinkering activities. *Mind, Culture, and activity*, *23*(2), 141-153.

Engeström, Y. (2007). Putting Vygotsky to work: The change laboratory as an application of double stimulation. In *The cambridge companion to Vygotsky*. Cambridge University Press.

Gerofsky, S. (2010). Mathematical learning and gesture: Character viewpoint and observer viewpoint in students' gestured graphs of functions. *Gesture*, *10*(2-3), 321-343.

Goodwin, C. (2000). Action and embodiment within situated human activity. *Pragmatics*, 32: 1489–1522.

Gutiérrez, K., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational researcher*, *32*(5), 19-25.

Hahn, T., & Jordan, J. S. (2017). Sensible objects: Intercorporeality and enactive knowing through things. In *Cognition in 3E: Emergent, Embodied, Extended* (pp. 37-54). Springer, Cham.

Hall, R., & Jurow, A. S. (2015). Changing concepts in activity: Descriptive and design studies of consequential learning in conceptual practices. *Educational Psychologist*, *50*(3), 173-189.

Hall, R., & Nemirovsky, R. (2012). Introduction to the special issue: Modalities of body engagement in mathematical activity and learning. *Journal of the Learning Sciences*, *21*(2), 207-215.

Hall, R., Ma, J. Y., & Nemirovsky, R. (2014). Rescaling bodies in/as representational instruments in GPS drawing. In *Learning technologies and the body* (pp. 124-143). Routledge.

Hall, R., & Stevens, R. (2015). Interaction analysis approaches to knowledge in use. In *Knowledge and Interaction* (pp. 88-124). Routledge.

Kirsh, D. (2010). Thinking with the body. In *Proceedings of the annual meeting of the cognitive science society* (Vol. 32, No. 32).

Kremling, J., Arndt, N., Roman, A., Zilm, M., & Straehler-Pohl, H. (2018). Dancing on the junction of mathematics and bodily experience. The Mathematics Enthusiast, 15(1), 201-227.

Lakoff, G., & Núñez, R. (2000). *Where mathematics comes from* (Vol. 6). New York: Basic Books.

Lave, J. (2011). *Apprenticeship in critical ethnographic practice*. University of Chicago Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University.

Lerman, L. (2014). *Hiking the horizontal: Field notes from a choreographer.* Wesleyan University Press.

Ma, J. Y. (2016). Designing disruptions for productive hybridity: The case of walking scale geometry. *Journal of the Learning Sciences*, *25*(3), 335-371.

Ma, J. Y. (2017). Multi-party, whole-body interactions in mathematical activity. *Cognition and Instruction*, *35*(2), 141-164.

Marin, A., Taylor, K. H., Shapiro, B. R., & Hall, R. (2020). Why Learning on the Move: Intersecting Research Pathways for Mobility, Learning and Teaching. *Cognition and Instruction*, 1-16.

Moschkovich, J. (2002). A situated and sociocultural perspective on bilingual mathematics learners. *Mathematical thinking and learning*, *4*(2-3), 189-212.

Meyer, C., Streeck, J., & Jordan, J. S. (Eds.). (2017). *Intercorporeality: Emerging socialities in interaction*. Oxford University Press.

Nasir, N., Hand, V., & Taylor, E. V. (2008). Culture and mathematics in school: Boundaries between "cultural" and "domain" knowledge in the mathematics classroom and beyond. Review of Research in Education.

Nemirovsky, R., Rasmussen, C., Sweeney, G. & Wawro, M. (2012). When the classroom floor becomes the complex plane: Addition and multiplication as ways of bodily navigation. *Journal of the Learning Sciences*, 21: 287–323.

Sengupta-Irving, T., & Agarwal, P. (2017). Conceptualizing perseverance in problem solving as collective enterprise. *Mathematical Thinking and Learning*, *19*(2), 115-138.

Stevens, R. (2012). The missing bodies of mathematical thinking and learning have been found. *Journal of the Learning Sciences*, *21*(2), 337-346.

Vogelstein, L. (2020) Physical Research: Professional Dancers Exploring Collective Possibilities in a Solidifying Substrate. Proceedings of the International Conference of the Learning Sciences, 2020, 737-739.

Vogelstein, L., Brady, C., & Hall, R. (2017, June). Mathematical Reflections: The Design Potential of Ensemble Performance. In *Proceedings of the 2017 Conference on Interaction Design and Children* (pp. 583-588).

Vogelstein, L., Brady, C., & Hall, R. (2019). Reenacting mathematical concepts found in large-scale dance performance can provide both material and method for ensemble learning. ZDM Mathematics Education 51(2).

Vossoughi, S., Jackson, A., Chen, S., Roldan, W., & Escudé, M. (2020). Embodied pathways and ethical trails: Studying learning in and through relational histories. *Journal of the Learning Sciences*, *29*(2), 183-223.

A New Mixed-methods Study of Learning-at-disturbance in Experienced Designers

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Abstract: We propose and validate a new mixed-methods approach that enables micro-level analysis of knowledge construction as well as high-level understanding of learning dynamics across person, space and time. The learners being examined here are experienced designers who exhibit adaptive expertise of reconstructing knowledge and adjusting behaviors in situation. To study this learning process of designers, first, we draw on theories of disturbance-based learning and identify high-arousal moments, or high-learning potentials, by capitalizing on unobtrusive emotional arousal measures of vocal pitch and electrodermal activity. Next, designers' learning at disturbance is characterized and understood through contextualization and triangulation with video observation and retrospective self-report using distributed views of learning. Together, our work shows how physiological measures such as voice could be integrated into the study of situated knowledge construction in the wild, and how the current mixed-methods approach offer new and more comprehensive ways of seeing and understanding knowledge in action.

keywords: knowledge-in-action, emotion, distributed cognition, multimodal learning analytics

Coming from the field of engineering design, our research is concerned with understanding the learning process in experienced designers' social practices. The focus on experienced designers and the stance of situated learning at disturbance is a confluence of multiple forces.

First, at the practical end, we want to unpack the expertise shown by adaptive expert designers, as compared to routine experts. Adaptive experts (Schön, 1983; Schwarz, Bransford & Sears, 2005) are able to reflect in action, adjust assumptions and modify behaviors during the process of product design in order to create new and meaningful product outcomes for peculiar problems at hand. A real-world example is elegantly described by Schön (1983). In a project of treating children malnutrition in rural Colombia in the 1960s, an unusual engineer Dean H. Wilson unlearned his convictions of system engineering through trial and error, and in turn, created successful educational interventions by grasping opportunities that lied in the intelligence of the local community. The pedagogical question of how to enable our engineering students and novice designers, to build up such adaptive ability has incubated the current research. Second, at the theoretical end, we are influenced by the interconnected streams of thoughts that, in Dewey's words, "thinking starts with felt difficulty" (Dewey, 1910). Our work is built upon this notion that surprise, confusion and discomfort have pivotal effects on learners' performance (Kapur & Bielaczyc, 2012) and knowledge development (Kegan, 1983; Bamberger, 2014; D'Mello, et al., 2014). For participants of social communities in our changing world, disturbance is ubiquitous, instead of rare, psychological phenomena (Berlyne, 1960; Moscovici, 1984).

As a result, we have come to see engineers and designers as dynamic learners who are often disturbed in their work, regardless of their expertise level and social-interaction context. In making this conscious choice of research perspective, we are aware that the teacher-student, parent-child, and master-apprentice paradigms are the basic building blocks of most educational research and have greatly driven the advance of learning sciences. On the other hand, change, the process of developing new beliefs and behaviors, is a process that would also occur for experienced professionals at work. In Schön's account, Dean H. Wilson's learning at work happened when he was a professor and expert engineer.

We join the emerging efforts of multimodal learning analytics (Blikstein & Worsley, 2016) and integrate technological tools with qualitative research to study the scarcely investigated learning process of experienced designers in the wild. Our work is a synergy and reflection of knowledge-construction-in-situ research as well as a methodological probing of how to study the interrelation of emotion and learning in the future.

Theoretical stance grounded in distributed views of learning

The views that situate learning in social and physical engagement have a long history in learning sciences since Piaget time. A leap of its development was seen in the 1980s and early 1990s (Bamberger & Schön, 1983; Brown, Collins & Duguid, 1989; Lave & Wenger, 1991; Pea, 1993). Despite different takes, the distributed views unanimously challenge the traditional view that knowledge is "a property of the minds of individuals" (Pea, 1993). We highlight a few influential theories below.

Knowledge-in-action is a concept initiated by Bamberger and Schön (1983), defined as "the current state of a person's mental constructions". The concept captures "the sense of movement and instability associated with, even necessary to, learning and change". According to Bamberger (2014) and Schön (1983), knowledge is mobile as a result of constantly interacting with the changing context instead of being stable, abstract and codified, the latter of which are often characteristic of other sociocultural views of knowing, such as cognitive schemas (Crocker, et al., 1984) and social representations (Moscovici, 1984). While knowledge-in-action stresses the continuous mobility of knowledge, as the learner interacts with materials at hand and the social context, distributed intelligence emphasizes the role of materials (e.g., technological tools that support learning) in terms of distributing and empowering intelligence, which is traditionally regarded as "a property of the minds of individuals" (Pea, 1993). This view is echoed in Papert's constructionism, which places significance on the role of different media in children's knowledge (re)construction (Ackermann, 2001). Others (Hutchins, 1995; Suchman, 1987; Lahlou, 2018) have demonstrated how workers' actions, which reflect their knowledge and expertise, are augmented with, controlled by and channeled through physical and social realities.

A designer's knowledge lives and grows through his/her mental, social and physical mediations, and in doing a design task, the designer engages in moment-by-moment construction of knowledge as he/she moves across time and space. This distributed view is contrasted with the traditional view in which to design is to enact a codified body of knowledge and skills. In addition, we take the stance there is not "a single, coherent and non-contradictory account of what happened", and that "real action is often ambiguous and may have multiple determinations" (Lahlou, 2018). However, references to the specific situation and designers' subjective experiences would lead to more complete interpretation and meaningful analysis (Xue & Desmet, 2019).

A new mixed-methods approach

Empirical approaches to study learning at disturbance range (e.g., experimental design in Kapur & Bielaczyc, 2012, inductive analysis in Bamberger, 2014). In works that adopt a situated view of knowledge, however, ecological validity has non-negotiable priority (Bamberger & Schön, 1983; Shaw, et al., 1997; Rahman & Barley, 2017; Parekh & Gee, 2019; Kulikowich & Young, 2001). The situated nature of knowledge favors approaches where real-world phenomena are largely preserved. Where intermediate self-reports are collected to gain access to participants' subjective experiences, ecological validity is compromised, and thus ecological momentary assessment has remained a challenge (Ram, et al., 2017).

Recent years have seen an emergence of new, non-obtrusive technological solutions and analytics (Blikstein & Worsley, 2016; Andrade, et al., 2016; Di Mitri, et al., 2018; Eteläpelto, et al., 2018) to enhance the ethnographic and phenomenological study of learning. Physiological measures, primarily electrodermal activity (EDA), are increasingly used for approximating students' emotional arousal in various learning contexts (Pijeira-Diaz, et al., 2018; Villanueva, et al., 2018). EDA refers to the variation of the electrical conductance of the skin in response to sweat secretion, which is produced by the sympathetic nervous system. Our skin becomes a better conductor of electricity when we receive external or internal stimuli that are physiologically arousing (Boucsein, 2012). And emotional arousal has long been regarded as an indicator for curiosity (Berlyne, 1960) and active participation (Pijeira-Diaz, et al., 2018). In contrast to EDA, Vocal pitch as a proxy for emotional arousal (Mauss & Robinson, 2009) has not found its way into learning sciences research. Vocal pitch is considered in literature as "less controllable and more leaky channels" of high emotional arousals that are not revealed by verbal content or facial expressions associated with the message (Zukerman & Driver, 1985; Dietrich, et al., 2019). The advantage of voice and sweat gland is that they make unobtrusive ecological assessment feasible, but they should also be used with caution. Unlike controlled-lab studies, their instrumentations in the wild would induce a lot of real-world noises which may make speech data difficult to clean up and electrodermal responses hard to interpret. In addition, the mapping between the basic physiological processes of emotion and experiences of emotion (i.e., what is felt) is still poorly understood (Barrett, et al., 2007). Subjective perspective-based video analysis, when triangulated with retrospective self-report, is a powerful qualitative measure (Lahlou, 2011) of experience and behavior, and could complement the bodily measures for validity-driven analysis.

The current research has been conceived to take advantage of aforementioned instrumentations. Our research question is a methodological one: *How to capture, characterize and understand the knowledge-(re)construction process of experienced designers at disturbance*? Considering our goal is to study learning through high-learning-potential moments of disturbances, emotional arousal measures of EDA and vocal pitch make it possible to identify high-arousal moments amongst large amounts of time-series data. To deal with the limitations of physiological measures, multiangle video data and retrospective self-reports are collected for interpreting the objective measures as well as to match our theoretical position.

The study of learning-at-disturbance in experienced designers

Participants and a half-day design task in the wild

Experienced designers were recruited based on accomplishments. They all started as engineers and went through rigorous human-centered design programs (from 1970s to 2019) from an engineering department at a U.S. university. The designers were randomly paired to work on a task in a naturalistic setting for three hours. None of them collaborated before. With a previously established measure (Atman, et al., 2010), we assessed their confidence, frequency of engagement in design activities, as well as how supportive their work environment is towards different types of design activities. The designers had on average 14 years of design work experience. Despite large variance of experience (sd: 15.28 years), they were on average highly confident (avg: 86.31 out of 100 with ad: 4.78), receive positive work-context support. We will focus on designer Diver (anonymous label) for qualitative analysis, Diver regarded himself as a design innovator, product designer, consultant, educator, researcher as well as magician. He was frequently engaged in the early front-end of product design, and these years only occasionally worked on the later stages of product realization. Diver had 40 years of design experience.

An ill-defined design problem was introduced. Given a set of videos and written materials, the participants were asked to create solutions to radically improve the dining experiences of families with small children. Video materials contain pre-collected data of eating scenarios from several families. To realize "in the field" experience, we crafted a temporary design studio situated at a place with easy access to children's facility, kitchen and residences of families with small children. The designers were physically unconstrained from the design studio. Two hours into the study, two families with their children came in for user testing. We suggested the users not make compliments only, but provide honest, critical and helpful feedback to the designers. By the end of the three hours, each team delivered a pitch as if to their client with some prototypes in hand.

Data collection and analysis

We used multiple observational channels to account for uncontrolled variables in the wild. Video cameras were mounted at the four corners of the studio. Each designer wore a miniature eye-level video camera, AXON Flex 2, to capture how situations are lived from the perspective of the participant (Lahlou, 2011) and keep track of design activity wherever the participant is, and it also provides audio data for speech acoustics analysis. Each participant also wore an Empatica E4 wristband on the dominant hand. The device acquires time-series data of EDA, movement, skin temperature, heart rate variability. Only EDA is used in the current study. Within a week after the study, participants shared subject experiences in a 2-hour one-on-one interview. Large prints of snapshots of the participants' own views, artifacts produced during the project, video clips of their subjective view, and other tools were used when appropriate to facilitate the unfolding of internal experiences.

Designers' engagement level is approximated by vocal pitch and skin conductance response (SCR) frequency, interpreted through triangulation. Audio data for each participant is extracted, manually cleaned up for speaker diarization and partitioned into utterances with ELAN software and analyzed with PRAAT software. Laughing, whistling and other sounds are separated from vocal speech. Creaky voices are identified with the Covarep program in Matlab and cleared from the dataset. To understand intraindividual change, each designers' utterances are segmented by design phase and social situation to calculate average and standard deviations of each phase and changes across phases. To allow for between-subject comparison, the baseline was acquired by rescaling vocal pitch to standard deviations above and below each designer's average vocal pitch (Detrich, et al., 2014). Utterances that are 1.5 standard deviations or more than the local average (i.e., z-score) are regarded as pointers to pronounced episodes of "felt difficulties", and thus high-learning potentials. These deviates are analyzed qualitatively through triangulation with EDA, self-report and video analysis. EDA retrieved from Empatica E4 was processed with Continuous Decomposition Analysis (CDA) as implemented in Ledalab program with Matlab. SCR is exported using a minimum amplitude criterion, which is a threshold that the rise in skin conductance value must reach or surpass to qualify as SCR. Since the current study took place in an uncontrolled environment, a score of 0.05 mS is used (Boucsein, 2012). We use SCR frequency to categorize the data into different levels. 1–3 peaks/min (ppm) is marked low (Dawson, et al., 2017), values higher than 20 ppm are interpreted as high arousal (Boucsein, 2012), while anything in between is medium. Signals less than 1 ppm are discarded for the purpose of data cleanup. Each designer's SCR frequency is also segmented by design phase and social situation. Lastly, retrospective self-reports are transcribed to provide a window into the subjective experiences of designers to support the data analysis.

Results

With the proposed measures, how to capture, characterize and understand the knowledge-construction process of experienced designers? We highlight case examples from designer Diver and show some micro-level analysis of "felt difficulties" which trigger designers' learning in action. Additionally, the mixed-methods approach allows comparative analysis of learning dynamics across person and time.

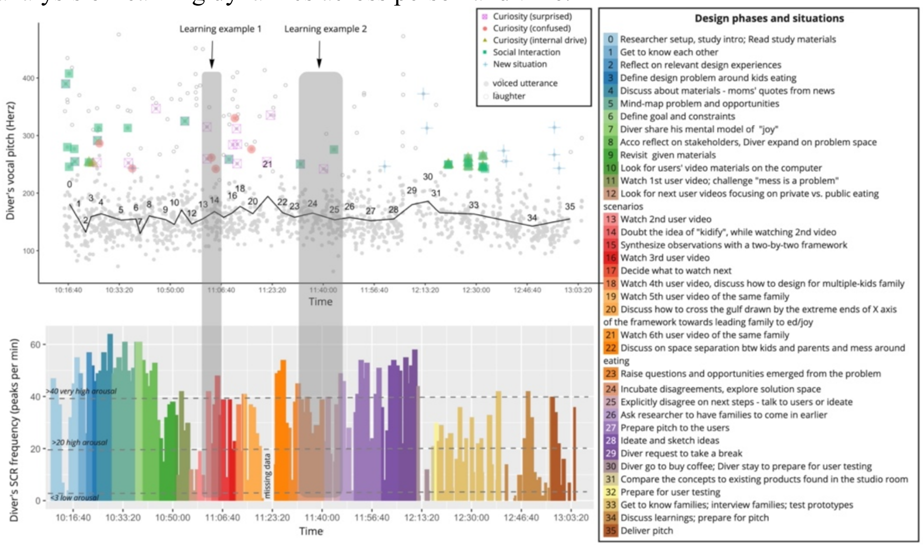

Figure 1. Designer Diver's engagement map; Top-left: Average vocal pitch over time (error bars not shown for simplicity) and types of high-pitch utterances; Bottom-left: SCR frequency, where arousal levels are based on standards (Boucsein, 2012; Dawson et al., 2017). The identification of high-learning-potential episodes (as indicated by colored shapes in top-left graph) is based on 1.5 z-score rule, and subsequently qualitatively coded through triangulation with SCR, retrospective self-report and video analysis. Grey bars highlight case examples.

Zoom-in: Characterizing and sensemaking knowledge reconstruction at disturbance

Learning example 1

Consider designer Diver's 2-minute experience here as he responds to a video material about a child interacting with food and utensils (Figure 2). Within the short time, Diver is channeled to speak in a distinctively high voice (1.5 z-score) a few times. In the quotes below, Diver's high vocal pitches are marked in *italic*.

After silently watching the video for a while, Diver turns to his partner Acco to offer his observation that adult products are scaled down for kids in softer materials, "*but it isn't clear*" (z-score: 1.89), he pauses, and does not finish the sentence before continuing, "we've seen these modifications in adult world of plates and utensils. So within the culture we are trying to kidify it enough that (unfinished)... It isn't clear it's helping the kids. And I think the parents go, this looks like it is for kids". He continues with a related observation from past experiences that some adult bottle designs are actually influenced by baby products and that "it literally went the other way around!" As the video plays along, he turns his attention back and forth between the TV screen and his partner. "*But I'm realizing it's a baby bottle!"* (z-score: 1.53), he excitedly points to the screen (as shown in Figure 2), "*But that…",* Diver quickly brings his hand back to hold his chin, and then stretches out to gesture, contradicting his earlier comment: "*and it works for her! It works perfectly. She had no problem with that*." (z-score: 1.66). While Acco acknowledges Diver's observation, Diver keeps watching the video, holding a fist by his chin, asking in a deeper and lower voice: "So are we looking at this the wrong way, that we wanted to have", he briefly pauses and turns to Acco, taking a lighter voice, "kids become adults versus learn from the kids and modify our adult world (with laughter)? That might not be hard to sell!"

Let us go through the thin slice again with our theoretical and analytical tools. A designer's knowledge lives and grows through their mental, social and physical mediations. And here, designer Diver curiously *saw* "kidification" as channeled by the video of child interaction with utensils. Diver's design knowledge around children's products is manifested in his ability to see kidification; In comparison, two less experienced designers in the study found this specific video material uninteresting. Moreover, instead of simply acknowledging kidification, Diver questioned it, and spent time on it, making it a rather intriguing issue. In addition to high voices, his body language suggests excitement, and his verbal expressions suggest confusion ("*but it isn't clear*") and curiosity (repetitive and contradictory statements). As he navigated the video, Diver broke down his assumption again and again, to further his understanding about kidification, from "*It isn't clear it's helping the kids*" to "*...it works for her! It works perfectly. She had no problem with that*" to questioning "are we looking at this the wrong way". The disturbance and elicited curiosity are also evident from the perspective of SCR frequency, where a steep rise occurs in the local proximity of the video-watching activity (Figure 1, bottom-left).

Example 1 not only shows the "mobile continuity" (Bamberger & Schön, 1983) of situated knowledge which is distributed in the physical (TV), mental (Diver's embodied expertise) and social (cultural practices associated with the child's dining) spaces, it is also a high-learning episode. Diver is grabbed by the visually colorful and soft utensils, curiously stuck on why designers should assume baby products are scaled downs of adult products. This question drives Diver, as a seasoned children's product designer, to unlearn the default assumption and reconstruct his knowledge in the space. It is notable that kidification might not be an entirely new concept to Diver. He may have developed this concept of kidification in his previous experiences. However, this alternative view is not made obvious and questionable until this disturbing moment as he engages with the video material, which allows Diver to adjust and expand his situated knowledge.

Figure 2. Designer Diver's subjective view (left) and a third-person camera view (right) of a high-learning moment for Diver, located at phase 14 in Figure 1. Left: Diver extends his left arm and points at the TV, saying "*But I'm realizing it's a baby bottle!".* Right: Acco (standing) observing user behaviors as Diver (sitting) talks.

Learning example 2

At a later point of time, Diver has a tense disagreement with Acco. After the user-behavior observations, Diver indicates a few times of his interest to talk to actual users. As Acco does not respond, Diver makes it an explicit request. But instead of supporting Diver's suggestion as Acco always does until this point, Acco proposes to design some sacrificial concepts first. Hearing that, a high-pitch voice leaks from Diver before Acco finishes his sentence. "*Hmm! um-hum!*" (z-score: 1.68). Diver is verbally positive, but his vocal pitch suggests surprise and discomfort. As an experienced designer, Diver is able to regulate his emotions and make conscious balance between maintaining teamwork and making the right pathway. He opens up to go with Acco's thinking process to ideate. After a few minutes of exploring the solution space, Diver is channeled back to think of talking to users, because one of their concepts is hinged on the question "when do kids transition from baby food [to family food]?" "That", Diver points to the TV, "looks like my plate, only it's not working!... And we literally had to separate ourselves from the kids because it doesn't work…Ah, I, I would love to ask about when you eat together, when you don't". In response, Acco insists on spending the limited time on coming up with some concepts and preparing for user-testing. Diver attempts to persuade Acco again — "We've thrown some ideas out around this stuff, and I'd love to see — are we even close to be on track", and he adds, "and our hypothesis is that they (parents and kids) are struggling eating together. I just, I want to validate that". But Acco also persists in his thinking. "*Okay"* (z-score: 2.14), responds Diver in an abnormally high voice.

As Diver reflected in the retrospective interview, he regarded the division with Acco as "the high point of perplexity". In Diver's view, the project ended in "anticlimax" partly because of that, even though they receive positive and encouraging feedback from the users during the user-testing phase. Diver was deeply convinced, based on his experience, that it is not wise to go too deep in concept generation without validating their underlying assumptions with users first. Intriguingly, Diver started navigating this "felt difficulty" with a positive attitude and open mind. During this process, there is no doubt that Diver was guided to shape understanding about the design project at hand, as new questions surfaced (e.g., when do kids transition from baby food to family food?). By cooperating on ideation, Diver built a new mental container that would accommodate product ideas while not stretching his own convictions too much. But that only led to building up tension in the conflict. At the moment when Acco expressed strong interest to work on concepts, Diver realized they had different conceptions of "concept" and "ideation" — while for Diver they already had some high-level ideas, to Acco these were not concrete concepts ready to be tested with users. As shown in the analysis, Diver's knowledge about Acco and how to work with Acco was being reconstructed moment by moment as well.

This experience also had a pivotal effect on Diver's subsequent performance. He was less curious about the task and less engaged behaviorally as well. Diver laughed much less (Figure 1, top-left) and showed fewer learning behaviors as indicated by the high-pitch criteria. Shifting lens to EDA, Diver's arousal does not make obvious sense as in example 1, since phase 24 and 25 are actually lower than the local proximity, despite the high baseline. This could be better understood through contextualization. In Diver's reflection, he described design progress as "going along where your energy is" and emphasized how important it is to "keep the energy up". For

Diver, the splitting point with Acco was a deflation of energy he gained from earlier activities. This is observable in his physical activation as well. Diver changed from the active posture of standing up and working by the whiteboard at phase 22 and 23 back to sitting down, as he tried to resolve the conflict. In comparison to example 1 in which Diver's high-pitch utterances suggest stimulation, excitement and curiosity, the high-pitch utterances of example 2 are briefer in length and suggest undesirable tensions.

The two examples here are complicated and pronounced ones, whereas in some other cases, the situated experience is rather brief. For instance, earlier in the process, hearing Acco's joke about their shared design training, Diver jokes as well: "*Okay, checked! Extra credit! We are done, we are out of here!*" (z-score: 1.83) It is clearly a team bonding interaction, where Diver is positively surprised and channeled to build his knowledge about his unfamiliar partner and how to work with him.

It is worth noting that not all high-pitch utterances suggest disturbance-based learning. Some of them are not elicited by disturbing stimuli but are due to uncertainty and curiosity to learn. For instance, in the user-testing phase, Diver asks one parent: "*Do you guys ever eat together at that table or do you eat separately*?" (z-score: 1.67). According to Diver's retrospective self-report, the answer to this question was very critical to validating his assumption behind the product idea. There are also exceptional arousal rises due to entering or expecting new situations, for instance, Diver raises his voice to say "*Okay!*", suggesting moving on to the next design phase. Fluctuation of pitch as associated with situation change has less to do with the kind of disturbance in our theoretical framing and can be distinguished by triangulation with qualitative analysis.

Zoom-out: Learning dynamics across time, between people

Designers' arousal level, as measured by EDA and vocal pitch, has notable changes across design phases and social situations. For instance, as shown in Figure 3, Designer Diver is situated in a much more highly aroused state in the early exploration than in user-testing, reflection and pitch delivery. More specifically, in the beginning phases, Diver is physically and socially more stimulated, as shown in his dense laughter and high-pitched verbal expressions. In addition, clusters of disturbing moments within a person would emerge from the mapping over time. For designer Diver, the beginning phases of the design task are filled with positive disturbances as he interacts with the unfamiliar partner. The bodily signal graphs also show that Diver's disturbance-based learning peaks during the time of observing user behaviors through video materials.

In comparison to Diver, the video materials are less stimulating for some other designers with much fewer disturbing incidents. This observation allows us to revisit Diver to understand his knowledge and expertise, acknowledging his ability to see problems from what is otherwise perceived normal for other people. Figure 3 gives another example comparing Diver and Analyte, who was from another design team. Interestingly, Analyte's arousal stays low to medium throughout except for a few salient phases, such as the user-testing stage. Notably, Diver's arousal in the user-testing phase is low, whereas in the same phase it is highest for Analyte. In addition to possible individual differences in EDA, the differences can be better understood from analyzing their retrospective reflection. While Diver cares for keeping the energy up by immersing himself into the work, Analyte tends to detach himself from the design work as for him, "it was professional" and it was about applying "the process" and "rules of engagement".

As shown by these brief examples, meaningful interpersonal and intraindividual comparisons are made possible with the multimodal data of vocal pitch and EDA through contextualization and triangulation.

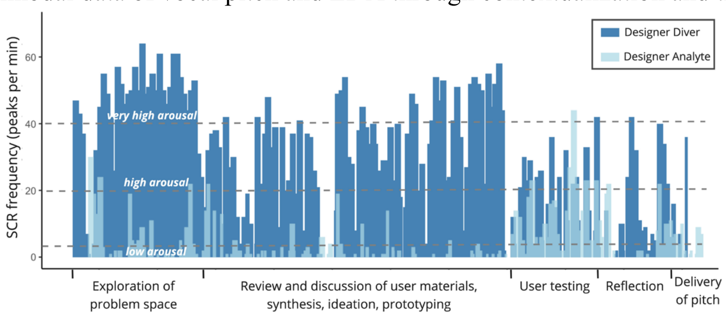

Figure 3. Comparison of designer Diver and Analyte who had distinctively different arousal profiles.

Discussion

How to capture, characterize and understand the knowledge-(re)construction process of experienced designers at disturbance? In pursuit of a methodologically rigorous approach, we integrate vocal pitch and electrodermal activity into the qualitative analysis of knowledge construction in situ. Such a mixed-methods approach enables researchers to study experienced designers' momentary emotional disturbances and situated knowledge work in the wild. As demonstrated so far, on the one hand, we are able to do micro analysis of how designers curiously chew on disturbances and adapt their assumptions in the moment and in context. On the other hand, it also gives a broader view of designers' learning dynamics across person and time.

Reflecting on the different measures of experience, we find electrodermal activity is sensitive to energy level and stress level, which is otherwise regulated in vocal expressions. In comparison, vocal pitch captures well involuntarily leaked momentary surprises (Detrich, et al., 2014), despite that most talking was well regulated with vocal pitches gravitating towards the mean. Meaningful phase-based segmentations of time-series data enable comparison of arousal level using mean and standard deviations. These objective measures have unique advantages and are complementary to traditional observational and self-report measures. It is otherwise difficult to see internal disturbances that are regulated in external behavior. Practically, participants in retrospect would not remember or voluntarily report exhaustively their swift disturbing experiences during a long activity, despite that the two given examples of knowledge construction process are quite emotional in situ. On the other hand, first-person perspective camera is promising for its unique advantage of approximating real-life observation and gives meaning to the lifeless physiological numbers.

We have applied some instrumentation and analytical tools from affective science. In affective science, however, scientists tend to avoid applying different measures due to poor concordance, as any one measure has its biases that are associated with variance unique to it (Mauss & Robinson, 2009). As a result, construct validity of arousal or stress is often unaddressed. In addition, EDA is sensitive to real-world noises when instrumented in the wild. Our study addresses the validity problem by approaching emotion arousal with contextualization and triangulation through multiple measures. This complexity-embracing approach, combined with basic bodily signal analytics, enables us to see discordance between different measures as opportunities to trigger new questions and new ways of data interpretation. Taken together, the current approach offers new and more comprehensive ways of seeing and understanding knowledge in action. Important questions going forward include how to capitalize on the technical conveniences for remote research given the challenges presented by the pandemic, and based on the current research insight, how to design coaching interventions to guide learners to navigate disturbances.

Conclusion

Designers, in the process of creative design, constantly construct their design thinking, feeling, behaving and learning. Adaptive design experts in particular exhibit extraordinary ability of reshaping knowledge and adjusting behaviors in situ — they learn as they design, in order to create new and meaningful products to solve peculiar problems at hand. In this paper we reflect on the past research of distributed learning in situ and propose new ways to advance this body of knowledge. We hope our research will open up fruitful discussions on how to advance learning sciences in the future. At the practical end, engineering educators are deeply concerned about bringing up next-generation designers to effectively, collaboratively and creatively deal with the complexities and uncertainties of the peculiar problems at hand. We hope the study will inspire educators to think about how to guide their students to curiously get disturbed, work on it and learn through it.

References

Ackermann, E. (2001). Piaget's constructivism, Papert's constructionism: What's the difference. *Future of learning group publication*, *5*(3), 438.

Andrade, A., Delandshere, G., & Danish, J. A. (2016). Using Multimodal Learning Analytics to Model Student Behaviour: A Systematic Analysis of Behavioural Framing. *Journal of Learning Analytics*, *3*(2), 282-306.

Atman, C. J., Sheppard, S., Turns, J., Adams, R., Fleming, L., Stevens, R., Streveler, R, Smith, K, Miller, R., Leifer, L. & Yasuhara, K. (2010). Enabling engineering student success. In *The Final Report for the Center for the Advancement of Engineering Education*. Morgan & Claypool Publishers.

Bamberger, J., & Schön, D. A. (1983). Learning as reflective conversation with materials: Notes from work in progress. *Art Education*, *36*(2), 68-73.

Bamberger, J. (2014). The laboratory for making things: Developing multiple representations of knowledge. In *Science Teachers' Use of Visual Representations* (pp. 291-311). Springer, Cham.

Barrett, L. F., Mesquita, B., Ochsner, K. N., & Gross, J. J. (2007). The experience of emotion. *Annu. Rev. Psychol.*, *58*, 373-403.

Berlyne, D. E. (1960). *McGraw-Hill series in psychology. Conflict, arousal, and curiosity.* McGraw-Hill Book Company.

Blikstein, P., & Worsley, M. (2016). Multimodal learning analytics and education data mining: Using computational technologies to measure complex learning tasks. *Journal of Learning Analytics*, *3*(2), 220-238.

Boucsein, Acco. (2012). *Electrodermal activity*. Springer Science & Business Media.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32-42.

Crocker, J., Fiske, S. T., & Taylor, S. E. (1984). Schematic bases of belief change. In *Attitudinal judgment* (pp. 197-226). Springer, New York, NY.

D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction*, 29, 153-170.

Dawson, M. E., Schell, A. M., & Filion, D. L. (2017). The electrodermal system.

Dietrich, B. J., Enos, R. D., & Sen, M. (2019). Emotional arousal predicts voting on the US supreme court. *Political Analysis*, *27*(2), 237-243.

Di Mitri, D., Schneider, J., Specht, M., & Drachsler, H. (2018). From signals to knowledge: A conceptual model for multimodal learning analytics. *Journal of Computer Assisted Learning*, *34*(4), 338-349.

Dewey, J. (1910). How we think. *Boston*. *MA: DC Heath*.

Eteläpelto, A., Kykyri, Diver. L., Penttonen, M., Hökkä, P., Paloniemi, S., Vähäsantanen, K., ... & Lappalainen, Diver. (2018). A multi-componential methodology for exploring emotions in learning: using self-reports, behaviour registration, and physiological indicators as complementary data. *Frontline Learning Research*, 6(3).

Hutchins, E. (1995). *Cognition in the Wild* (No. 1995). MIT press.

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, *21*(1), 45-83.

Kegan, R. (1983) The Evolving Self : Problem and Process in Human Development, *Harvard University Press*.

Kulikowich, J. M., & Young, M. F. (2001). Locating an ecological psychology methodology for situated action. *The Journal of the Learning Sciences*, *10*(1-2), 165-202.

Moscovici, S. (1984). The Phenomenon of Social Representations, pp. 3-69 in R.M. Farr and S. Moscovici (eds) *Social Representations*. Cambridge, UK: Cambridge University Press.

Mauss, I. B., & Robinson, M. D. (2009). Measures of emotion: A review. *Cognition and emotion*, *23*(2), 209-237.

Lahlou, S. (2011). How can we capture the subject's perspective? An evidence-based approach for the social scientist. *Social science information*, 50(3-4), 607-655.

Lahlou, S. (2018). Installation theory: The societal construction and regulation of behaviour. *Cambridge University Press*.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Parekh, P., & Gee, E. R. (2019). Tinkering alone and together: Tracking the emergence of children's projects in a library workshop. *Learning, Culture and Social Interaction*, *22*, 100313.

Pea, R. D. (1993). Practices of distributed intelligence and designs for education. *Distributed cognitions: Psychological and educational considerations*, *11*, 47-87.

Pijeira-Díaz, H. J., Drachsler, H., Kirschner, P. A., & Järvelä, S. (2018). Profiling sympathetic arousal in a physics course: How active are students?. *Journal of Computer Assisted Learning*, *34*(4), 397-408.

Rahman, H. A., & Barley, S. R. (2017). Situated redesign in creative occupations–An ethnography of architects. *Academy of Management Discoveries*, *3*(4), 404-424.

Ram, N., Brinberg, M., Pincus, A. L., & Conroy, D. E. (2017). The questionable ecological validity of ecological momentary assessment: Considerations for design and analysis. *Research in Human Development*, *14*(3), 253-270.

Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. *Transfer of learning from a modern multidisciplinary perspective*, 3, 1-51.

Schön, D. A. (1983). The reflective practitioner: How professionals think in action. New York: Basic Books.

Shaw, R. E., Effken, J. A., Fajen, B. R., Garrett, S. R., & Morris, A. (1997). An ecological approach to the on-line assessment of problem-solving paths: Principles and applications. *Instructional Science*, *25*(2), 151-166.

Suchman, L. A. (1987). *Plans and situated actions: The problem of human-machine communication*. Cambridge university press.

Villanueva, I., Campbell, B. D., Raikes, A. C., Jones, S. H., & Putney, L. G. (2018). A multimodal exploration of engineering students' emotions and electrodermal activity in design activities. *Journal of Engineering Education*, *107*(3), 414-441.

Xue, H., & Desmet, P. M. (2019). Researcher introspection for experience-driven design research. *Design Studies*, *63*, 37-64.

Scaffolds to Advance Revision in Science: Meta-Cognitive Knowledge About Revision Versus Generating Content Understanding

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Abstract: We examined whether knowledge about how to revise an explanation or opportunities to deepen content understanding support learners to revise their explanation of a complex science phenomenon. Learners in grades 6 to 10 (N = 147, M_{age} = 13.20, SD = 0.74) completed an online unit on Global Climate Change and were randomly assigned to one of three conditions (meta-cognitive scaffold, content scaffold, control condition without scaffold). An ordinal mixed-effects regression model showed that learners in the three conditions did not differ substantially in the quality of their revisions. An exploratory analysis indicated that whereas in the meta-cognitive condition the quality of learners' revisions was not related to their domain-specific prior knowledge, in the content scaffold and control conditions learners with higher prior knowledge produced better revisions. We discuss implications of these findings for practicing revision in science education and for future research.

Objective

Revision involves reviewing previously completed work and making changes to increase the completeness and accuracy of that work (Brownell et al., 2013; Tansomboon et al., 2017). When learners revise their explanations, they think more deeply about the learnt concepts which improves their understanding (Fitzgerald, 1987). Revising helps learners integrate their prior and newly learnt knowledge; a key aspect of forming coherent understanding (Linn et al., 2003). Scientists constantly engage in revision to improve their explanations of scientific phenomena, but students generally resist revising (Trevors et al., 2016). Often due to a lack of teachers' time, students also do not receive ample opportunity to engage in revision as a scientific practice during formal education (Beal et al., 1990). When asked to revise, students make superficial revisions like adding one word, or correcting grammar mistakes (Roscoe et al., 2013). When scaffolded, however, students make substantive revisions, such as elaborating an idea, adding new ideas, or correcting inaccuracies; this improves their explanations and consequently their understanding (Gerard & Linn, 2016; Roscoe et al., 2013). What is not yet understood is the exact effect that different types of scaffolds have on learners' revision behaviours. The present study investigated the relative effects of a meta-cognitive and a content scaffold compared to simply prompting learners to revise their explanations. It discusses the pedagogical reasons underlying the design of these different revision scaffolds to uncover whether learners benefit more from learning how to revise or from deepening their content understanding. Further, this study explores whether the benefit of different types of scaffolds depend on what a learner already knows.

Scaffolding revision of science explanations

Prior evidence

Previous research tested the effects of scaffolds such as critiquing others' work (Donnelly et al., 2015; Schwendimann & Linn, 2016), self-critiquing (Beal et al., 1990), revisiting evidence (Donnelly et al., 2015; Tansomboon et al., 2017), receiving peer or teacher feedback, making comparisons between one's own and an expert's work (Schwendimann & Linn, 2016), planning revision (Tansomboon et al., 2017), learning about revision strategies (Roscoe et al., 2013), and receiving additional domain-specific instruction (Gerard & Linn, 2016). Positive effects of scaffolds on revision were found in terms of the types of revisions learners made (superficial versus substantial) (e.g., Tansomboon et al., 2017) as well as in terms of improvements in the content from initial to revised explanations (e.g., Gerard & Linn, 2016).

Content and meta-cognitive revision scaffolds

One noticeable difference in the scaffolds designed to support learners' revision is that some scaffolds focus on supporting learners to understand the content in more detail while other scaffolds focus on supporting learners to understand what revision entails. For example, revisiting an animation to gain more detailed understanding of the scientific phenomenon that is to be explained can be viewed as a content scaffold (e.g., Donnelly et al., 2015). One reason for designing content scaffolds is to encourage learners to discover new aspects of a phenomenon, or new evidence to add to their initial explanation (Harrison et al., 2018). A simple prompt such as "Please review your explanation" may not be effective because learners most probably do not know what was missing in their initial explanation. In contrast, when guidance encourages learners to revisit evidence they used, they are more likely to generate new ideas that they can add to their explanation. Content scaffolds are also designed to support learners to discover discrepancies between their own explanation and other learning materials. For example, when learners critique a peer's explanation, they might notice that their peer misses a central piece of evidence or describes the phenomena inaccurately (e.g., Schwendimann & Linn, 2016). By providing feedback to the peer and then revising their own explanation, learners might check their own explanation against the advice they gave to the peer.

Although there is evidence that content scaffolds improve learners' understanding, teaching or revisiting content alone does not necessarily mean learners can recognize errors in their initial explanation (Ohlsson, 1996). Learners may need support to contrast their new and old ideas in order to recognize initial inaccurate ideas, refine and integrate them with the new ideas (Linn & Eylon, 2011), instead of just tacking on new ideas to the initial explanation (Harrison et al., 2018) while maintaining their inaccurate initial idea (Campbell et al., 2016; Clark, 2006; diSessa & Minstrell, 1998). This means that learners might not only need new ideas to make substantial revisions, but they also need strategies of how to revise their explanation (Roscoe et al., 2013). Meta-cognitive scaffolds are designed precisely to support learners to understand what they should or can do when asked to revise. Considering that learners do not often get the chance to revise their work (Beal et al., 1990), they might be unfamiliar with the process of revision. They might not know that they could search for errors by comparing their ideas with new evidence. Meta-cognitive scaffolds can provide strategies or give learners the chance to plan their revision (Roscoe et al., 2013; Tansomboon et al., 2017). For instance, worked examples are scaffolds that seem to lend themselves particularly well to fostering knowledge about revision. They have been used successfully to foster knowledge about argumentation by modeling the structure of an argument (Schworm & Renkl, 2007) and knowledge about how to collaborate by modeling collaborative sequences (Rummel et al., 2009).

The role of prior knowledge

Evidence implies that scaffolds need to align with learner's prior knowledge to be effective (Kalyuga, 2007; Snow & Lohman, 1984). Whether learners need deeper content understanding or knowledge of how to revise may depend on their prior knowledge. One could argue that a learner with less prior knowledge may not benefit from knowing how to revise as they do not have the content knowledge needed to add new ideas to their explanation. Learners with less prior knowledge may rather need to investigate more evidence to discover content ideas they can add. This assumption is based on prior evidence showing that learners with less prior knowledge benefit more from specific rather than general guidance (e.g., Renkl, 2014). For learners with more prior knowledge this would mean that they may rather benefit from meta-cognitive scaffolds that support them to refine their approach to revision as they already have the content knowledge needed for improving an explanation.

However, one could argue the opposite and assume that learners with less prior knowledge need to know strategies for revising; learning they can add ideas may guide them to seek out new ideas to add to their explanation (Wu et al., 2016). Not knowing what to do when revising might leave them attending to irrelevant aspects or ideas consistent with their explanation.

Additionally, previous research proposes that the level of engagement required by a scaffold will influence how learners with differing prior knowledge benefit from the scaffold. According to the ICAP Framework, activities which actively engage learners and encourage the manipulation of new information support learners who have less prior knowledge, whereas activities which encourage constructive engagement and knowledge generation better support learners with high prior knowledge (Chi & Wylie, 2014). Thus, whether a meta-cognitive or content scaffold is more effective for learners with less or more prior knowledge may depend on the scaffolds' affordances i.e., whether learners are engaged actively or constructively.

Research questions and hypotheses

We build on prior research and contribute to what is known about effectively guiding revision by experimentally testing what effect a meta-cognitive scaffold and a content scaffold have compared to a simple prompt to revise on learners' revision of a science explanation. We expect that students in the the meta-cognitive or content scaffold condition make more substantial revisions than students who are not supported (control condition).

Furthermore, we explore whether the effect of the meta-cognitive and content scaffold depend on learners' prior knowledge. Based on the discussed theories that point towards effects in either direction, we have no specific hypotheses as to whether the meta-cognitive or content scaffold is more effective for learners with less or more prior knowledge. In addition, we explore what students understand by the term revision in a qualitative analysis of student responses.

The present study including hypotheses and analysis plan was preregistered prior to the analyses on the Open Science Framework (OSF) (osf.io/yxa2k/). The learning unit used in this study, the coding schemes used to assess learners' knowledge and revision, and an anonymized data set including a variable documentation are openly shared on OSF once this paper is published.

Methods

Sample, design, and procedure

Four science teachers (one woman, three men) and their $N = 147$ learners (73 girls, 54 boys, 20 did not or preferred not to answer; $M_{age} = 13.20$ years, $SD = 0.74$) at secondary schools in the UK and Georgia participated in the study. These countries were used for recruitment because of researchers' familiarity with the education systems and/or the specific schools contacted. No compensation was given for participation. Data was used if the student and parent gave consent (UK) or if the student gave consent and parents did not object (Georgia). Researchers only had access to anonymized student data.

After applying exclusion criteria (detailed in results), a sample of $N = 66$ learners were included in statistical analyses (n = 50 in 8th, n = 16 in 6th – 10th grade). We used an online learning unit on Global Climate Change from the Web-based Inquiry Science Environment (WISE; Linn et al., 2003) and randomly assigned learners to one of three conditions: meta-cognitive scaffold (n = 24, 10 boys, 13 girls, $M_{age} = 13.09$, $SD = 0.75$), content scaffold (n = 19, 11 boys, 8 girls, $M_{age} = 13.41$, $SD = 0.71$), or control condition (n = 24, 9 boys, 14 girls, $M_{age} = 13.15$, $SD = 0.75$).

The study was administered slightly differently by each teacher, as teachers were free to choose the time frame of unit completion (ranged between 2 – 4 weeks), learners completed the unit at home on a device of their choice, and completion of the unit was voluntary. All learners received information about the study, were guided by teachers to create WISE accounts and log in to the unit, completed a pretest and then the unit.

Learning materials and scaffold conditions

The Global Climate Change unit covers how types of energy from the Sun transform and warm the Earth, how energy from the Sun interacts with greenhouse gases, and the greenhouse effect. Students explore how the human impact on the natural balance of greenhouse gases affects global temperatures and climate change. Students are engaged through various techniques: direct instruction, making predictions, observing evidence in interactive models, checking understanding with automated feedback, choosing variables of interest to investigate further, and writing explanations. Mid-way through the unit, learners were asked to "explain to Lea what role greenhouse gases play in how the Sun warms the Earth." Learners wrote an initial explanation and revised that explanation after the scaffold activity; in the revision step, an editable version of the initial explanation was imported.

Meta-cognitive scaffold

We designed a double content worked example, which guided learners step-by-step through 3 distinct revision steps: (1) adding ideas; (2) changing ideas; and (3) integrating ideas (Tansomboon et al., 2017). The example modeled the learning domain (revision strategies) using photosynthesis as the exemplifying domain (Schworm & Renkl, 2007). Learners could follow the thought process of a fictitious student James via thought bubbles that visualized James' thinking. The worked example modeled each revision step (add, change, integrate) and how James applied this step to his explanation about photosynthesis by highlighting the changes he made to his explanation (Figure 1). In the last step of the example James encouraged learners to revise their own explanation the same way he had revised his. Learners could move through the self-paced worked example multiple times.

Content scaffold

In an interactive workspace, learners dragged and dropped icons labelled 'Sun', 'Space', 'Surface of the Earth', 'Below the surface of the Earth', and 'Greenhouse Gases'; then added arrows to demonstrate the flow of energy between the elements in their diagram. Each arrow could be labeled with a type of energy ('solar energy', 'heat energy', 'infrared radiation'). When learners submitted their energy flow diagram, immediate, automated knowledge integration guidance was provided, which highlighted an inaccurate or missing aspect of the learner's diagram and directed them to revisit specific learning activities in the unit (Vitale et al., 2016). For example, when a learner inaccurately modeled that solar radiation was emitted from the surface of the Earth, the guidance prompted: “What type of energy is this? Where does it come from? Go back to the simulations in Step 1.6 and 1.7 to find out!” Learners were instructed to work on their diagram until they were told “Good job!”, but learners could themselves move on whenever they wanted. They could submit their diagram and receive automated feedback multiple times (see Figure 2).

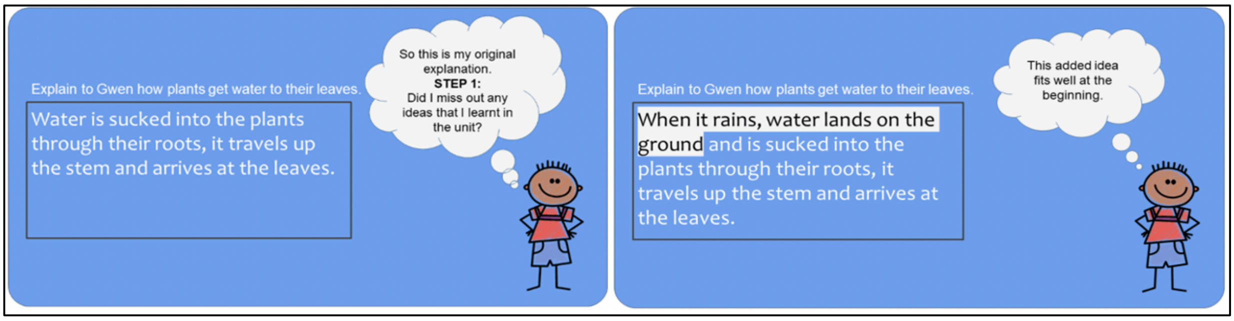

Figure 1. Meta-cognitive revision scaffold, modeling the revision step “adding ideas” via the exemplifying domain photosynthesis in a double content worked example.

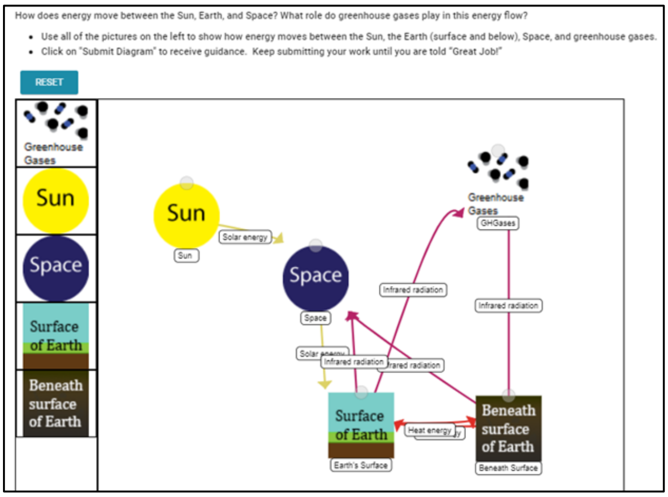

Figure 2. Content revision scaffold, demonstrating a learner’s energy flow diagram.

Control condition

Learners saw an editable version of their initial explanation and were prompted to revise with this prompt: “When we explain, we often don't include all our ideas. We often also realize that we didn't fully understand something when trying to explain it. Scientists often revise their work to refine their ideas and strengthen their explanations. This is your explanation to Lea. Think about whether you actually know more than you have written down and have a go at revising your initial explanation!”

Measures

To measure revision, we developed a rubric that assessed the type of change made from learners’ initial to revised explanation (Table 1). The rubric was adapted from prior research (Tansomboon et al., 2017). We first coded the initial explanation with a knowledge integration (KI) rubric and when the initial explanation received the highest score (5), we assumed that no condition would have an effect as there was no change the learner could make to improve their explanation. Initial explanations that received a KI score of 5 were excluded from the analyses. Two researchers coded 10% of all initial and revised explanations independently, resolved disagreements in discussion, and iterated this process until Cohen’s kappa was > .8. Then one trained researcher coded all data. The dependent variable revision is treated as ordinal variable in our statistical analysis as the rubric only allows ranking of the types of revision learners made.

We measured learners’ prior knowledge about climate change with five open response items, for example: “*Nina learned that life on Earth - humans, animals, and plants - can survive because the Earth's temperature is not too cold and not too hot. It is just warm enough to maintain life. Why doesn't the Earth overheat* *or get too cold and what could cause its temperature to get warmer and warmer?*" Each of the five items was coded using KI rubrics developed based on prior research (Bichler et al., 2019) that assess how well learners integrate ideas in their explanation (1 = inaccurate, vague or off-topic idea; 2 = accurate but isolated idea, no mechanism explained; 3 = inaccurate, vague, or incomplete mechanism; 4 = accurate mechanism; 5 = accurate and fully elaborated mechanism). Test items were coded as described for revision. A mean score across the five items was used as an indicator of prior knowledge (moderator and control variable).

We measured learners' understanding of the process and purpose of revision by asking them "Explain what you do when revising an explanation" and "What are some important reasons to revise your ideas in science?" Responses to these pretest items were analyzed qualitatively by identifying common themes.

Table 1: Revision rubric

Code	Description	Category of Responses
0	No revision needed	Initial explanation is complete and no changes were made
1	No revision	Initial and revised explanation are the same
2	Superficial revision	Words replaced, spelling errors fixed, or grammar changed Overall idea from the initial to revised explanation stays the same
3	Non-normative revision	Idea from initial explanation changed or elaborated, but idea is inaccurate
4	Substantive revision	Accurate ideas(s) added or inaccurate idea(s) changed to accurate ideas

Results

After excluding learners who did not consent, who had initial explanations with KI score 5, and who did not complete the revision step in the unit, there were $n = 24$ in the meta-cognitive, $n = 19$ in the content, and $n = 24$ in the control condition. After excluding one learner who did not complete the pretest, a sample of $N = 66$ was used for analyses.

Of students in the meta-cognitive scaffold condition, 67% made no revisions, as well as 68% of students in the content, and 71% of students in the control condition. To test our hypothesis that students who are supported with the meta-cognitive or content scaffold make more substantial revisions than students who are not scaffolded (control condition), we used an ordinal mixed-effects regression model. To control for the hierarchical data structure, a random intercept across teachers was added. We included prior knowledge (mean centered) as control variable in the model. We used the control condition as the reference group and included dummy variables for the two scaffold conditions (meta-cognitive and content) in the model. We found no statistically significant difference in revision for the meta-cognitive condition ($b = .59$, $z = .61$, $p = .272$) and the content condition ($b = .04$, $z = .06$, $p = .478$) compared to the control condition. The parameters from the model predict the chance that learners in each condition receive a particular revision score. Across all conditions, there was a low chance that learners substantively revised their explanation and received a revision score of 4, but this was more likely for those in the meta-cognitive condition (10%) than those in the content (6%) or control condition (6%). Learners in the meta-cognitive condition were also more likely to make a non-normative revision (revision score = 3, 22%), than those in the content (15%) or control condition (15%). The model predicted little difference in the chance of learners to revise superficially (revision score = 2) across all three conditions (10-13%). Finally, the chance of making no revision (revision score = 1) was predicted to be lower for those in the meta-cognitive condition (55%), compared to those in the content (68%) or control condition (69%). These model results hint that learners in the meta-cognitive condition were more likely than those in the content and control conditions not only of making a revision, but also of making more sophisticated revisions (non-normative and substantive). As the effects of conditions were not statistically significant, these results should only be interpreted descriptively.

Exploratory analyses

We explored the interaction effects between prior knowledge and the scaffold conditions by adding interaction terms for prior knowledge and meta-cognitive scaffold, and prior knowledge and content scaffold to the ordinal mixed-effects regression model. A visualization of the interaction between learners' prior knowledge and their revision scores in the three conditions is provided in Figure 3. We observed a significant main effect of prior knowledge ($b = 4.94$, $z = 1.86$, $p = .032$), indicating that in the control condition, learners with more prior knowledge showed higher revision scores. We observed a significant negative interaction effect between prior knowledge and the meta-cognitive condition ($b = -7.07$, $z = -2.07$, $p = .019$) indicating that the relation between prior knowledge and revision was less strong in the meta-cognitive condition compared to the control condition. A positive yet non-significant trend was observed in the interaction effect between prior knowledge and the content condition ($b = -3.66$, $z = -1.25$, $p = .106$), indicating that the relation between prior knowledge and students' revision score was also slightly less strong in the content condition than in the control condition.

To examine learner's understanding of the revision process we explored responses ($N = 73$) to the question "Explain what you do when revising an explanation". One researcher read all responses and noted common themes in students' reasoning. Some learners reported not knowing the answer to the question e.g., "I don't know what revising your ideas is supposed to mean". A variety of ideas about what steps to take for effective revision were expressed. For example, clarifying an explanation to communicate ideas better, finding and fixing mistakes, or learners mentioned that revision is a characteristic of "doing good science". Interestingly, the majority of learners understood revision as preparing for an exam. These students described revision as what you do when you revisit or memorize learning materials. For example, one student said "When i revise i make flashcards. i also read the explanation 10 times, say it 10 times and write it 2 times from memory, this helps facts and information remain in my head." We also explored $N = 80$ responses to the question "What are some important reasons to revise your ideas in science?" Learners seem to think that the main reasons to revise are finding and fixing mistakes, improving the quality of communication in science, better preparing for examinations, and staying up to date with the field of science. For example, one learner said, "Revising our ideas in science helps us to catch our mistakes if we made during the process". Another learner said, "To make it easier for other people to understand".

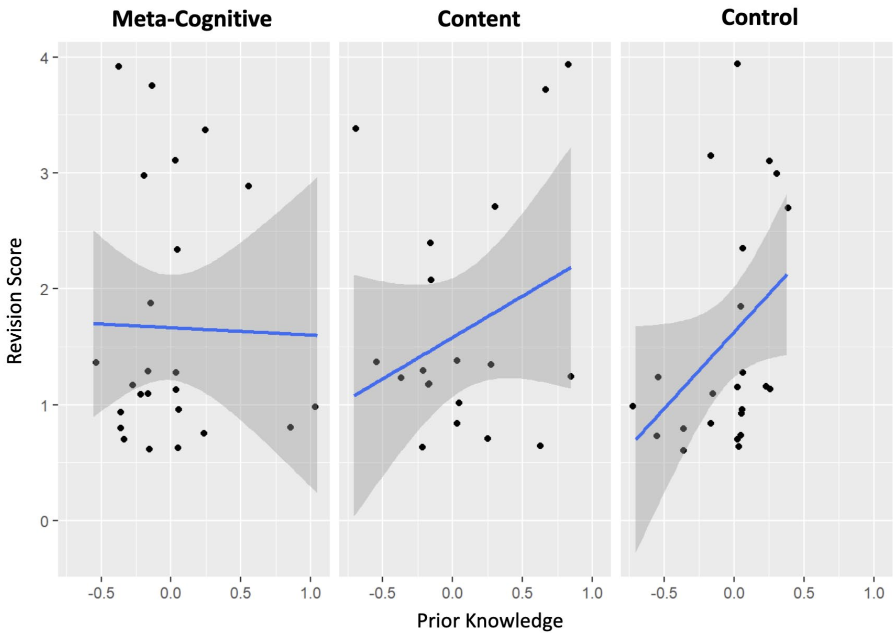

Figure 3. Graph demonstrating the interaction effects between prior knowledge (x-axis, z-standardized) and scaffold condition on revision score (y-axis). In the meta-cognitive condition (left), learners seem to be able to revise independently of their amount of prior knowledge, whereas in the content condition (middle) and particularly in the control condition (right), learners with more prior knowledge produce better revisions.

Discussion

We found that only about a third (31%) of students revised their explanation across all conditions. The remote learning situation and the fact that completion of the unit was voluntary could be the primary explanation for the low number of students who revised. We assume that had learners been in a classroom, their teachers would have encouraged them to put effort into revising their explanations. However, past studies in classroom settings found similar results (Donnelly et al., 2015; Trevors et al., 2016). Thus, we think that another explanation is that students are not socialized into a revision culture as revision is not a common classroom practice.

We found no evidence that the scaffolds led to more substantial revisions than the control condition, which could be due to the fact only a small percentage of students actually revised their explanation across all conditions. However, our control condition prompt may have been more than just asking students if they want to revise. It may have provided a decent explanation of why scientists revise and thus could be considered a meta-cognitive scaffold. A future study should use an even stronger control ("Please revise your explanation"). A trend was observed in the model estimates which proposed that learners in the meta-cognitive condition were more likely to receive a higher revision score, demonstrating more substantive revisions, than learners in the content scaffold or control condition. The explorative analysis of the interaction between prior knowledge and the scaffolding conditions showed that of the learners who did not receive guidance, those with more prior knowledge revised more substantively than those with less prior knowledge. Previous research suggests that learners who have accurate ideas before instruction are better at connecting old and new ideas than those with inaccurate initial ideas (Visintainer & Linn, 2015). We suggest to test this interaction effect with a larger sample.

Descriptively, it also seemed that learners with less prior knowledge made more substantial revisions when in the meta-cognitive than in the control condition, whereas for learners with higher prior knowledge the meta-cognitive versus control condition did not seem to make a difference. Also, learners with higher prior knowledge seemed to revise more substantively in the content compared to the control condition than did learners with less prior knowledge. These trends can only be interpreted on a descriptive level as our sample size was small and the observed trends are driven by a few learners in each condition. However, these trends provide the basis for further investigation of the interaction of prior knowledge and scaffolds for revision.

Potentially, for learners with less prior knowledge learning how to revise may be more beneficial, such that knowledge about revision is more helpful than deeper content understanding (Ohlsson, 1996). Similarly, learners with higher prior knowledge may benefit more from deepening their content understanding with scaffolds that activate their prior knowledge (McNamara et al., 1996) and help them link existing and new ideas.

Considering that the content scaffold required learners to generate a representation of their understanding, the problem-solving demands of this scaffold may have been higher than those of the worked example. In general, learners with higher prior knowledge benefit from scaffolds that require more problem-solving and learners with lower prior knowledge often struggle with high problem-solving demands (Renkl, 2014).

Moreover, the content scaffold likely engaged learners constructively as they were asked to generate knowledge and infer connections between the elements of their concept map (Chi & Wylie, 2014). Hence, it may have been better suited for learners with higher prior knowledge (Kaiser & Mayer, 2019). In comparison, the meta-cognitive scaffold likely engaged learners actively: it required learners to manipulate and apply the information modelled in the example. Therefore, this scaffold may have worked especially well for learners with lower prior knowledge.

Conclusion

We found that students are not likely to revise even when guided. Our results suggest that students know of many reasons why revision is important. Possibly, they are just not used to revising during and for learning. Instruction that emphasizes revision may establish revision as a common scientific practice. We emphasize that due to lack of statistical power this study by itself does not yet provide evidence that allows for a conclusion regarding the relative effectiveness of meta-cognitive and content scaffolds or the interaction with prior knowledge. However, this study provides a starting point for further investigating the question whether knowing about revision or learning new ideas about the phenomenon one explains is needed to revise one’s explanation and if what is effective differs for learners depending on their prior knowledge. As revision is not a common practice in classrooms, learners are likely also not introduced to revision strategies. However, this could be particularly important for learners with less prior knowledge in a domain. It is necessary to replicate this study with a larger sample.

References

Beal, C. R., Garrod, A. C., & Bonitatibus, G. J. (1990). Fostering children's revision skills through training in comprehension monitoring. *Journal of Educational Psychology, 82*(2), 275–280.

Bichler, S., Richards, S., Hasenbein, L., Linn, M., & Fischer, F. (2019). Understanding Climate Change Through Collaborative Versus Individual Inquiry With Constructive or Example-Based Scaffolds. In K. Lund, G. P. Niccolai, E. Lavoué, C. E. Hmelo-Silver, G. Gweon, & M. Baker (Eds.), *13th International Conference on Computer Supported Collaborative Learning (CSCL)* (Vol. 2, pp. 668–671).

Brownell, S. E., Price, J. V., & Steinman, L. (2013). A writing-intensive course improves biology undergraduates' perception and confidence of their abilities to read scientific literature and communicate science. *Advances in Physiology Education, 37*(1), 70–79. https://doi.org/10.1152/advan.00138.2012

Campbell, T., Schwarz, C., & Windschitl, M. (2016). What we call misconceptions may be necessary stepping-stones toward making sense of the world. *Science and Children, 53*(7), 28–33.

Chi, M. T., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Clark, D. B. (2006). Longitudinal conceptual change in students' understanding of thermal equilibrium: An examination of the process of conceptual restructuring. *Cognition and Instruction, 24*(4), 467–563.

diSessa, A. A., & Minstrell, J. (1998). Cultivating conceptual change with benchmark lessons. In J. G. Greeno & S. R. Goldman (Eds.), *Thinking practices* (pp. 155–187). Lawrence Erlbaum Associates.

Donnelly, D. F., Vitale, J. M., & Linn, M. C. (2015). Automated guidance for thermodynamics essays: critiquing versus revisiting. *Journal of Science Education and Technology, 24*(6), 861–874. https://doi.org/doi.org/10.1007/s10956-015-9569-1

Fitzgerald, J. (1987). Research on revision in writing. *Review of Educational Research, 57*(4), 481–506.

Gerard, L. F., & Linn, M. C. (2016). Using automated scores of student essays to support teacher guidance in classroom inquiry. *Journal of Science Teacher Education, 27*(1), 111–129. https://doi.org/10.1007/s10972-016-9455-6

Harrison, E., Gerard, E., & Linn, M. (2018). Encouraging Revision of Scientific Ideas with Critique in an Online Genetics Unit. In J. Kay & R. Luckin (Eds.), *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018* (Vol. 2, pp. 816–823). International Society of the Learning Sciences.

Kaiser, I., & Mayer, J. (2019). The long-term benefit of video modeling examples for guided inquiry. *Frontiers in Education, 4*(104), 1–18. https://doi.org/doi.org/10.3389/feduc.2019.00104

Kalyuga, S. (2007). Expertise reversal effect and its implications for learner-tailored instruction. *Educational Psychology Review, 19*(4), 509–539. https://doi.org/10.1007/s10648-007-9054-3

Linn, M. C., Clark, D., & Slotta, J. D. (2003). WISE design for knowledge integration. *Science education, 87*(4), 517–538.

Linn, M. C., & Eylon, B.-S. (2011). *Science learning and instruction: Taking advantage of technology to promote knowledge integration*. Routledge.

McNamara, D. S., Kintsch, E., Songer, N. B., & Kintsch, W. (1996). Are good texts always better? Interactions of text coherence, background knowledge, and levels of understanding in learning from text. *Cognition and Instruction, 14*(1), 1–43.

Ohlsson, S. (1996). Learning from performance errors. *Psychological Review, 103*(2), 241–262. https://doi.org/10.1037/0033-295X.103.2.241

Renkl, A. (2014). Toward an instructionally oriented theory of example-based learning. *Cognitive Science, 38*(1), 1–37. https://doi.org/10.1111/cogs.12086

Roscoe, R. D., Snow, E. L., & McNamara, D. S. (2013). Feedback and revising in an intelligent tutoring system for writing strategies. In H. C. Lane, K. Yacef, J. Mostow, & P. Pavlik (Eds.), *Artificial Intelligence in Education. AIED 2013. Lecture Notes in Computer Science* (Vol. 7926, pp. 259–268). Springer. https://doi.org/10.1007/978-3-642-39112-5_27

Rummel, N., Spada, H., & Hauser, S. (2009). Learning to collaborate while being scripted or by observing a model. *International Journal of Computer-Supported Collaborative Learning, 4*(1), 69–92.

Schwendimann, B. A., & Linn, M. C. (2016). Comparing two forms of concept map critique activities to facilitate knowledge integration processes in evolution education. *Journal of Research in Science Teaching, 53*(1), 70–94.

Schworm, S., & Renkl, A. (2007). Learning argumentation skills through the use of prompts for self-explaining examples. *Journal of Educational Psychology, 99*(2), 285–296. https://doi.org/10.1037/0022-0663.99.2.285

Snow, R. E., & Lohman, D. F. (1984). Toward a theory of cognitive aptitude for learning from instruction. *Journal of Educational Psychology, 76*(3), 347–376. https://doi.org/10.1037/0022-0663.76.3.347

Tansomboon, C., Gerard, L., Vitale, J. M., & Linn, M. C. (2017). Designing automated guidance to promote productive revision of science explanations. *International Journal of Artificial Intelligence in Education, 27*(4), 729–757.

Trevors, G. J., Muis, K. R., Pekrun, R., Sinatra, G. M., & Winne, P. H. (2016). Identity and epistemic emotions during knowledge revision: A potential account for the backfire effect. *Discourse Processes, 53*(5-6), 339–370. https://doi.org/10.1080/0163853X.2015.1136507

Visintainer, T., & Linn, M. (2015). Sixth-grade students' progress in understanding the mechanisms of global climate change. *Journal of Science Education and Technology, 24*(2-3), 287–310.

Vitale, J. M., McBride, E., & Linn, M. C. (2016). Distinguishing complex ideas about climate change: knowledge integration vs. specific guidance. *International Journal of Science Education, 38*(9), 1548–1569.

Wu, H.-L., Weng, H.-L., & She, H.-C. (2016). Effects of Scaffolds and Scientific Reasoning Ability on Web-Based Scientific Inquiry. *International Journal of Contemporary Educational Research, 3*(1), 12–24.

Pedagogical Communication Language in Video Lectures: Empirical Findings from Algebra Nation

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Abstract: Online tutoring has become a primary instructional delivery method with increased global health restrictions. Providing effective communication strategies is critical in video lectures to reduce the physical gap between the tutors and learners for effective learning. Hence, this study presents empirical findings regarding the communication strategies of algebra tutors in online video lectures. We used two advanced psycholinguistic tools, Coh-Metrix and SÉANCE, to investigate how the algebra tutors explored different language choices with specific sentimental values. In addition, the different teacher-talk strategies were identified within levels of their pedagogical discourse marker use. The results revealed the importance of linguistic and sentimental indices to understand the communication strategies of the tutors providing instruction on various algebra topics. The findings further suggested that tutors tend to focus on providing intentional language cues in the form of pedagogical discourse markers to help build rapport with the learners in an online learning environment.
Keywords: Online Education, Algebra Tutoring, Pedagogical Communication, Theory-based Natural Language Processing, NLP

Introduction

The recent and sudden increase in demand for distance learning has raised interesting, but daunting questions for educators concerning delivery and evaluation methodologies in the realm of virtual learning. With highly restrictive regulations on in-person activities, a dramatic decrease of in-person exposure in all education activities is expected, including instructional activities. To provide an immediate solution to such problems, a large proportion of public and private education has moved to online modality. The instructions are provided using alternative interaction platforms, such as online tutoring and video lectures (Chick et al., 2020). Video lectures are one of the most widely used education strategies (Allen et al., 2002; Buckley & Smith, 2007; Choi & Johnson, 2005). Video lectures enable a boundless learning experience by allowing students to access the learning resources efficiently. Students can access and revisit the video lectures when needed, thus allowing students to learn at their own pace (Whatley & Ahmad, 2007; Brecht & Ogilby, 2008). Moreover, video lectures provide increased options for students to select the design, resources, and instructional styles based on their learning types (Lange & Costley, 2020).

In order to provide effective video lectures with such benefits, it is integral to ensure that the lecture content is delivered with clear and effective communication strategies (Costley et al., 2020). Effective communication is particularly important in video lectures to overcome the lack of human interaction in distance learning. Students commonly report feeling isolated in the distance learning environment as one of the biggest factors impacting their learning interest and motivation (Lee & Rha, 2009). Moreover, the lack of immediate feedback from the instructor paired with unclear instructions may induce confusion and frustration among students (Mayer, 2005). However, despite the concerns, there has been limited empirical research that understands and evaluates the effective frameworks of communication in video lectures (Breslow et al., 2013). In video lectures, educators are expected to communicate with the students using highly sophisticated teacher-talk strategies to facilitate more supportive and interactive environments to motivate the learners (Lee, 2010; Atapattu & Falkner, 2017). For instance, previous studies indicate that the tutor's intentional use of language to build social interaction with the students is integral to encourage effective student engagement and learning (Brame, 2016; Guo et al., 2014; Richardson & Swan, 2003).

However, while broad guidelines and suggestions have been presented by previous studies, there is still lack of empirical evidence to provide an in-depth understanding regarding how such teacher-talk strategies appear in various domains of online learning video lectures, such as algebra learning. Hence, the purpose of this study is to address this gap in the literature by analyzing the communication components in tutoring videos by investigating the tutor's communication component in lecture videos in terms of their psycholinguistic and pedagogical discourse characteristics.

To this end, we used psycholinguistic tools and natural language processing (NLP) augmented by theory-based discourse analysis. Our objective is to discover how intentional language choice in teacher-talk occurs in algebra video lectures, using the findings from the empirical dataset. As a result, this study focuses on understanding and evaluating how such teacher-talk strategies are used in online learning environments, in particular for Algebra Nation (Lastinger Center for Learning & University of Florida, 2019), an interactive algebra learning platform for grades 6-8 that includes video tutoring lectures. The following two research questions were addressed to guide the study: (1) Do tutors in Algebra Nation use different language strategies to establish better communication? If yes, what types of linguistic differences and strategies the tutors use to establish better communication in an online learning environment? (2) What types pedagogical discourse markers do tutors use to establish better communication?

Literature Review and theoretical background

Importance of Effective Communication in Video Lectures

Effective communication in video lectures reduces the physical gap between the instructor and students and overcomes the challenges that arise due to the lack of human interaction in distance learning (Lee, 2010; Atapattu & Falkner, 2017). Previous studies have emphasized the importance of instructors' communication strategies for enhancing effective learning in video lectures (Richardson & Swan, 2003; Guo et al., 2014; Brame, 2016). For instance, Richardson and Swan (2003) indicated that the communication style of the instructors in video lectures could have a significant impact on students' cognitive performance and their satisfaction. Similarly, Guo et al. (2014) suggested that the tutors' speaking style in the video lecturers is one of the important factors that impacts the effectiveness of video lectures. The empirical study focused on analyzing 6.9 million video watching sessions from courses on the edX MOOC platform to understand the effect of various factors on student engagement and learning outcomes. The findings suggested that students could engage better with talking-head videos. Students identified that talking-head videos are more "intimate and personal", thus, positively impacting their engagement. Also, students could engage more with video lectures when the instructor spoke faster. The study provided important insights to investigate the communication style of the instructor to increase lecture effectiveness. However, the suggestions were relatively limited to diagnostic recommendations regarding a tutor's language use for ideal communication styles in video lectures.

Pedagogical discourse marker framework

The role of strategic teacher-talk using discourse markers has long been emphasized in traditional classroom learning (Consolo, 2000; Morell, 2007). Fung and Carter (2007) introduced a comprehensive framework, which categorizes commonly used pedagogical discourse markers into four functional levels (Table 1). The comprehensive pedagogical discourse framework was designed to provide systematic structures of evaluation of such intentional instructional cues. The framework categorizes commonly used pedagogical discourse markers into four different functional levels: Interpersonal, Referential, Structural, and Cognitive. Each function focuses on providing a pleasant student learning experience by a) reducing social distance between a teacher and a student [interpersonal], b) providing grammatical connectives to the sentences [referential], c) signaling topic shift [structural], and d) denoting thinking processes [cognitive]. In the current study, we adopted the Interpersonal, Structural, and Cognitive categories to provide a customized evaluation and analytic framework of the tutors' communication strategies in the video lectures. The referential category was not adopted in the analysis as the category introduced discourse markers of low interest based on the primary research questions of the current study. In short, the functional paradigm of pedagogical discourse marker frameworks (Fung & Carter, 2007) was adopted to enhance the interpretability of the empirical findings from the natural language processing analyses.

Table 1: Functional Paradigm of Pedagogical Discourse Marker Framework (Fung & Carter, 2007)

Interpersonal Function	Structural Function	Cognitive Function
- Marking shared knowledge (e.g., *see, you see)* - Indicating attitudes (e.g., *well, I think*) - Showing responses	- Opening and closing of topics - (e.g., *let's start*) - Sequence (e.g., *first, second, next*) - Topic shifts (e.g., *how about*) - Summarizing opinions (e.g., *so*)	- Denoting thinking processes (e.g., *well, I think, I see*) - Reformulation & self-correction (e.g., *I mean*) - Elaboration (e.g., *for example*) - Hesitation (e.g., *well, sort of*) - Assessing learner's knowledge

(e.g., *okay, yeah, great, I see*)	- Continuation of topics (e.g., *yeah, so*)	(e.g., *you know*)

Methods

Data

We analyzed 125 video lectures by five tutors collected from Algebra Nation. Algebra Nation is an online learning platform, which provides free learning resources to students and teachers. The learning contents in Algebra Nation follow the core standards for Algebra 1 in the designated state to provide effective algebra learning modules, such as online practice tools, interactive wall post, and dynamic video lectures. In the current study, we analyzed the video lectures, which included 25 topics from three main algebraic concepts introduced by each instructor. The lectures spanned between 10.7 and 22.0 minutes (M=17.2; SD=5.0). The video content was designed to follow the same algebra workbook content. The workbook content introduced algebraic concepts and practice questions to help improve student learning[1]. Given that the videos covered the same workbook content, we hypothesized that the differences in the videos' length stemmed from the varying problem-solving and communication strategies used by the tutors. As such, we focused on analyzing the communication strategies geared towards engaging and motivating students, referred to as the "communication" component in the following sections.

Analysis Framework

The analysis was conducted in three stages to investigate how teacher-talk strategies were employed in video lectures from Algebra Nation. In the first stage, the video lecture transcripts were parsed into three categories based on their content. This was to identify and extract the "communication" component from the video transcripts, which served as the primary focus of the current analysis. The other two categories included the "workbook" and "lecture" components. These components referred to the parts of the text where the tutor rephrases the workbook content and explains algebraic concepts or solutions. The second stage of the analysis focused on understanding the differences in language use in the communication component among the tutors using the psycholinguistic features. We extracted an extensive list of psycholinguistic indices from the communication content of the video lecture transcripts using Coh-Metrix (McNamara et al, 2014) and SÉANCE (Crossley et al., 2017). Then, we used the Random Forest classifier to investigate whether the psycholinguistic features could accurately classify the tutors. The feature importance indices were inspected to understand the relative contribution of the variables to the classification outcome. In stage 3, we focused on understanding the differences in the tutor's language by identifying and comparing pedagogical discourse markers. This was achieved by extracting discourse markers using n-gram-based clustering. We then identified the discourse markers patterns used by each tutor. The findings from the last two stages of the analysis are described and explored thoroughly in the Results section.

Results

Differences in the Language Use and Sentimental Component

A total of twenty-six features were identified to provide deterministic information to classify the algebra tutors based on their communication language use (Random Forest (RF) Classifier, accuracy on the test set=86.7%). The final feature set included fourteen sentiment component scores from SÉANCE and twelve Coh-Metrix indices. Tables 2 and 3 and Figure 1 provide detailed descriptions of the SÉANCE and Coh-Metrix indices included in the final model. More specifically, four specific categories of Coh-Metrix indices were located to have high classification power. The four categories included, "Word Information", "Text Easability", "Syntactic Pattern Density", and "Situation Model". The word information index (WRDPRP1p, "First-person plural pronoun incidence") shows the highest contribution (8.9%) to accurately classify the communication components in video scripts based on tutors. This suggests the frequency of tutors using words, such as "we" and "us" could work as a good indicator for differentiating communication components among the tutors. Also, the polysemy for content words (2.6%) and verb incidence scores (4.3%) were identified as deterministic variables from the word information category. Polysemy for content words identifies the average number of distinct meanings the word represented. Hence, it is often highly related to the ambiguity of text due to the larger room for varying interpretations. This suggests the varying level of ambiguity of the communication component could help differentiate the teacher-talk among the algebra tutors. Similarly, the tutors' communication components could be differentiated using their text easability measured by narrativity (3.7%), verb cohesion (3.4%), syntactic simplicity (3.2%), and connectivity (2.6%). This suggests the varying level of difficulty, or easability, of the communication of the tutors as an important indicator to differentiate their teacher-talk strategies. In terms of the syntactic pattern density features, the noun phrase density score (4.6%), expanded temporal connectives incidence score (3.7%), and the preposition phrase density score (3.5%) were identified as deterministic features. Lastly, one feature was identified as significant in the situation model category. This category of features represents the level of mental representation of the readers based on the content provided in the text. Specifically, the intentional content features (3.7%) attempt to understand the "intentional actions, events, and particles" provided in the text (McNamara et al., 2014, p.66). Hence, our findings indicate that the tutors' use of intentional language in the communication content significantly identifies the varying teacher-talk strategies among the algebra tutors (Figure 1, Table 2).

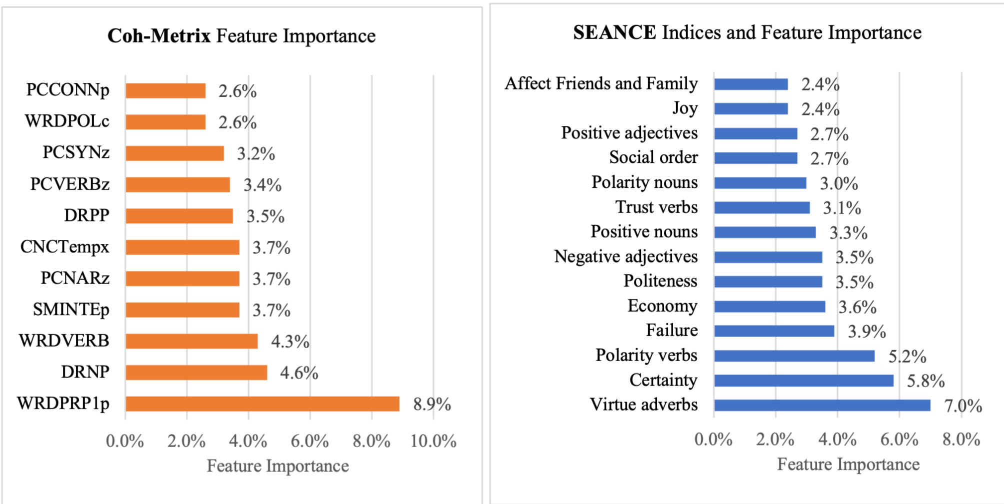

Figure 1. Final Random Forest classifier feature importance of the top 25 Coh-Metrix and SÉANCE features

Table 2: Final Random Forest Feature Importance of Coh-Metrix Indices

Category	Index	Description	Importance (%)	Total (%)
Situation Model	SMINTEp	Intentional content	3.7%	3.7%
Syntactic Pattern Density	DRPP	Preposition phrase density	3.5%	11.8%
	NCTempx	Expanded temporal connectives incidence	3.7%	
	DRNP	Noun phrase density	4.6%	
Text Easability	PCCONNp	Connectivity	2.6%	12.9%
	PCSYNz	Syntactic simplicity	3.2%	
	PCVERBz	Verb cohesion z score	3.4%	
	PCNARz	Narrativity	3.7%	
Word Information	WRDPOLc	Polysemy for content words	2.6%	15.8%
	WRDVERB	Verb incidence	4.3%	
	WRDPRP1p	First person plural pronoun incidence	8.9%	

The SÉANCE indices thus identified how the varying language choices conveyed different sentimental values in the algebra tutor's communication component. The final 14 indices from SÉANCE included various component scores regarding virtue adverbs, certainty, polarity verbs, failure, economy, politeness, negative adjectives, positive nouns, trust verbs, polarity nouns, social order, positive adjectives, joy, and affect friend and family. Table 3 provides detailed information on the description and the importance of each component score with example words. Given the current dataset contains the communication component of algebra video lectures, the findings provide important insights regarding the types of words tutors differentially select to communicate with the students differently. More specifically, the use of adverbs related to virtue (7%), certainty (5.8%), and failure (3.9%) showed relatively high contributions to the classification outcomes. To summarize, the random forest feature importance outcomes with psycholinguistic features from Coh-Metrix and SÉANCE indicated the varying word selection in communication components among the tutors. The findings suggest that the intentional choice of words, measured by the word information, the syntactic structure, and the text easability indices, varied significantly among the tutors. Also, the various sentiment behind the word choices were identified as an important factor differentiating the communication components of the five algebra tutors.

Table 3: Final Random Forest Feature Importance of SÉANCE Component Scores

Component	Description & Importance	
Virtue adverbs	Nouns related to worship and forgiveness (e.g., *blame, conviction, earn*)	7%
Certainty	Words indicating "a feeling of sureness, certainty, and firmness" (e.g., *absolute*)	5.8%
Failure	Verbs indicating power decreasing (e.g., *attack, banish, beat*)	3.9%
Economy	Words related to economy (e.g., *account, affluence, agricultural*)	3.6%
Politeness	Words concerned with a tools or forms of invoking formal power (e.g., *civil*)	3.5%
Negative adjectives	Negative adjectives (e.g., *abject, abrasive, abominable*)	3.5%
Positive nouns	Positive nouns (e.g., *acceptance, abundance, accomplishment*)	3.3%
Trust verbs	Words describing the state of trust (e.g., *admire, adore, anticipate*)	3.1%
Social order	Words concerning social order (e.g., *adhere, appall, corrupt*)	2.7%
Positive adjectives	Positive adjectives (e.g., *absorbent, able, accessible*)	2.7%
Joy	Words related to joy (e.g., *superb, affection, complement*)	2.4%
Affect Friends and Family	Nouns related to friends and family (e.g., *brother, company, friend)*	2.4%

Pedagogical Discourse Marker Identification

We next identified how such differences in word use or language use in communication components occur differently for each tutor using pedagogical discourse marker clustering analysis. Unlike the previous analysis, the findings from the pedagogical clustering analysis can potentially reveal the explicit differences in pedagogical language use among the tutors. Seventeen pedagogical discourse marker clusters were identified using K-means clustering analysis of 6,119 sentences belonging to the "communication" components. The final model used tf-idf vectorization with n-grams ranging from 1 to 5. The k-means clustering results identified a number of interpretable discourse marker cluster categories. However, we also noted a non-negligible proportion of samples indicating relatively unclear results (18.9%). This could be largely due to the noisy structure of the text data.

While the results located interpretable groups of pedagogical discourse markers, it was necessary to provide theoretical support to decipher their core functional roles in teacher communication. As a result, the final set of discourse marker clusters was evaluated using Fung and Carter's (2007) framework. Table 4 provides the final discourse marker identification results that are organized based on the discourse marker function framework. This framework identifies the core functional category of pedagogical discourse markers using the primary functions, such as the "interpersonal", "structural", and "cognitive" functions (Fung & Carter, 2007). A mapping was found for each cluster by locating the best-fitting category based on the pedagogical function. The resulting categories consisted of seven specific discourse function categories.

Table 4: K-means Clustering Results based on the Pedagogical Discourse Markers by Fung & Carter's (2007)

Core Functional Category		Discourse markers	Cases (N)
Interpersonal Function	Marking shared knowledge	*we are close; we are almost there*	45
		we know that; we know what to do; we have this to solve	145
		That is what is happening; that is what is up; that is how we do	188
	Indicating Attitudes	*This is very important; you should be careful; this is a bit tricky.*	98
	Showing Responses	*That is good; that looks good; awesome job*	312
		Ok, that is cool; cool; alright; all right; fantastic	1,459
		That is true; that is incorrect; yes; no	386
		There you go; here you go; just like that; there it is.	190
		you got this; you guys are smart; keep studying hard	178
Structural Function	Opening and closing of topics	*Hi everyone; hey Algebra Nation*	128
		Thank you; I will see you next time; see you in the next video.	140
	Topic Shifts	*Let's see; let's take a look; let's jump in*	855
		It is up to you; you can do either way.	214
Cognitive Function	Denoting thinking processes	*We are going to; you are going to; you will; we will*	326
		Same thing applies here; same idea here	131

		Sorry; sorry about that	32
	Assessing listener's knowledge	*Thinking about this; what about this; you know what?*	136

The findings indicated that the majority of the pedagogical discourse markers served interpersonal functions (Table 4). Pedagogical discourse markers from interpersonal functions focus on reducing the physical gap between the tutors and the students by indicating "shared knowledge component", "providing tutors' attitudes about the topic explicitly", and "providing immediate feedback and responses". Also, a number of discourse markers were identified from the structural function. These markers suggest that the algebra tutors in the current dataset intentionally provided cues to help students feel that lecture contents are organized and structured. Lastly, two pedagogical discourse makers of the cognitive function were discovered, which attempt to "denote thinking processes" and "assess students' knowledge". The cognitive function discourse markers indicate that the algebra tutors tended to challenge students by assessing the student's level of understanding regarding the lecture content. Additionally, the findings indicate that the tutors consciously communicate the lecture content by explaining their thinking processes to students for effective learning experiences.

Conclusion and discussion

This study aimed to understand the teacher-talk strategies in the communication component from video lectures focusing on algebra content. We focused on identifying the deliberate use of word choices in video lectures and the sentiment behind those word choices in video lectures. The findings from our first analysis suggested that the word information, easability, and narrativity of the tutor's speech, and the intentional verb choice in the communication component of the lecture videos showed distinct differences between the tutors. The results reinforced the suggestions from the previous literature, which highlighted the importance of word choices in building social partnership with the students through careful and intentional word choices (e.g., first-person plural, intentional verbs, easability of text). Moreover, the tutors' intentional language choice significantly varied in terms of the primary sentiment conveyed in their communication component. While the previous literature emphasizes the importance of particular sentimental values, such as "enthusiasm" and "excitement" in the tutor's communication component, the current findings discovered how the varying types of sentimental values are incorporated in the tutors' communication component, such as "virtue", "certainty", and "failure".

In our second analysis, we investigated how specific language choices occur in the form of pedagogical discourse markers in tutors' communication components. Pedagogical discourse markers are intentional language cues that the tutors provide to convey various functions in instructional conversation (Fung & Carter, 2007). For instance, adequate use of pedagogical markers could help build interpersonal communication ("interpersonal function"), help structure, and organize the lecture contents ("structural function") and encourage activation of cognitive processes ("cognitive function"). We discovered 17 different types of pedagogical discourse markers from the tutors' communication component in algebra video lectures. The majority of the discourse markers served the "Interpersonal" function, which focuses on reducing the physical gap between the instructors and students by "marking shared knowledge', "communicating tutors' attitudes" and "showing responses to students". Similarly, a number of discourse markers focusing on "structural" and "cognitive" functions were incorporated by the tutors to help structure the video contents, to let students denote thinking processes, and to access the learner's level of understanding. Moreover, the five algebra tutors showed distinct patterns in the use of discourse marker functions to covey video lectures on various algebra topics. Three different patterns of discourse marker function combinations were identified. Tutors tended to adopt the pattern representing the dominant use of discourse markers with interpersonal functions to "show response to provide immediate feedback to students. The findings in our study provide important implications for understanding and evaluating the tutors' communications strategies in video lectures with theoretical contributions. Our findings provide new insights into how the intentional use of language in communication components occurs in real-life video lectures. The mixed-methods investigation has strong potential to provide important insights on how intentional language choice, the sentimental value of language, and the pedagogical function of the language vary in tutoring videos. This finding affords a more complete list of suggestions and recommendations for effective communication strategies in video lectures.

References

Allen, M., Bourhis, J., Burrell, N., & Mabry, E. (2002). Comparing student satisfaction with distance education to traditional classrooms in higher education: A meta-analysis. *The American Journal of Distance Education, 16*(2), 83-97.

Atapattu, T., & Falkner, K. (2017, March). Discourse analysis to improve the effective engagement of MOOC videos. In *Proceedings of the Seventh International Learning Analytics & Knowledge Conference* (pp. 580-581). Vancouver, Canada: Association for Computing Machinery.

Brame, C. J. (2016). Effective educational videos: Principles and guidelines for maximizing student learning from video content. *CBE—Life Sciences Education*, *15*(4), es6.

Brecht, H., & Ogilby, S. (2008). Enabling a comprehensive teaching strategy: Video lectures. *Journal of Information Technology Education: Innovations in Practice*, *7*(1), 71-86.

Breslow, L., Pritchard, D. E., DeBoer, J., Stump, G. S., Ho, A. D., & Seaton, D. T. (2013). Studying learning in the worldwide classroom research into edX's first MOOC. *Research & Practice in Assessment*, *8*, 13-25.

Buckley, W. & Smith, A. (2007). Application of multimedia technologies to enhance distance learning. *RE:view Rehabilitation Education for Blindness and Visual Impairment, 39*(2), 57-65.

Chick, R. C., Clifton, G. T., Peace, K. M., Propper, B. W., Hale, D. F., Alseidi, A. A., & Vreeland, T. J. (2020). Using technology to maintain the education of residents during the COVID-19 pandemic. *Journal of Surgical Education, 77*(4), 729-732.

Choi, H. J., & Johnson, S. D. (2005). The effect of context-based video instruction on learning and motivation in online courses. *The American Journal of Distance Education, 19*(4), 215-227.

Consolo, D. 2000. Teachers' action and student oral participation in classroom interaction. In J. Hall, & L. Verplaetse (Eds.), *Second and foreign language learning through classroom interaction* (pp. 91-107). Lawrence Erlbaum Associates.

Costley, J., Fanguy, M., Lange, C., & Baldwin, M. (2020). The effects of video lecture viewing strategies on cognitive load. *Journal of Computing in Higher Education*, *33*, 19-38.

Crossley, S. A., Kyle, K., & McNamara, D. S. (2017). Sentiment analysis and social cognition engine (SÉANCE): An automatic tool for sentiment, social cognition, and social-order analysis. *Behavior Research Methods*, *49*(3), 803-821. https://doi.org/10.3758.s13428-016-0743-z

Fung, L., & Carter, R. (2007). Discourse markers and spoken English: Native and learner use in pedagogic settings. *Applied linguistics*, *28*(3), 410-439.

Guo, P. J., Kim, J., & Rubin, R. (2014). How video production affects student engagement: An empirical study of MOOC videos. In *Proceedings of the first ACM conference on Learning@ scale conference* (pp. 41-50). Atlanta, GA: Association for Computing Machinery.

Lange, C., & Costley, J. (2020). Improving online video lectures: Learning challenges created by media. *International Journal of Educational Technology in Higher Education*, *17*. https://doi.org/10.1186/s41239-020-00190-6

Lastinger Center for Learning, & University of Florida. (2019). *AlgebraNation*. http://lastingercenter.com/portfolio/algebra-nation-2/

Lee, E. H. (2010). An analysis of online lecture discourse of a Korean NNS teacher and an American NS teacher. *Linguistic Research*, *27*(1), 209-229.

Lee, H. J., & Rha, I. (2009). Influence of structure and interaction on student achievement and satisfaction in web-based distance learning. *Journal of Educational Technology & Society*, *12*(4), 372-382.

Mayer, R. E. (2005). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge handbook of multimedia learning* (pp. 31-48). Cambridge University Press.

Morell, T. (2007). What enhances EFL students' participation in lecture discourse? Student, lecturer, and discourse perspectives. *Journal of English for Academic Purposes, 6*, 222-237.

McNamara, D. S., Graesser, A. C., McCarthy, P. M., & Cai, Z. (2014). *Automated evaluation of text and discourse with Coh-Metrix*. Cambridge University Press. https://doi.org/10.1017/CBO9780511894664

Richardson, J., & Swan, K. (2003). Examining social presence in online courses in relation to students' perceived learning and satisfaction. *Illinois Digital Environment for Access to Learning and Scholarship*. http://hdl.handle.net/2142/18713

Whatley, J., & Ahmad, A. (2007). Using video to record summary lectures to aid students' revision. *Interdisciplinary Journal of E-Learning and Learning Objects*, *3*(1), 185-196.

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Coherence across Conceptual and Computational Representations of Students' Scientific Models

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Abstract: We articulate a framework for characterizing student learning trajectories as they progress through a scientific modeling curriculum. By maintaining coherence between modeling representations and leveraging key design principles including evidence-centered design, we develop mechanisms to evaluate student science and computational thinking (CT) proficiency as they transition from conceptual to computational modeling representations. We have analyzed pre-post assessments and learning artifacts from 99 6th grade students and present three contrasting vignettes to illustrate students' learning trajectories as they work on their modeling tasks. Our analysis indicates pathways that support the transition and identify domain-specific support needs. Our findings will inform refinements to our curriculum and scaffolding of students to further support the integrated learning of science and CT.

Introduction

The Next Generation Science Standards (NGSS; NGSS Lead States, 2013) identify modeling as one of the eight science and engineering practices that prepare students for the 21st century workforce. Modeling enables students to generate, integrate, and test theoretical ideas (Lehrer & Schauble, 2015), providing authentic experiences that deepen students' understanding of scientific phenomena. The practice of modeling is also central to the discipline of computer science (CS) (e.g., K-12 CS Framework (2016)). Integrating science and CS has compelled researchers to develop frameworks guiding their synergistic learning in K-12 classrooms (e.g., Sengupta et al., 2013; Weintrop et al., 2016). While educational policy promotes the integration of CS practices as part of science instruction, little guidance is provided on how teachers may support students in meeting these expectations across disciplines (e.g., NGSS Lead States, 2013).

Technology-enhanced environments can scaffold students in computational modeling processes that engage inquiry and problem solving (e.g., Jonassen, Strobel, & Gottdenker, 2005; Keating et al., 2002; Sengupta et al., 2013; Weintrop et al., 2016). Computational modeling experiences need to be anchored to strong underlying conceptual models of the phenomena being investigated in order to leverage the unique affordances of both conceptual and computational model representations. Together, conceptual and computational representations provide a more complete depiction of phenomena and support students in deriving linkages between model representations (Frederiksen et al., 1999). Limited research describes how students make transitions and connections among model representations and identifies the instructional supports they require.

In this paper, we focus on middle school students' learning of science and computational thinking (CT) as they engage in modeling tasks over the course of a 3-week curriculum unit integrating Earth science, engineering design, and CT (Chiu et al., 2019). Our approach centers on understanding students' ability to model the Earth science concept of water runoff by working through a sequence of representations from conceptual to computational modeling. Our study addresses the following research questions: (1) How do we characterize students' learning trajectories from conceptual to computational modeling? and (2) How do the different modeling vignettes that students generate along this trajectory relate to one another and show students' learning of relevant science and CT concepts?

Theoretical and empirical foundations

Supporting scientific modeling using conceptual and computational representations

Scientific modeling enables students to delve deeper into understanding phenomena by explaining and predicting system behavior (Schwarz & White, 2005). Examples of common conceptual models in K-12 science education include models of food webs, planetary orbits, and the water cycle. Recently, there have been efforts to introduce computational modeling methods to help students gain a better understanding of scientific phenomena (e.g., Sengupta et al., 2013; Weintrop et al., 2016). Computational models provide explicit mechanisms for constructing and visualizing phenomena, reasoning about scientific processes as a sequence of events (as opposed to creating aggregated mathematical models), and providing explicit opportunities to study step-by-step changes in model behavior (versus continuous dynamics). Moreover, computational models of scientific phenomena help to contextualize complex CT concepts (e.g., conditional logic) to support CT learning.

However, research has identified that students may have significant difficulties with developing computational models in science. For instance, students may struggle to understand the science concepts underlying their computational models and to represent system variable relationships computational expressions (Sengupta et al., 2013). These challenges may stem from students' difficulty in identifying model components, interactions among components, or the underlying scientific principles underlying the model (e.g., Forbes, Zangori, & Schwarz, 2015). Students may have trouble generalizing or abstracting the scientific processes into variables and expressions (Basu et al., 2016). These findings indicate a need to anchor the design of computational modeling tasks to conceptual modeling activities and to examine the types of support students may need to make the transition from conceptual to computational models.

For effective participation in this important STEM practice, students and teachers need support as they grapple with the dual complexities of scientific and computational modeling. There is limited research that examines how students' science and CT knowledge evolves over the course of a computational modeling unit that introduces science and CT concepts and practices. Additional research can advance understanding of the synergistic relation between science and CT and how learning in each discipline supports and/or impedes learning in the other. These insights will in turn help scaffold integrated learning of the underlying science and CT concepts. In this paper, we analyze students' learning artifacts as they develop a sequence of models of water runoff to examine how instruction can help students transition from conceptual to computational models.

Design perspectives

We integrated three design perspectives in developing an integrated science + CT computational modeling unit:

- **Evidence-centered design (ECD)** - We use ECD (Mislevy & Haertel, 2006) to analyze the integrated science + CT domain, systematically unpack the target science and computing concepts and practices, and identify connections between the science and CT views of the modeling practice. ECD helps designers link the features of instructional tasks and assessments to evidence of students' proficiency with the target knowledge and skills. In this case, we aim to promote both science and CT-oriented modeling proficiency across evolving modeling representations.
- **Maintain coherence across system representations** - In order to address novice students' difficulties in deriving links among the evolving representations, the conceptual coherence needs to be made explicit (Ainsworth, 2006; Frederiksen et al., 1999). For instance, in this study, each of the evolving modeling representations makes explicit the conservation relationship among rainfall, absorbed water, and water runoff at different levels of abstraction and generality.
- **Domain-specific modeling languages (DSMLs)** - We have created a DSML to make it easier for students to express their scientific understanding of the science concepts and relations into a set of computational constructs that model the science phenomena (e.g., water runoff) (Hutchins et al., 2020). DSMLs enable students to place greater focus on the science concepts and system variables without having to attend to the details of program construction.

Overall, we hypothesize that the three design perspectives will support students as they work through the linked modeling representations from conceptual to computational, thus reducing the difficulties they face in integrating science and CT modeling concepts.

Curriculum description

The Water Runoff Challenge (WRC) is a three-week, NGSS-aligned unit that challenges students to redesign their schoolyard using different surface materials to minimize the amount of water runoff after a storm while adhering to a series of design constraints. These include the overall cost and accessibility, while providing for different functionalities for the schoolyard (Chiu et al., 2019). The WRC targets NGSS performance expectations for upper elementary Earth science and engineering design curricula, emphasizing the movement of surface water in a system after heavy rainfall and the human impact of this runoff on the environment.

Figure 1 illustrates our designed learning trajectory and criteria from conceptual to computational model construction. Initially, students were expected to apply the matter conservation principle (science concept): Total rainfall = total absorption + total runoff, through the construction of paper-and-pencil conceptual models. Each subsequent modeling form required application of additional CT concepts to specify the model in a more general form (see Figure 1). To support this, we implemented an intermediate paper-and-pencil Rule Creation task (Figure 2(b)) to elicit an additional representation of the science phenomenon enabling students to express the relation between the science concepts: total rainfall, total absorption, absorption limit, and total runoff. Students are tasked with expressing three scenarios (i.e., when rainfall is greater, less than, and equal to the surface absorption limit) as semi-structured rules. These relations take into account the conservation laws while using conditional logic expressions to specify when different situations apply (e.g., no runoff versus a certain amount of runoff). Students then transfer their rules into a computational model using the given DSML blocks to create the model components (i.e., the three rules). Translating the rules to the computational modeling activity requires additional knowledge of variables and mathematical and relational operators. We detail each activity, below.

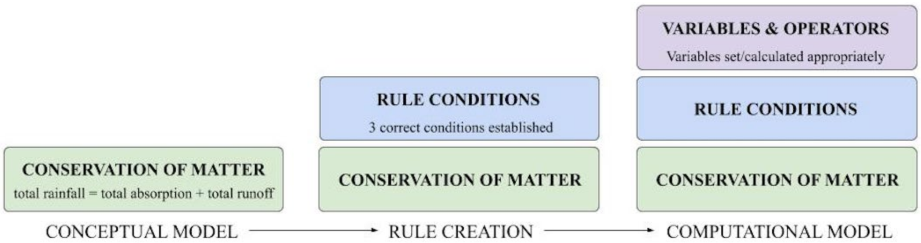
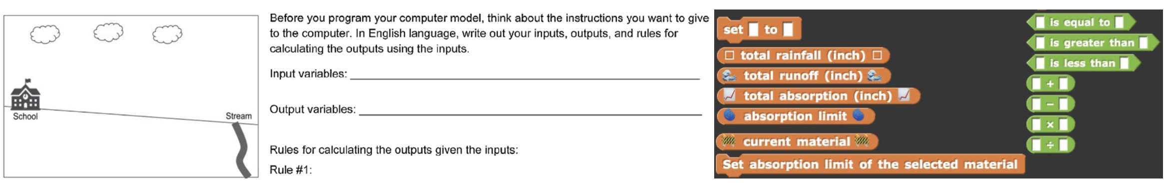


Figure 1. Learning trajectory from conceptual to computational model tasks.

In the WRC, students are introduced to the science concepts of matter conservation and the absorption characteristics of different surface materials. Students then develop pencil-and-paper conceptual models that express the amount of water runoff in terms of the total rainfall and water absorbed by the different materials. As a first step to understanding runoff, students use paper and pencil to generate an input-output model that includes rainfall, absorption, and runoff. Students can describe the conservation relation numerically, pictorially, and/or through a descriptive written response. For instance, to complete Figure 2(a), students are tasked with predicting the amount of absorption and runoff for 3 inches of rainfall and a 1-inch absorption limit of the surface material. As a second step in the model evolution process, the students then create a more precise conceptual model on paper, where they create rules to describe the three different runoff conditions.

After additional scaffolding, where students practiced writing conditional constructs in an unplugged activity (the Rule Creation task, Figure 2(b), described above), the students created their computational runoff model in the computational modeling environment using DSML constructs (Figure 2(c)) that facilitate the translation of the runoff rules into the computational model (Chiu et al., 2019). Example student models appear in the Findings section (Figure 3). The DSML blocks help students assign variables to specific values, and translate their runoff rules to "if" constructs (e.g., "if total rainfall is greater than the absorption limit", then "set total runoff to [total rainfall ⊠absorption limit]"). Students also needed to assign the value of total rainfall and the absorption limit before the conditional block statements. After students constructed a working computational runoff model, they could study the effects of different surface materials on runoff from the schoolyard to the surrounding area.

In designing each of the model building activities, we maintained coherence across the three representations, and gradually introduced students to CT concepts and practices. This approach provides a framework for evaluating students' modeling artifacts across different representations and how these representations support students' learning trajectories.



(a) (b) (c)

Figure 2. Task examples for paper-and-pencil conceptual modeling (a) and rule creation (b), and the DSML used for the computational modeling task (c).

Methods

We conducted a three-week classroom study with 99 sixth-grade students in the U.S. using the WRC. All participating students had some prior programming experience with block-structured programming using Scratch (Maloney et al., 2004). The participating teachers were experienced science teachers and received four days of professional development before the study. Three researchers provided additional support but mostly acted as observers during the study. Students worked for 45 min per day, three days a week during their regular science classes, and 75 min, twice a week with additional personalized-learning time.

Data sources, scoring, and analysis

We examined three primary types of student data: paper-based artifacts, students' final computational models, and a pre-post assessment. All tasks evaluated for this paper were completed in class.

Students' paper-based **Conceptual Models** were coded based on whether their representation of the conservation of matter principle (see Figure 1) was *mechanistic* (and correct), *numeric* (and correct), or *developing*. In order to achieve a *mechanistic* score, students were required to show or use text (via pictorial or descriptive representation) the causal relations resulting in the division of the total rainfall into absorption of water and the amount of runoff using a correct algebraic or numerical expression. A *numerical* score indicated the representations showed all of the required elements and correct values, without describing the causal relations. A *developing* score reflected misunderstandings or errors in students' application of the conservation of matter principle. Students' numerical, pictorial, and written descriptions were coded separately, and students' understanding was represented by the highest score they received on a single part.

For the **Rule Creation** task, each rule that students developed was scored separately. For Rule Conditions (see Figure 1), students received scores for expressing the correct conditional relation between total rainfall and absorption limit (e.g., if total rainfall is greater than the absorption limit). The conservation relation was scored for a correct expression of the values for each required output: total absorption and total runoff.

Students' **Computational Models** were scored using a predefined rubric targeting the application of the conservation of matter rules, the conditional statements for the different rules, and the variable assignments (for rainfall, absorption, runoff). The maximum score possible is 15. To achieve that, students had to assign appropriate values to total rainfall and absorption limit, generate the code for the three conditional statements based on a comparison of variables (total rainfall and absorption limit) and update the absorption and runoff variables for each of the three conditions. Students were given points for generalizability only if they used expressions comprising variables and operators to express variable values (e.g., setting total runoff to "total rainfall ⊠ absorption limit" in the overflow condition) as opposed to just assigning numeric values to variables.

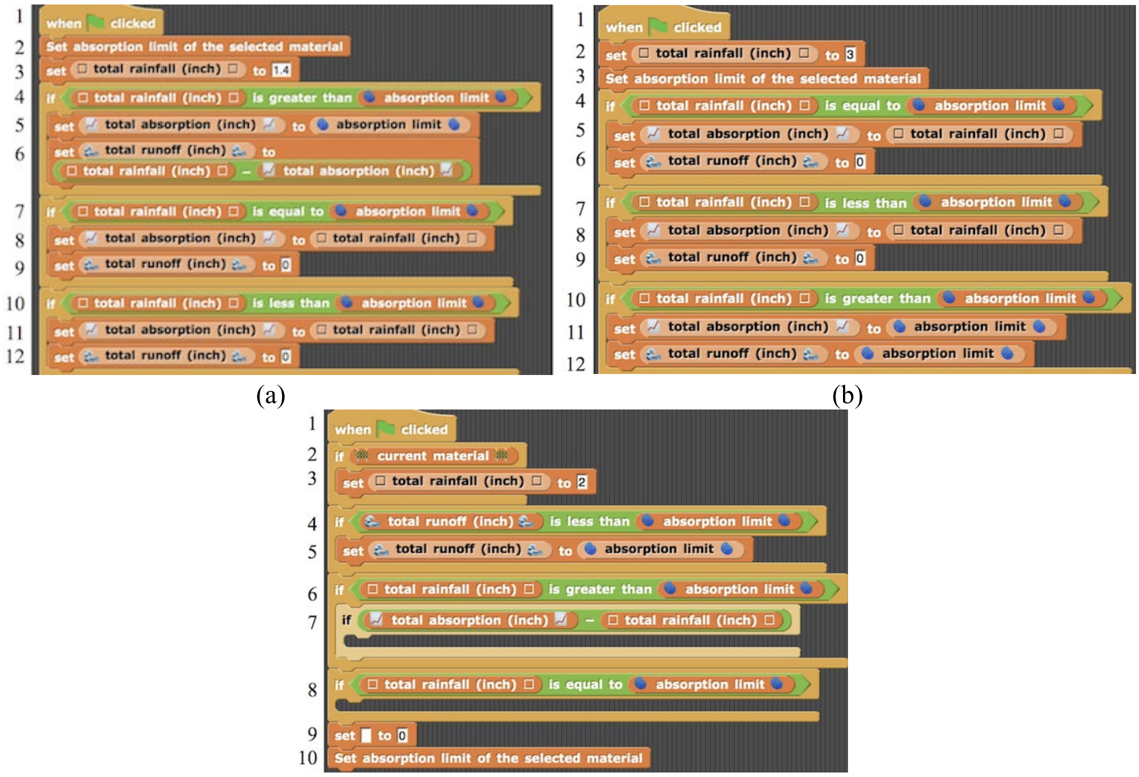
Students completed a paper-and-pencil **pre-post assessment** that was split into a science and engineering component and a CT component. Our science and engineering pre-post assessment aligns with a number of NGSS Performance Expectations (PEs). Students could get a maximum score of 23 points. The CT assessment tasks were aligned with the concepts and practices addressed in the modeling activities (e.g., variables, operations, conditionals, program development) and had a maximum score of 13 points. The rubrics used for coding and scoring these assessments were updated from our previous work (McElhaney et al., 2019). Two researchers received 5 hours of training on the rubrics, graded 5% of the test submissions (randomly selected) together to establish initial grading consistency, and then graded another 20% to establish inter-rater reliability (Cohen's κ at ≥ 0.8 level on all items). All differences in the coding were discussed and resolved before the remaining 75% of test submissions were graded by a single researcher.

To answer our research questions, we summarize class learning trajectories through correlation analysis and present three contrasting student vignettes (with pseudonyms Alex, Marley, and Taylor). Where appropriate, we position the performance of these three students relative to the range of student performances we observed.

Findings

Summary of student performance on modeling artifacts and pre-post assessments

Students successfully completed the WRC as intended. Pre-post assessment scores were determined to be normally distributed and a paired t-test analysis showed significant learning gains in science and engineering ($p < 0.0001$, Cohen's $d = 0.82$) and CT ($p < 0.0001$, Cohen's $d = 0.83$). We classified 32 students' Conceptual Models as mechanistic, 59 as numerical, and 7 as developing (1 student packet missing). For the Rules Creation task's Rule Condition component, 57 students correctly described the three conditions while 35 had errors in at least one rule condition (remaining responses were either illegible or missing). For the conservation of matter component, 35 students correctly calculated both absorption and runoff for each rule with 63 students incorrectly calculating or missing elements (1 student packet missing). The main issue with the conservation of matter performance during rule creation were missing variable assignments for either runoff or total absorption in each condition (e.g., students would only describe the resulting runoff when describing what happens when total rainfall is greater than the absorption limit). The Computational Model mean score for the class (we could retrieve 62 student models) was 13.75 (stdev = 2.42), which we will use as reference during the case studies. Spearman's Rho Correlation analysis indicated a moderate but significant correlation between the pictorial representation and Rule-based conceptual model scores (r = 0.35, p = 0.0007, n = 90), but a small non-significant correlation between Rule-based model and Computational Model scores (r = 0.19, p = 0.13, n = 62), implying the relation may not be linear. We observed that 68% of the students had correctly working computational models and 92% implemented the three conditions correctly. These results suggest that students' understanding of the runoff system improved upon constructing their computational models (though some students received help from the teachers or the researchers when constructing their models). For a deeper evaluation of students' modeling processes over time, we present contrasting vignettes for three students. Each student's final computational model is shown in Figure 3.



(c)

Figure 3. Final code for Alex (a), Marley (b), and Taylor (c).

Student 1: Strongly integrated science and CT

We selected Alex (name altered) for their strong performance on the pre-post assessment and curricular activities. On the pre-post assessment, Alex's score improved from 17.5 to 20 on the science and engineering assessment and from 10 to 13 and on the CT assessment.

During the conceptual modeling task, Alex correctly modeled each rule and demonstrated mechanistic understanding of conservation of matter. In response to the prompt to model water flow for 3 inches of rainfall and a 1inch absorption limit, Alex wrote: "*1 inch of that gets absorbed into the ground and since that's the absorption limit, the rest of the two inches becomes runoff*." This response indicated that Alex correctly calculated the runoff and total absorption based on the absorption limit and total rainfall and correctly described the process and mechanistic causal relations.

Alex's conservation of matter knowledge transferred to the Rule Creation task, where they could correctly define each rule (both the conditions and the output) via descriptive written responses. For example, in describing the "greater than" rule, Alex wrote: "*If the total rainfall is greater than absorption limit, set absorption to absorption limit, set total runoff to total rainfall⊠absorption*." This also translated to their building the correct computational model for a score of 15 out of 15. As shown in Figure 3(a), Alex correctly built each condition (lines 4, 7 and 10) and set each variable in the correct location and in a generalizable form (e.g., for the greater than condition (lines 4-6), the student calculated total runoff using the subtraction operator and used the variables total rainfall and total absorption, after setting total absorption to the absorption limit). Using our conceptual framework (Figure 1), Alex's learning trajectory is illustrated in Figure 4.

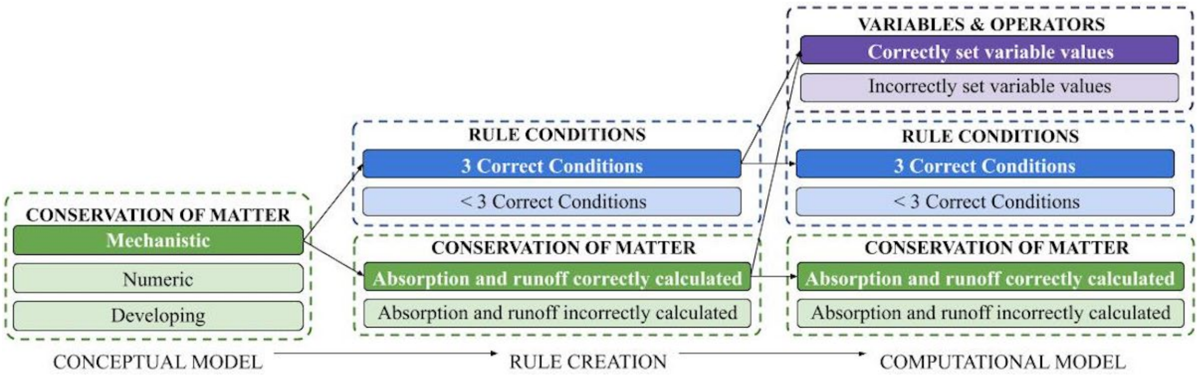


Figure 4. Alex's learning trajectory.

Student 2: Conservation of matter difficulties, high CT proficiency

Marley demonstrated pre-post CT learning gains (improving from a score of 6 to 8), but Marley's science and engineering scores decreased from pre-to-post (from 14 to 11). These results are consistent with Marley's trajectory from conceptual to computational model as described below.

Marley appeared to have difficulties implementing the conservation relation during the conceptual modeling task. For instance, when illustrating what happens when rainfall is less than the absorption limit, Marley indicated an absorption total greater than the total rainfall and stated "*it absorbs more rainfall than actual rain*" indicating a potential confusion about total absorption and absorption limit. During the Rule Creation task, Marley showed knowledge of conditional logic, providing a written response addressing each condition (e.g., "*If total rain = absorption [limit]*"); however, they did not correctly define the outputs for each rule indicating they did not fully understand the conservation law. Marley's ability to apply conditional logic translated to the computational modeling task. Their final computational model (Figure 3b) shows that Marley eventually built correct conditional blocks for two rules (lines 4-6 and 7-9), but struggled with the condition where rainfall exceeds the absorption limit (lines 10-12), thus receiving a score of 12 out of 15.

These results indicate that Marley leveraged conditional logic understanding to support the translation of the conservation of matter concepts into computational form (e.g., decomposing the code into conditional parts and then constructing blocks needed for each output). However, difficulties in the science domain may have limited their ability to correctly build and debug the model. Marley's learning trajectory is illustrated in Figure 5. While they demonstrated CT proficiency, the persistence of their struggles with the conservation law affected their ability to construct the correct computational model.

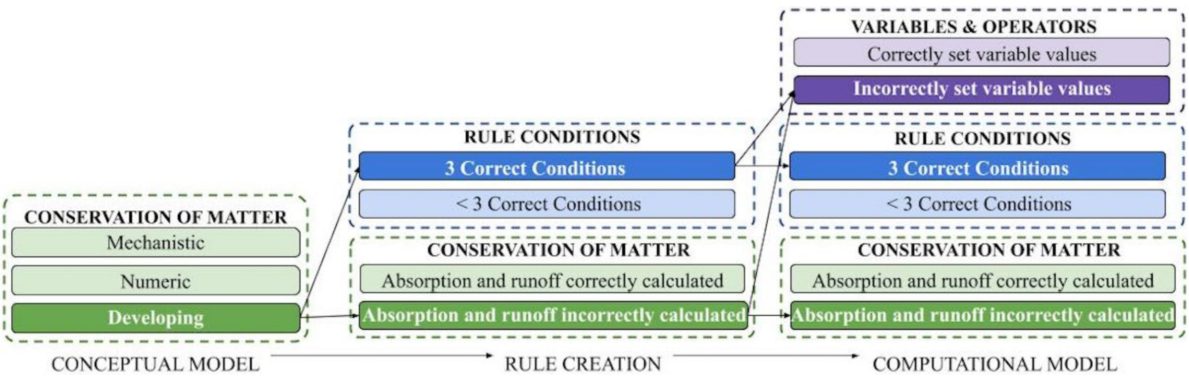


Figure 5. Marley's learning trajectory.

Student 3: Conservation of matter progress, but difficulties with CT integration

Taylor earned a relatively low score on the pre-assessment, but did achieve pre-post gains in both science and engineering (improving from 11.5 to 14.5) and CT (improving from 5 to 8). During the conceptual modeling task, Taylor demonstrated a numerical understanding of the conservation of matter rules. Taylor correctly determined the total absorption and calculated the runoff based on a prompt of a total rainfall of 3 inches and an absorption limit of 1 inch. In their description, Taylor wrote "*the cloud rained 3 inches and the ground absorbed 1 and others become runoff.*" This description does indeed include all needed variables, but does not describe the mechanistic reasoning behind why or how to calculate the runoff. However, for the Rules Creation task, Taylor was able to correctly define each rule condition and successfully calculate absorption and runoff for each rule, demonstrating an improved ability to apply the central matter conservation relationship.

The computational modeling task appeared to be difficult for Taylor. Although the science task indicated their ability to correctly apply domain knowledge, Taylor had difficulties translating that knowledge to a computational form. As illustrated in Figure 3(c), Taylor tried multiple arrangements of conditional blocks, including an if-block in which the expression was set to a "*total absorption* ⌧*total rainfall*" expression (line 7) inside of the if-block for the greater than condition (line 6). Taylor's computational model received a score of 5 out of 15. these code snippets indicate that Taylor understood how to create if-blocks for each rule condition (e.g., total rainfall is greater than absorption limit); however, they seemed unable to translate their domain knowledge to correctly assign variables (e.g., total runoff), debug, or correct their code.

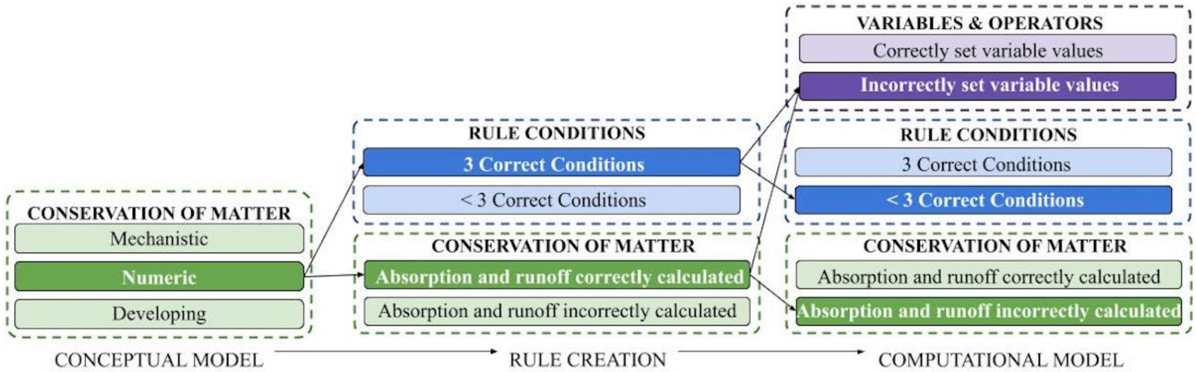


Figure 6. Taylor's learning trajectory.

Interestingly, after being shown the expert computational model and completing the remainder of the tasks, Taylor demonstrated learning gains in both the science and engineering and CT components, illustrating the potential for computational science modeling to help contextualize difficult CT concepts (e.g., conditional logic). Although they were not able to achieve a working computational model on their own, Taylor's successes in prior domain-knowledge application and usage of the model to problem-solve suggest improvements in their CT knowledge and skill. Taylor's final learning trajectory is shown in Figure 6.

Discussion and future implications

The overarching goal of our analysis is to develop linked model representations to scaffold students' computational models in science and understand how students transition across model representations to identify situations where they may have difficulties. This is especially critical in the context of integrated science and CT instruction and serves to disentangle the contributions of each domain and determine how students apply science and CT knowledge across model representations. Leveraging our conceptual framework (Figure 1), our analysis examines the impact of science domain knowledge on CT applications (and vice versa). Overall results showed that while there was a strong correlation between the conceptual model and the rule-based model, there was not a strong correlation between the rule-based model and the computational model, indicating additional personalized support may be needed for the more complex computational modeling task. For instance, although Marley was unable to correctly apply the conservation of matter rules during the conceptual modeling and rule creation tasks, their CT abilities guided them to an almost complete computational model and a high CT posttest score. Alternatively, Taylor indicated improvements in science, but demonstrated difficulties in translating that knowledge to a computational form. In these cases, using the curriculum design and student performance, we can identify the science and CT specific supports needed by the student in the computational modeling environment, and help students develop successful learning-by-modeling trajectories. In addition, these results align with other research findings that CT can serve as a vehicle for learning STEM concepts, but limitations in domain understanding may also impede computational model construction (cf. Sengupta et al., 2013). In terms of curriculum design, the majority of students indicated some proficiency in developing if-blocks in the computational model corresponding to the rules created in the Rules task. We believe this finding highlights a successful implementation of our coherence principle to support the transition from conceptual to computational modeling.

As schools move toward increased integration of computation in K-12 STEM classrooms, the learning sciences community must advance its understanding of the learning processes and support needs of students. Our analysis provides an exploratory step in identifying such cases, deepening understanding of how students integrate domain and CT knowledge for the development of multiple modeling representations. The identification of domain-specific instances of support along the learning trajectory may be supportive of more personalized (individual or group) feedback by the system or teacher. In addition, to promote student learning, our curriculum design approach and the coherence among modeling representations provide a systematic framework for evaluating applications of science and CT concepts over time. We believe this approach can inform curriculum design and scaffolding approaches that deepen understanding of how the domains are integrated, how students translate that knowledge to new representations, and where students may need additional support. Further research in applying our approach to other domains may support generalizability.

References

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and instruction*, *16*(3), 183-198.

Basu, S., Biswas, G., Sengupta, P., Dickes, A., Kinnebrew, J. S., & Clark, D. (2016). Identifying middle school students’ challenges in computational thinking-based science learning. *Research and Practice in Technology Enhanced Learning*, *11*(1), 1-35.

Chiu, J., McElhaney, K. W., Zhang, N., Biswas, G., Fried, R., Basu, S., & Alozie, N. (2019, April). A principled approach to NGSS-aligned curriculum development integrating science, engineering, and computation: a pilot study. Paper presented at the *NARST Annual International Conference*, Baltimore, MD.

Frederiksen, J.R., White, B.Y. and Gutwill, J. (1999), Dynamic mental models in learning science: The importance of constructing derivational linkages among models. *J. Res. Sci. Teach.*, *36*, 806-836.

Forbes, C. T., Zangori, L., & Schwarz, C. V. (2015). Empirical validation of integrated learning performances for hydrologic phenomena: 3rd-grade students' model-driven explanation-construction. *Journal of Research in Science Teaching*, *52*(7), 895-921.

Hutchins, N.M., Biswas, G., Zhang, N., Snyder, C., Lédeczi, Á., & Maróti, M. (2020). Domain-Specific Modeling Languages in Computer-Based Learning Environments: a Systematic Approach to Support Science Learning through Computational Modeling. *Int J Artif Intell Educ*, 30, 537–580.

Jonassen, D., Strobel, J., & Gottdenker, J. (2005). Model building for conceptual change. Interactive Learning Environments, 13(1-2), 15-37.

K–12 Computer Science Framework. (2016). Retrieved from http://www.k12cs.org.

Keating, T., Barnett, M., Barab, S. A., & Hay, K. E. (2002). The virtual solar system project: developing conceptual understanding of astronomical concepts through building three-dimensional computational models. *Journal of Science Education and Technology*, *11*(3), 261-275.

Lehrer, R., & Schauble, L. (2015). The development of scientific thinking. In R. M. Lerner, L.S. Liben, & U. Mueller (Eds.), *Handbook of child psychology and developmental science*, *2*(7), 671-714.

Maloney, J., Burd, L., Kafai, Y., Rusk, N., Silverman, B., & Resnick, M. (2004) Scratch: A sneak preview. In Proceedings of Creating, Connecting, and Collaborating through Computing, 104–109.

McElhaney, K.W., Basu, S., Wetzel, T., Boyce, J. (2019). Three-dimensional assessment of NGSS upper elementary engineering design performance expectations. Paper Presented at the *2019 NARST Annual International Conference*.

Mislevy, R. J., & Haertel, G. D. (2006). Implications of evidence-centered design for educational testing. *Educational Measurement: Issues and Practice*, *25*(4), 6-20.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Schwarz, C. V., & White, B. Y. (2005). Metamodelling knowledge: Developing students’ understanding of scientific modelling. *Cognition and Instruction*, *23*(2), 165–205.

Sengupta, P., Kinnebrew, J.S., Basu, S., Biswas, G., Clark, D. (2013). Integrating Computational Thinking with K-12 Science Education Using Agent-based Computation: A Theoretical Framework. *Education and Information Technologies*, *18*(2), 351-380.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147.

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New Views, New Roles: How Parents Supported Learning During the Transition to Remote Learning

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Abstract: Sweeping pandemic-driven school closures led to an unprecedented need for parents to become active participants in their children's day-to-day schooling. In this paper we report findings of a remote diary study that captured 109 diverse families' experiences during the first wave of U.S. closures with the goal of understanding the ways in which families were adapting to remote learning. We address three main questions: (1) What learning partner roles did parents assume when schools transitioned to remote teaching and did they vary by family income level?; (2) How did these learning arrangements help families address the unique challenges they faced? and (3) Were there unexpected benefits? Our findings show how parents took on new roles by listening in on instruction, supervising learning, providing technical support, brokering connections, and collaborating. Benefits included new insights about what and how their children were learning.

Key terms: COVID-19, remote methods, families, diary studies, learning partners

Introduction

The pandemic-driven school closures have dramatically blurred the boundaries between homes and classrooms. Although buildings were shuttered, most districts expected school to continue during the academic year and provided varied sources of support for academic learning and school community during this time. Parents and other adult caregivers at home took on new roles as facilitators of remote learning as they simultaneously adapted to new arrangements for work and strategized to protect their families' health and wellbeing. Experiences differed dramatically with more challenges faced by families who had fewer financial resources, lacked broadband access, and or had greater demands for work outside of the home (Pew Research Center, 2020). What we know less about is *how* families reorganized to capitalize on what schools were able to provide as well as their own resources.

In order to advance our capacity to support remote learning in the future, we need to understand how parent and child interests and funds of knowledge serve as assets and sources of resilience during the adaptation to remote learning, as well as how interruptions to work and school routines may disrupt the capacity to leverage them. The unique configurations of demands on families and the resources schools were able to provide, make it evident that adaptation processes and outcomes will be highly situated. If we are to understand and define resilience-building practices in ways that can set the stage for innovation, theoretically and methodologically varied approaches will be needed to surface learning practices that emerge within particular family-school ensembles and capture trends across families.

In this paper we report select findings from a remote diary study that captured a diverse set of families' experiences during the first wave of U.S. school closures in the Spring of 2020 with the goal of understanding the impact of the Covid-19 pandemic on family life and the ways in which families were adapting to remote learning. We consider the questions: (1) What learning partner roles did parents take on when schools transitioned to remote teaching and did they vary by family income level? (2) How did these learning arrangements manifest for particular families to address the unique challenges they faced? and (3) Were there unexpected benefits? To answer these questions, we analyze responses from parents and other adult caregivers to a series of daily prompts about remote learning at home over the course of approximately two weeks. We present quantitative and qualitative summaries of the types of learning support roles and benefits that were identified across all participants and share two family case portraits that showcase how adults at home supported engagement and learning by extending school assignments, brokering access to resources, and creating and collaborating on projects.

Theoretical background

To frame our inquiry, we draw on ecological and sociocultural perspectives of development. This view foregrounds learning as a cultural process that builds on prior practices and routines but that is characterized by innovation as tools and needs change (Marin & Bang, 2018; Moll et al., 1992). Learning is recognized as deeply social, facilitated by joint attention and mutual engagement with multiple roles for both guides and learners. Finally, learning is viewed as distributed and influenced by activities and resources provided across settings (Nasir et al., 2020). This ecological and sociocultural framing leads to an analytic focus on the ways that both children and caregivers dynamically shape learning activities and social interactions, including ways that learning occurs through "intent participation" (p. 176) by observing and listening in on ongoing activities (Rogoff, 2003). Parents' funds of knowledge, grounded in their own expertise and valued activities, help to shape activities as do children's interests and preferences. Ethnographic studies of family learning find that routine activities such as cooking, going on family outings, and connecting to nature provide opportunities to engage in math and science, even though many learners might not connect these to academic domains (Goldman & Booker, 2009; Zimmerman & Bell, 2014). The expression of parents' funds of knowledge is particularly important to understand now as they take on new roles in supporting their child's social, emotional and academic learning and as they develop novel insights through the process. Accordingly, we focus on how caregivers worked to coordinate, tailor and extend opportunities during this time and begin to describe some of the benefits that resulted. We build on prior research that identified unique parent roles as brokers, collaborators, and guides through varied forms of joint media engagement (Barron et al., 2009; Takeuchi & Stevens, 2010).

Methods

Ethnographic research with families has been a key feature of the literature on family learning and parent roles in supporting children's learning. However, Covid-19 challenged the field to quickly respond at scale to understand the changes that families were experiencing within the constraints of public health orders. In order to document the impact of the pandemic on families as it unfolded, our team chose to conduct a remote diary study with a socioeconomically diverse sample of families around the U.S. Diary studies are a form of experience sampling (Csikszentmihalyi & Larson, 1984) that allows researchers to systematically collect participant reflections on moments in their lives as those moments occur. In previous work, our team tested the method employed in this study for investigating how digital resources are used for learning at home (Barron et al., 2020) and demonstrated its utility for documenting learning moments happening in homes around the country.

Starting in May of 2020, several weeks after schools began closing, we collected daily documentation from 109 families across the U.S., with children aged 5-10 using dscout, a smartphone-based remote qualitative research platform. dscout maintains a panel of over 100,000 participants around the U.S. who are roughly representative of the smartphone owning population. dscout allowed our research team to interact with families and collect rich qualitative data without face-to-face contact, affording broader geographic reach and pandemic-safe practices. The approach also has affordances for participants, including freedom of movement while working through parts of the study and uploading videos and pictures in real time. The ease of submission ensures greater accessibility; a busy parent, for example, can snap a quick picture of their child doing an activity and upload it while also making dinner. Videos taken at home with background noise from children and pets provide rich context previously reserved for expensive and potentially intrusive home visits.

A total of 1,375 people from dscout's participant panel expressed interest in participating by completing an initial screener questionnaire, which included IRB consent to participate in research; 264 respondents fit our study criteria: (a) having a child between ages of 5-10 living at home, (b) the child's school had moved to remote instruction and was in session for the entire duration of the study, and (c) the applicant had given consent for their responses to be used for research. These 264 applicants were sorted into three household income groups: \$0-49K (15%), \$50-99K (44%), \$100K+ (41%). Thirty-seven initial participants were randomly selected from each group. In total, 109 participants from 28 states completed the study. Most (67%) were female and 55% self-identified as white, 16% as Black, and 15% as Latinx, 9% as Asian, and 4% as Middle Eastern or North African. While most participants were parents, some were other adult caregivers in the homes of children (for example, adult siblings, grandparents, live-in partners of a biological parent).

Data collection was organized in five parts that participants completed over the course of two weeks (Table 1); each part included multiple-choice survey items, open-ended text responses, image uploads, and video prompts. Part 3 (learning diary entries) asked participants to capture one learning moment per day for six days. Participants submitted 668 diary entries that each focused on a single learning moment. Our team used a mixed-methods approach to explore the data, including descriptive quantitative summaries; coding open-ended text responses and video transcripts across cases to capture variation in themes using inductive and deductive approaches (Saldaña, 2013); and developing case portraits to help theorize parent-identified examples of learning collected in the diary entries.

Table 1. Data collection components organized in dscout

Component	Topics covered
Application	Demographics; school closing status; remote learning challenges; IRB consent for research
Part 1	Pre-pandemic home and school academic access and support
Part 2	During-pandemic learning resources provided by schools; how parents were supplementing and supporting learning (based on earlier work on parent learning partner roles, Barron et al., 2009)
Part 3	Six unique entries (one per day), each including: photo and verbal description of a learning moment; identification of activity origin and content; ratings of enjoyment and learning
Part 4	How families were learning about Covid-19; examples of questions children were asking and reflection about a conversation they had with their child about the pandemic
Part 5	Reflection on possible benefits of remote learning and insights about what and how their child learned; evaluation of how well child kept up and how caregivers adapted to remote learning

Findings

RQ1: What learning partner roles did parents take on during remote learning?

Participants were asked to indicate if they had "arranged any learning situations for their child while they were out of school due to the pandemic," from a list of items (Table 2) adapted from earlier work (Barron et al, 2009). The majority of parents collaborated with their children on projects and brokered new learning opportunities for them by seeking out online activities. Although many considered themselves to be playing the role of a direct teacher, over a third also reported learning from their child as they navigated learning at home together.

Table 2. Parent learning partner roles

	N participants	%
Collaborating and co-learning		
Collaborated on projects with my child	65	59.6%
Learned something from my child	42	38.5%
Guiding academic work		
Acted as a classroom teacher	50	45.9%
Acted as a project manager to help them manage time/work	32	29.4%
Providing resources		
Used reading materials I had around to support my child's learning	49	45.0%
Bought my child extra books, videos, computing devices to supplement	43	39.4%
Brokering opportunities		
Looked for activities my child can do online	68	62.4%
Signed my child up for an online educational program/website	28	25.7%
Coordinating connections to learning partners		
Asked a family member or friend to help/tutor my child online	10	9.2%
Hired an online educator for other subject areas (music, art, other)	3	2.8%

We compared learning partner responses from three household income groups (lower = \$0-49K, middle = \$50-99K, and higher = \$100K+). Parents and other caregivers reported an average of 4.7 learning partner roles (SE = 0.245) reflecting the diversity and breadth of ways that they were supporting learning. This was not significantly different across home income groups suggesting that despite differences in financial resources all caregivers were finding ways to enhance learning opportunities, complementing what teachers could provide.

Qualitative descriptions of the learning moments shared in the daily diary entries through video reflections allowed us to broaden our understanding of the ways in which caregivers were playing the roles they selected in the checklist. For this paper, we share five roles evident in the ways parents supported their children's learning while school buildings were closed. *Collaborating*, *guiding work*, and *brokering opportunities* are examples of roles apparent in earlier research (Barron et al., 2009) but manifested in slightly different ways during remote learning. *Listening in* and *providing technical assistance* are examples of distinct roles that emerged from this data. Examples are drawn from transcripts of caregiver provided diary entry video submissions describing the learning activity, what was being learned, and who was involved.

Collaborating

Some diary entries described caregivers working and learning together with the child. These collaborative moments spanned different activity types, including family-initiated projects, classroom-generated work, deep learning discussions, and reading a novel together. Importantly, in these moments identified as collaborating, both parents and children are engaged in a shared learning experience as opposed to a child asking for help or a parent instructing them. One example is Lucy's description of a generative open-ended science discussion with her kids that unfolded over the course of an outside walk.

> ...we went on a puddle walk and we talked about all the different things we saw. We talked about things that floated in the water, the different worms that were coming up. …one of those unexpected learning moments where we got to incorporate the fun things and activities and going out into the world and getting some exercise with some learning and talking about just nature and how water- we talked about the water cycle and where rain comes from and what all the clouds were up there for and all those sorts of things while on our puddle walk. (Lucy G)

Guiding academic work

Caregivers often talked about moments during which they were helping their children with schoolwork. Sometimes they directly taught required concepts and skills, while other times they operated in a more supervisory capacity. As supervisors, they helped read and interpret assignment instructions, double-checked their child's work, and helped with time and task management, including ensuring that assignments were completed and online classes were actively attended. For example, Agnes was at the ready to ensure that her Kindergarten daughter was successful achieving the day's academic expectations:

> ...this packet was the math packet and she was doing the tens and ones learning that and actually she knows it pretty well so there was very very little that I need to do. But I was there just in case she did have any questions and then also [to] check her work to make sure that she did it correctly... (Agnes W)

Brokering opportunities

Caregivers frequently play key roles in enabling their child to access learning experiences, such as signing them up for science camp. During remote learning, these brokering moments were identified at a more immediate scale. Caregivers connected their child to activities or learning resources from day to day, based on their child's expressed or observed interests and also specifically to extend or supplement learning activities that originated from school. In this example, Pranav noticed a particularly fun engineering activity her Kindergarten son did during virtual class and encouraged him to continue it in different directions after the class was over.

> So, the teacher gave them the activity, so my kid was creating that cube [using sticks and marshmallows] and, and other kids were creating the cube as well on the Zoom. ... And he really enjoyed this activity and competing with his friends on Zoom, and he was proud to show his teacher. … And we made him, you know, make some other shapes as well after the class, little rectangles and triangles. (Pranav R)

Providing technical assistance

In talking through a learning activity, caregivers sometimes described how they helped with technology requirements. One way was to troubleshoot technology issues as they came up for the child (e.g., resetting routers to address connectivity issues, finding passwords to log their child into an online learning platform, and tracking assignments on learning management systems). This role also covered parents designing technical workflows to enable the submission of assignments or the coordination of novel technology scenarios to support learning. For example, Arielle reported needing to facilitate her fourth-grade daughter's access to assignments:

> The other challenging part is the fact that a lot of the teachers did not send home their textbooks. So, everything is being scanned and given to them through Google Classroom. So that's been

> another problem and what we've been doing is printing them out for them and then I just re-scanned them into the computer to email them to their teachers. (Arielle K)

Listening in

During moments identified as listening in, the caregivers actively observed their child participating in a virtual class or meeting, often listening in from a distance. This type of activity is a common form of human learning in informal settings (Rogoff, 2003). Moments of listening in on virtual instruction were frequently paired with reflections about teacher-child interactions and child engagement, which sometimes prompted associated ideas for further support. For example, through listening in and observing a classroom session over Zoom, Cara admired the teacher's use of familiar tangible referents to teach fractions, particularly noting her daughters' focus, enjoyment, and understanding of the content. This gave Cara new ideas, and in her following diary entry, she extended a play activity with her first-grade daughter to partition shapes using Play-doh.

> And her teacher was really doing a good job in explaining to them how fractions and partition works by showing just practical examples and practical objects like, a piece of cake or a piece of pizza. So the kids will understand it very easily and without complication. ... I really thought that this session was so meaningful knowing my daughter's least favorite subject is Math, she looks so focused and was having fun. It gives me ideas too of how to deal with her when it comes to teaching Math. (Cara P)

RQ2: How did learning arrangements manifest for particular families?

While the quantitative indicators show that all families, regardless of income, took on a breadth of new roles as learning partners during this time of remote instruction due to Covid-19, the integrated case portraits summarize learning across diary entries and illustrate in more depth *how* they sustained their child's engagement in learning. They also contextualize the unique situations they faced and begin to help us understand how new roles and new views led to new insights and ideas. The following two cases differ in the age of their focal child (at the older and younger spectrums of our age range) and household income (higher and lower) but both reveal unique strategies, challenges, and benefits in their stories of learning moments. Table 3 shows a summary of participant-reported data for the two caregiver cases and narrative portraits follow.

Table 3. Summaries of demographic data and responses to roles and benefits as reported by case participants

Participant	Jade	Astrid
Relationship to child	Grandmother	Mother
Child gender, grade, age	5th grade male (11 years old)	Kindergarten male (6 years old)
Home income	Lower (25-49K)	Higher (125-149K)
Highest education level	High school	Post graduate work
Employment status	Part time cashier	Full time work in field of education
Roles identified in the questionnaire (Table 2)	Provided reading materials in the house Purchased new learning materials Found online learning opportunities Collaborated with child Signed child up for online program	Provided reading materials in the house Purchased new learning materials Found online learning opportunities Collaborated with child Learned something from child Acted as a project manager

Jade and Henry: Crafting projects, providing materials, and collaborating to learn

Jade was her fifth-grade grandson Henry's primary caregiver and was deeply involved with his learning during the pandemic. Henry has a documented learning disability and receives extra support from a resource teacher, but Jade's advocacy was important for helping him continue to progress during distance learning. At the start of the pandemic, the school worked to get connected remotely but were slow to provide clear plans and learning objectives that would meet Henry's needs. In response, Jade *listened in* on Henry's classes, occasionally stepping in to *supervise* and *broker activities* as needed to make sure that he had appropriate assignments and support. For instance, in math class Jade noticed that the concepts the teacher was covering were more advanced than the content Henry was working on, and she supported him to leave the meeting and work on math using Zearn or listen to a book from Epic's digital library. Listening in on virtual classes also gave Jade a view into challenges with peer interaction. On one occasion Jade noticed that he was being excluded during a group project, so she intervened with the teacher to allow Henry to work on his own. Connecting with Henry's resource teacher proved to be a recurring struggle because of the teacher's inconsistent Wi-Fi connection and schedule, forcing Jade to become a *technical assistant* for Henry as she monitored her phone for updated schedules and Zoom links. In addition to advocating for Henry's needs and adapting instruction in the moment, Jade *collaborated* with Henry on assignments, such as making a video of them cooking dinner for an assignment, and extending his learning through projects and connecting him to resources. She noticed Henry's interest in a historical fiction show, PBS' "Liberty Kids," originally assigned by his teacher, found the whole series on Hulu, and let Henry watch it in the morning while he played with Legos to improve his hand-eye coordination. For fun, Jade taught Henry how to sprout a carrot from a top, supporting conversations about how roots grow, photosynthesis and how to observe changes over time. Henry was able to share this project with his classmates during an online show and tell session.

Overall, distance learning proved both challenging and rewarding for Jade and Henry. Although Jade frequently expressed frustration in her entries about a range of struggles related to advocating for Henry's needs, she and Henry were able to share moments of excitement and have fun learning together. Having access to personalized instruction platforms enabled Jade to supplement Henry's learning, and she believed that these systems directly led to her grandson's reading and math levels moving forward one year. Additionally, by listening in to Henry's online sessions and observing how well he did when working at his own pace, she developed a more nuanced understanding of his strengths and challenges. In her final reflection she shared her plans to "work hard and be diligent on knowing exactly what he is studying in school to move him forward when he needs to be moved forward," articulating the value of her new role as a learning partner and advocate both in the current moment and in the future.

Astrid and Arlo: Leveraging technology to connect with family and support collaboration

Astrid was minimally involved with her kindergarten son Arlo's schoolwork. Arlo was already reading at a first-grade level and was bored by math worksheets that were too easy for him, which made it hard for Astrid and her husband to keep Arlo engaged with assignments. *Listening in* on class and *supervising* Arlo's work gave Astrid a new perspective on his behavior in class. She reflected, "I understand more why he might talk so much in class… he's bored!! I didn't really know…" Outside of class, Astrid noticed and documented more independent learning—Arlo is an avid reader, which Astrid described in an entry she submitted showing a picture of Arlo sitting in bed with his tablet. She explained that Epic was "like going to a library" for Arlo and that she "got an email from the app that said that he read 17 books yesterday [...] everything from UFOs to some stories about bears." Arlo's access to Epic was going to continue through the summer and Astrid planned to continue encouraging Arlo's use of the app because she saw how easy it was for Arlo to choose books that interested him and further his reading skills. In her final reflection Astrid noted that she and her husband were typically not involved in Arlo's schoolwork and that she appreciated this opportunity to be more involved in his learning. Despite the frustrations of too many apps, too many scheduling challenges, and too much to manage, she valued her new insights about his need to be challenged, made possible by the unique opportunity to sit in during online class sessions.

Overall, Astrid was more concerned about Arlo's social and emotional well-being than his academics. Daily Zoom classes offered some social interaction, but because Arlo was an only child, he and his parents created other opportunities to connect with family remotely and share learning experiences. Video chat access enabled Arlo to read to his three-year old twin cousins and collaborate with his grandfather on a STEM learning project. Astrid *brokered these activities* by being a *technical assistant* and resource provider. It was Arlo's idea to read to his cousins, and he modeled his reading performances for them based on Story Time Online, a site where famous authors read books aloud, reading the text and then showing the pictures in the book to his cousins. Arlo also chose the activity that he wanted to do with his grandfather, creating a balance scale, and Astrid assisted with the digital workflow by taking pictures of the pages of the book and sending them to her father ahead of time. Astrid and her husband were working while Arlo was online with his grandfather, *listening in* but otherwise not involved. She described how, "my kid led the process. My dad followed along and then once they built the scale they measured a bunch of different stuff [...] It was really neat actually just [to] see them working together and it was [...] something that we really hope that we can try to do again."

RQ3: Were there unexpected benefits?

Encouragingly, there were a number of benefits participants reported from partnering with their child during remote learning, including new knowledge and social learning networks (Table 4). Over three quarters of caregivers appreciated the unique opportunity to know more about their child's learning and over one third felt more connected to their child's academic environment, regardless of income.

Table 4. Reported beneficial situations related to teaching and learning at home

	N	%
I am more aware of what and how my child is learning than usual	84	77.8%
I am more connected with my child's school/teacher than usual	44	40.7%
Child teaches other family members	22	20.4%
Relatives and/or family friends are helping my child learn	17	15.7%

On the checklist, both Jade and Astrid reported being more aware of their child's learning, and Astrid additionally reported being more connected to Arlo's school/teacher and that other relatives were involved in his learning. The intersection of parent roles and perceived benefits is clear in both case portraits. Jade listening in on her grandson's class work prepared her to advocate for modifications to better fit his learning style. Her communication with the teacher shifted instructional strategies. Through the unique vantage point of listening in, Astrid gained insights about her son's need for more challenging activities which encouraged the family to embrace personalized content selection through digital libraries. Her coordination of new opportunities for her son connected him to bidirectional learning and collaboration with his grandfather and younger cousins.

Discussion

Our intent was to understand how an economically diverse set of families adapted to the first wave of school closures, the troubles they encountered, and the solutions they generated in real time. In the analyses reported in this paper, we found that caregivers across income groups supported distance learning by collaborating, guiding academic lessons, brokering access to additional resources and coordinating connections to additional partners. We also found parents taking on both new roles and existing roles with variations.

As exemplified in the case portraits, we found that when parents took on responsibilities as co-teachers, collaborators, brokers, and coordinators, they had novel opportunities to observe their child as a learner, expanding their opportunities to informally assess their child's social, emotional, and academic needs and in response design learning arrangements that addressed them. The learning diary data analyses also point to ways that access to technology is only part of ensuring equity of learning opportunities online; unequal access to synchronous classroom experiences may introduce new learning opportunity gaps (Pozos, et al. 2021). For example, when caregivers were able to listen in on synchronous lessons held on video conferences, they generated new insights about what was working for their child or not. These views offered the occasion to draw on teachers' practices to design and tailor their own learning arrangements or to craft alternative learning opportunities to make up for the challenges presented by remote teaching. Listening in during synchronous sessions also allowed caregivers a chance to notice social and emotional aspects of learning remotely, including children's strategies to make themselves comfortable, challenges and benefits of peer interactions, and struggles to focus and pay attention. In the short term, these insights were used to tailor learning activities. In the longer term, some caregivers were positioned to serve as more knowledgeable advocates for their child, a benefit that could lead to consequential outcomes over extended learning pathways (Nasir et al., 2020). Caregivers' experience with technology may also contribute advantages. For example, taking on responsibility as a technical assistant may be easier for those parents who are more fluent with technology (such as those who are themselves using Zoom for their work meetings) and have access to experience with various devices and the devices themselves. These examples of the intertwining of the technical and social aspects of remote learning are consistent with evolving conceptualizations of digital divides as multidimensional, overlapping, and intersectional (Van Deursen & Van Dijk, 2019).

Future directions

As researchers, caregivers, and educators move forward to improve remote learning, novel forms of collaboration and interdisciplinary approaches to knowledge creation will be needed that address the social and technical aspects of equitable learning. Our preliminary findings suggest several directions for use-inspired design and research to help meet the needs of children, caregivers, and the educators who serve them. In particular, these findings reflect the potential for design-based research to identify ways to catalyze new forms of parent/teacher collaboration organized to share insights about learning. Although unintentional, some teachers are implicitly providing caregivers with opportunities to learn about their child as a learner and about their classroom experiences. This insight might be leveraged in future designs that aim to strengthen the distributed teacher-family learning team. It is also clear that teachers have much to learn from the educators at home. Caregiver observations documented in the diary entries showed that they were attending to their child's feelings, their interests, and their understanding of content, providing crucial formative assessment data that most teachers are currently lacking and missing terribly (Darling-Hammond et al., 2020; Reich et al., 2020). The affective dimensions of learning moments are greatly in need of attention, and future work may productively focus on the practices and collaborative conditions that support resiliency as reflected by closer caregiver-teacher communication and mutual support of learners' interest, curiosity, joy and sustained engagement.

References

Alexander, K. L., Entwisle, D. R., & Olson, L. S. (2007). Summer learning and its implications: Insights from the Beginning School Study. *New Directions for Youth Development*, *2007* (114), 11-32.

Barron, B., Martin, C. K., Takeuchi, L., & Fithian, R. (2009). Parents as learning partners in the development of technological fluency. doi: 10.1162/ijlm.2009.0021

Csikszentmihalyi, M., & Larson, R. (1984). Validity and reliability of the experience-sampling method. In *Flow and the foundations of positive psychology* (pp. 35-54). Springer, Dordrecht.

Darling-Hammond, L., Schachner, A., & Edgerton, A. K. (with Badrinarayan, A., Cardichon, J., Cookson, P. W., Jr., Griffith, M., Klevan, S., Maier, A., Martinez, M., Melnick, H., Truong, N., Wojcikiewicz, S.). (2020). Restarting and reinventing school: Learning in the time of COVID and beyond. Palo Alto, CA: Learning Policy Institute.

Goldman, S., & Booker, A. (2009). Making math a definition of the situation: Families as sites for mathematical practices. *Anthropology & Education Quarterly*, 40(4), 369-387.

Kuhfeld, M., Soland, J., Tarawasa, B., Johnson, A., Ruzek, E., & Liu, J. (2020, May). Projecting the potential impacts of Covid-19 school closures on academic achievement. (EdWorkingPaper: 20-226). Retrieved from Annenberg Institute at Brown University: https://doi.org/10.26300/cdrv-yw05.

Marin, A., & Bang, M. (2018). "Look it, this is how you know:" Family forest walks as a context for knowledge-building about the natural world. Cognition and Instruction, 36(2), 89-118.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into practice*, *31*(2), 132-141.

Nasir, N., McKinney de Royston, M., Barron, B., Bell, P., Pea, R., Stevens, R., & Goldman, S. (2020). Learning pathways: How learning is culturally organized. In N. Nasir, C. Lee, & R. Pea (Eds.), Handbook of the cultural foundations of learning (pp. 195-211). Routledge.

Pozos, R.K, Martin, C. K., Barron, B., Lam, C., Nguyen, J., Lin, V., Levy, Z., & Garcia, S. (2021). Before the storm: How families were supported for the transition to distance learning. Annual Meeting of the International Society of the Learning Sciences (ISLS), Bochum, Germany.

Reich, J., Buttimer, C. J., Fang, A., Hillaire, G., Hirsch, K., Larke, L. R., … & Slama, R. (2020). Remote learning guidance from state education agencies during the covid-19 pandemic: A first look. Preprint https://edarxiv.org/437e2/

Rogoff, B., Paradise, R., Arauz, R. M., Correa-Chávez, M., & Angelillo, C. (2003). Firsthand learning through intent participation. *Annual review of psychology*, *54*.

Saldaña, J. (2013). *The coding manual for qualitative research, Second edition.* Sage.

Takeuchi, L., & Stevens, R. (2011). The new coviewing: Designing for learning through joint media engagement. New York, NY: Joan Ganz Cooney Center at Sesame Workshop.

Van Deursen, A. J., & Van Dijk, J. A. (2019). The first-level digital divide shifts from inequalities in physical access to inequalities in material access. New media & society, 21(2), 354-375.

Wang, X. (2020, July 22). New Education Data from the Household Pulse Survey. National Center for Education Statistics Blog. https://nces.ed.gov/blogs/nces/post/new-education-data-from-the-household- pulse-survey

Zimmerman, H. T., & Bell, P. (2014). Where young people see science: Everyday activities connected to science. *International Journal of Science Education, Part B*, *4*(1), 25-53.

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Challenges in Interpreting Student Responses for Three-Dimensional Classroom Assessment

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Abstract: Recent reforms in science education have emphasized the importance of students engaging in three-dimensional learning consisting of science practices, disciplinary core ideas, and crosscutting concepts. However, this kind of learning is challenging to assess, and necessitates multicomponent tasks that allow multiple opportunities for students to share their developing understandings. This paper explores the complexities that arise in interpreting student responses and planning for next instructional steps through the analysis of a three-dimensional, phenomenon-based task for high school students' modeling of cellular respiration. We describe two approaches for looking at student responses, and analyze the affordances and constraints of each method. We conclude by discussing practical considerations for classroom teachers and implications for developing three-dimensional classroom assessments.

Introduction

Science education has been undergoing a major wave of reform in the past decade. Building on shifts in situated and sociocultural theory that frame learning as changes in participation in disciplinary practices over time (e.g. Wenger, 1998), these reforms prioritize students' engagement in what has been called three-dimensional science learning (National Research Council [NRC], 2012). This kind of learning involves students participating in science and engineering practices to learn disciplinary core ideas and apply crosscutting concepts as they seek to explain everyday, observable phenomena around them (National Academies of Science, Engineering and Medicine [NASEM], 2019).

This new vision of science learning has placed great demands on classroom assessments that can capture the complexity of student engagement in disciplinary practice. While the field is developing new approaches to designs for assessment tasks, teachers, assessment and curriculum developers are still determining the kinds of tasks that can truly draw out all three dimensions of students' experiences. At the same time, once students have responded to these tasks, teachers are left to interpret student responses to determine next steps for instruction. This presents a heavy lift for teachers still working to understand the three-dimensional vision themselves.

In this paper, we take the example of a co-designed, three-dimensional formative assessment task for high school biology to examine the complexities revealed when interpreting student responses that combine science practices, disciplinary core ideas, and crosscutting concepts. We examine student responses by disaggregating the three dimensions, as well as holistically, determining similarities and differences that could be consequential to teachers' interpretations and determinations of next steps for instruction. We conclude by identifying design considerations for developing three-dimensional science assessments.

Formative assessment tasks as mediating artifacts

We view learning as changes in participation in disciplinary practices over time (Wenger, 1998). From this perspective, classroom assessment can be viewed as an activity in which teachers and students reflect upon how participation in practice is changing (e.g. Greeno & Gresalfi, 2009). This perspective on learning and assessment is starkly different from prior views of assessment as an activity that seeks to understand the 'knowledge in a learner's head,' framed from behaviorist and cognitive views of learning (Shepard, 2000). Further, we view assessment tasks as mediating artifacts that organize classroom activity (Wertsch, 1998). In the context of three-dimensional learning, where students' participation in disciplinary practice is being assessed, along with their understandings of disciplinary core ideas and application of crosscutting concepts, the tasks serve as material representations of student thinking (e.g. Cowie, Jones & Otrell-Cass, 2011) that teachers and students together reflect upon and respond to as they determine subsequent directions for learning.

Three-dimensional science learning

The new vision of science learning consists of three elements - science and engineering practices, disciplinary core ideas, and crosscutting concepts - in which students participate over time (NRC, 2012). This reconceptualization of science learning is built on the 'practice turn' in situated learning theory (Ford & Forman, 2006). Science and engineering practices are ways that scientists and engineers understand the world around them and design solutions to address problems (Schwarz, Passmore & Reiser, 2017). These practices include modeling, or creating simplified representations of phenomena that make its different elements explicit (e.g. Harrison & Treagust, 2000; Schwarz et al., 2009). Modeling has been called the central practice of three-dimensional learning, as it can be placed at the center of other practices such as asking questions, designing investigations, analyzing data, and developing explanations (Passmore, Schwarz, & Mankowski, 2017). Disciplinary core ideas are the second dimension of three-dimensional learning, and constitute the big ideas in life, physical, earth and space science. The third dimension, crosscutting concepts, are sometimes framed as the questions scientists ask themselves when they don't immediately know the explanation for an observable event (Furtak et al., 2021). Crosscutting concepts include systems and systems models, patterns, scale, and matter and energy cycling (NRC, 2012). The latter of these crosscutting concepts - energy and matter cycling - is unique as it is also a disciplinary core idea. For example, students may learn about the role of energy in force and motion in physics, and then relate energy to endo- and exothermic processes in chemical reactions before learning about energy transfer and transformations in photosynthesis and respiration in a biology course.

These three dimensions are designed to span grade bands and build in complexity as laid out in the Next Generation Science Standards (NGSS; NGSS Lead States, 2013). Accordingly, students' explanations of phenomena will deepen given these multiple opportunities to bridge everyday understandings with scientific principles and develop into describing causal relationships (Braaten & Windschitl, 2011).

Challenges in designing formative assessment tasks for three-dimensional learning

A central element to realizing the new vision of science learning is designing classroom assessment tasks that reinforce, rather than work at cross-purposes with, three-dimensional learning (NRC, 2012; 2014). Formative assessment tasks serve to surface what students know and can do so that teachers and students alike have information about the current learning goals. With this information, teachers can respond accordingly to leverage students' understandings towards meeting the objective. Three-dimensional formative assessment tasks use multiple components to elicit students' three-dimensional learning, and mediate classroom conversations that create space for students to share and respond to each other's developing ideas. In this way, three-dimensional formative assessment consists both of the tasks that teachers can use to draw out student thinking, and the practices that organize classroom activity around the sharing and working out of student ideas (Bennett, 2011).

Not all formative assessment tasks, however, draw out student ideas equally. Kang and colleagues (2014) found that some scaffolds can be more supportive of engaging students in developing an explanation for an observed phenomenon than others. In particular, contextualizing an assessment task with a phenomenon along with another scaffold supports student learning. For example, asking about forces in the context of a skateboarder rolling down a specific hill near the students' school provides an opportunity to apply developing ideas in an everyday and observable context. Then, scaffolding students' responses with sentence starters that help them identify causal relationships, or providing checklists that encourage them to provide specific elements in a model (e.g. to include both visible and invisible components), are more likely to help them share their thinking.

Formative assessment tasks can serve as the 'observation' of what students currently know and are able to do, and then teachers make inferences about the status of student learning to inform subsequent instructional experiences (e.g. NRC, 2001; 2014). The tasks can also serve as mediating artifacts around which other processes - such as whole-class discussions, or small-group conversations - allow students to share their ideas, and get feedback from their teacher and peers. Multicomponent tasks can be designed with this kind of feedback in mind so that students make initial and revised models and explanations, for example, with small-group and whole-class discussions in between. Then, through participating in these discussions, trying out ideas, and listening to their peers, students can integrate new ideas and representations into their models and explanations.

However, these kinds of task formats are still new, and the degree to which those tasks provide interpretable information for teachers is not entirely clear. The methods that teachers currently use for combing through student work to assess and/or identify next steps in instruction may no longer work for such complex three-dimensional tasks. For instance, sorting work into low, medium, and high categories will no longer be straightforward when a task is designed to capture multiple dimensions of learning, and if it contains initial and revised elements. If we are really trying to reconceptualize science learning, the NGSS forces us to rethink not just assessments, but also how to meaningfully interpret the learning demonstrated in such assessments.

In this paper, we seek to determine how we can score and evaluate student responses on these kinds of formative assessment tasks, and identify design considerations to facilitate more effective teacher use of formative assessment to support students' three-dimensional science learning.

Method

This paper analyzes data collected in a multi-year, research-practice partnership with high school science teachers in a large socioeconomically, linguistically, and ethnically diverse school district in the Western U.S. One of the goals of the partnership was to co-design formative assessment tasks around a modeling energy learning progression. In this paper, we focus on two biology teachers who co-designed a task around cellular respiration.

A learning progression for modeling energy

We founded our process of task design on a learning progression as a representation of the ways in which students might progress in their development of a disciplinary core idea or science practice (Corcoran, Mosher & Rogat, 2009). Learning progressions generally start with representing the experiences and preconceptions that students bring with them to school and progress with increasing sophistication of representing and interweaving ideas until reaching a level of mastery appropriate with grade level. We developed a three-dimensional learning progression for modeling energy transfers and transformations within the process of cellular respiration, including specific indicators or "look-fors" (Table 1). As this learning progression has served as a grounding framework for developing tools and routines in our work with supporting teachers to co-design 3-dimensional classroom assessments, it also serves as an analytical lens for evaluating what students know and can do from such tasks.

Table 1: Learning progression and sample DCI-specific look-fors (Buell et al., 2019)

Level	Description	Sample Look-Fors
5	• Students generalize their model to unknown or multiple phenomena and explain limitations of applying the model to a new phenomenon.	• [Task not designed for this level]
4	• Models illustrate a mechanism that can explain or predict the phenomenon, and make predictions about how changing one part of the model would influence energy flows elsewhere. • Students explain how the total energy of the system constrains the magnitude of change possible. • Students describe limitations of the model.	• Relationship between amount of inputs rate of cellular respiration; indicators of conservation and dissipation through different parts of the body; food molecules sustaining life processes
3	• Students' models relate changes in the phenomenon directly to changes in energy through transfers/ transformations by identifying specific, observable indicators. • Students begin to show evidence that their model is accounting for conservation and dissipation. • Model includes energy flows into, within, and out of the system.	• Relationship between amount of inputs and outputs in cellular respiration • Indicators of conservation and dissipation; eg. sweat, heat
2	• Students' models illustrate a relationship or pattern between the increase in one form of energy and the decrease in another form, or transferred from one location or object to another. • Students identify the most relevant components and relationships in the model and distinguish between the system and surroundings. • Model focuses on energy flows within the system only.	• Key inputs and outputs of cellular respiration (including oxygen, carbon dioxide); shows a flow of inputs in and outputs of cellular respiration
1	• Students use or develop a model that shows, through drawings or labels, the components involved in a phenomenon, some (but not necessarily all relevant) energy forms, transfers, or transformations.	• Components include food molecules or oxygen, but not a focus on how energy flows in cellular respiration

Data sources

We analyzed student responses to the respiration task co-designed with high school biology teachers and linked to the learning progression in Table 1. The task presents students with the phenomenon of how visiting athletes who play at elevation experience more fatigue than their 'home-team' counterparts, and was designed for use early in the unit about cellular respiration. The design of the task included multiple activity settings - individual work, as well as small group and whole-class discussions - intended to perform a learning function in which students surface their individual ideas, discuss them in multiple settings, and then create revised models. We analyzed 134 samples of student work collected from two biology teachers across six sections of their classes.

Each piece of student work consists of three subtasks: an initial model, three open-ended written-response questions, and a revised model.

Analytic approach

We developed a multifaceted coding system in order to capture the complexity of responses in students' initial and revised models, and in the explanations they provided on the basis of those models. The coding system allowed us to code each part separately (disaggregated approach, Table 2), and apply codes that looked at the whole task relative to the learning progression as an interpretive framework (holistic approach, Table 1). First, we segmented the student work into three subtasks (the initial model, the explanation, and the revised model). The disaggregated approach treated the initial model, explanation, and revised model as distinct entities. There are three codes for this approach: Phenomenon, Disciplinary Core Idea (DCI), and Type of Explanation. The Phenomenon code captured if students are writing or modeling their explanations in the context of the 'playing football at high elevation' phenomenon (Odden & Russ, 2019; Kang et al., 2014). The DCI code identified scientific content as related to the appropriate NGSS performance expectation (PE). Here, the PE (HS LS1-7) is centered around modeling matter and energy flows in the context of cellular respiration. The Type of Explanation code is meant to capture and identify the different approaches that can be taken in conceptualizing explanations of a phenomenon which might follow a "trajectory from describing 'what' happened to explaining 'how' and 'why' events happen" (Braaten & Windschitl, 2011, p. 663). We then interpreted the codes – which are organized hierarchically - as scores and created sum scores that aggregated student performance on the different categories.

Table 2: Codes for disaggregated approach to analyzing student work

Category	Code	Description
Phenomenon Student response links back to the phenomenon (Odden & Russ, 2019; Kang et al., 2014)	0	Does not refer to original phenomenon posed in task
	1	Refers to phenomenon
DCI (Disciplinary Core Idea) Identifies relevant macro and/or micro-level elements **of cellular respiration** (see Jin, Choi & Anderson, 2009)	0	DCI-related content not present
	1	Observable inputs and outputs, and ideas from everyday experiences
	2	Observable/experiential indicators with *some* identification of molecular inputs and outputs; Begins to connect macro and micro.
	3	Explanation describes *all* inputs and outputs including observable/experiential indicators
Types of Explanation This code indicates the kind of explanation students are using in order to explain the phenomenon (Braaten & Windschitl, 2011)	0	Explanation of phenomenon not present
	1	Everyday explanation
	2	Covering law - phenomena are the result of specific laws or law-like statements
	3	Emerging Causal - explicitly seeking underlying causes for events/phenomena
	4	Emerging Manipulationist - identifying mechanisms that answer how outcomes would change if the mechanism was manipulated or if there is a different desired outcome

Lastly, we used the modeling energy learning progression to holistically code the task as a whole. We drew upon the teacher-designed, performance expectation-specific "look fors" as indicators for holistically assigning the student work to a learning progression level. Although there are five levels to the learning progression, this classroom assessment task was situated at the beginning of an instructional unit and therefore not designed to attain a level 5. Three raters independently coded 20% samples of the student work, improving in Cohen's Kappa as an indicater of interrater agreement each round. Ultimately, given the high-inference nature of the coding approach, researchers adjudicated every piece of student work to reach 100% agreement.

Findings

Our analysis reveals differences, but also key overlaps, in the disaggregated and holistic coding approaches. We first present our findings from the disaggregated coding, and then look at broader themes from the holistic coding relative to the learning progression. Finally, we analyze the association between the two approaches.

Disaggregated approach

Table 3: Summary of Disaggregated and Holistic Coding Approaches

Code		Disaggregated Approach		
		Initial Model	Explanation	Revised Model
Phenomenon *Min=0, Max=1*	Mean	0.95	0.99	0.99
	SD	0.21	0.09	0.09
DCI *Min=0, Max=3*	Mean	1.19	1.31	1.40
	SD	0.80	0.55	0.84
Explanation Type *Min=0, Max=4*	Mean	1.18	2.00	1.37
	SD	0.81	1.02	0.81
		Holistic Approach		
Learning Progression *Min=1, Max=5*	Mean	1.52		
	SD	0.70		

Overall, the disaggregated approach revealed shifts between students' initial and revised models, as well as qualitative differences between student models and explanations (Table 3). The results of the Phenomenon code showed that in almost all instances (not including a small number of blank responses) students were modeling and explaining about the phenomenon. Across the initial model, explanation, and revised model, students referred to the phenomenon an average of 97.7% of the time. There were very few instances in which students provided an explanation devoid of context, which is in line with what we hope to see given the design of the task around a phenomenon.

The DCI and Explanation Type codes reveal differences across the subtasks. Across all student responses, we observed a shift towards more DCI understanding as students progress from the initial model (m = 1.19), to the written explanation (m = 1.31), to the revised model (m = 1.40). These shifts are visible in Figure 1, particularly in how more students reach a level 2 by the time they revise their model.

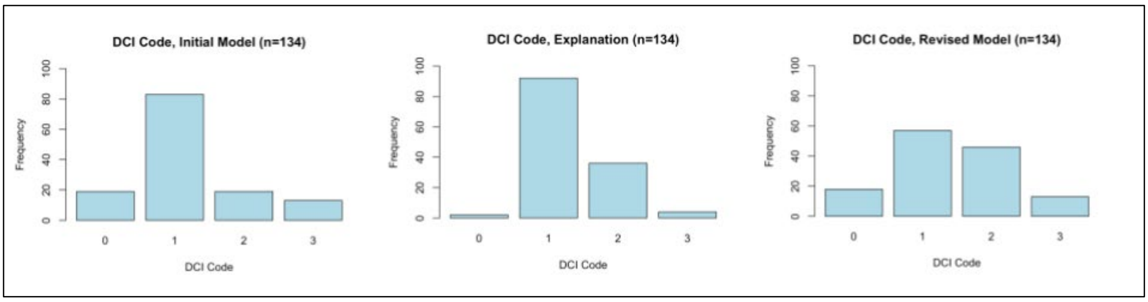

Figure 1. DCI code distribution across the three subtasks

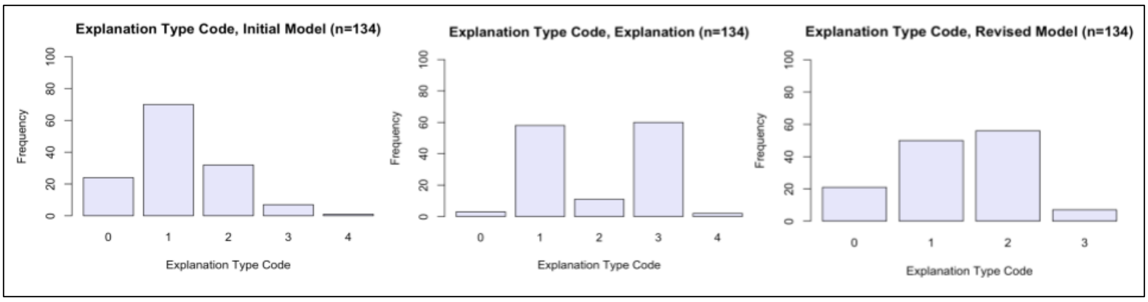

Figure 2. Explanation type code distribution across the three subtasks.

When we considered the explanatory approach of the responses, students shifted from using more everyday explanations towards integrating scientific principles by the revised model. The distribution of Explanation Type for Initial Model is skewed right (see Figure 2), indicating a tendency towards Everyday-type responses. There is a bimodal distribution in the Explanation part of the task, showing high frequencies of Everyday-type and Causal-type responses. This could again be explained by the design of the task as students were asked to explain differences experienced by “home” and “away” players, which might lend itself towards more Causal-type explanations. The distribution in the revised model shows a shift towards more Covering Law-type responses. Overall, this indicates a shift from Everyday-type to more Covering Law- and Causal-type explanations. In Figure 3, we see an illustrative example of a student who begins by drawing upon more everyday language, and by the revised model, has shifted towards including more content knowledge to more fully explain how cellular respiration fuels the football player. Next, we describe how this same example may be interpreted differently using the holistic approach.

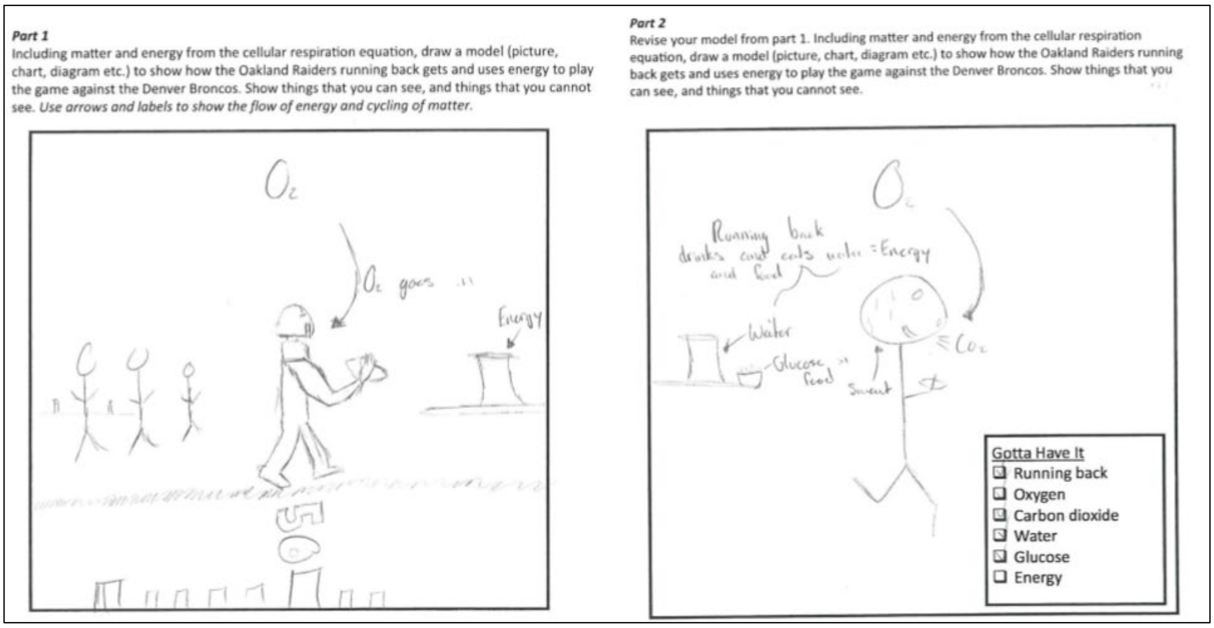

Figure 3. Student work example illustrating shift from initial to revised model.

Holistic approach

To apply the learning progression (LP) code, we looked at all three subtasks holistically and used the context-specific indicators, or “look-fors,” to determine an assigned level. The average learning progression level across all 134 samples of student work was about 1.5 (see Table 3). We can see in Figure 4 that the majority of students were placed at level 1 (n=78), while some students were placed at level 2 (n=41), and a fewer number of students were placed at level 3 (n=15). The high number of students placed at level 1 is not surprising given that this was the first task in the instructional unit. Returning to the student work in Figure 3, this example also highlights the student attending to dissipation of energy through an observable indicator, sweat. Including this element in the model corresponds to a level 3 element on the LP and may otherwise be overlooked by the disaggregated coding scheme.

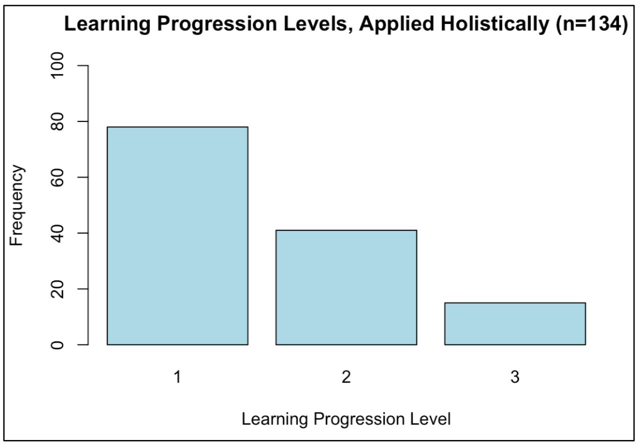

Figure 4. Distribution of holistic approach.

Comparison

When we directly compared each individual student’s disaggregated and holistic score, we found the Pearson correlation coefficient to be 0.78 indicating that the disaggregated and holistic approach are fairly comparable to each other. This indicates that if students are referencing the phenomenon, increasing their DCI understanding, and producing more sophisticated types of explanations, this will likely result in a higher learning progression level. Though, as we can see this relationship illustrated in Figure 5, the variance may be an important consideration for pracitioners. There is more variance with the disaggregated totals and level 1 of the LP, though we see much less variance as we approach level 3. We also see overlap in the disaggregated score between the upper and lower quartiles of adjacent LP levels, so the holistic approach potentially runs the risk of creating distinctions between students whose responses were similar relative to the specified codes. This might indicate a need for a more nuanced approach if analyzing student work falling mostly into level 1. This variance could be explained by students who drew detailed models with multiple elements represented but who may not have been including elements of the LP and might have missed key indicators of energy flow or dissipation, for example. This range may also reflect the difficulty of taking up modeling as a relatively new science practice for teachers and students alike.

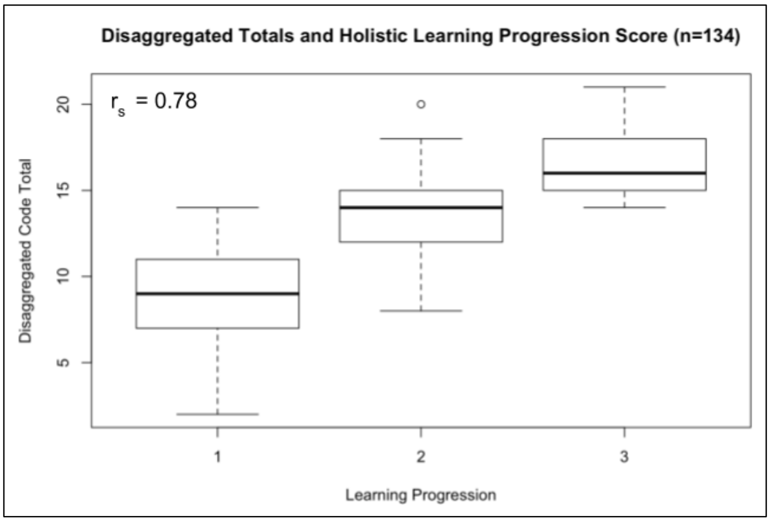

Figure 5. Relationship between disaggregated totals and holistic scores

Overall, our findings suggest that a classroom teacher with upwards of 120 students may find the holistic approach to be the most economical approach to evaluating student work; however, the teacher would want to consider how this approach does not account for changes from the initial to the revised model. Additionally, the holistic approach may be a simpler, mediating artifact for students to reflect on their progress. These results are also consistent with how we might expect the facilitation around a phenomenon to coincide with student gains in modeling energy, where teachers are supporting students in leveraging their everyday understandings towards the goal of modeling energy in the context of cellular respiration.

Discussion

In this paper, we have examined two approaches to scoring multicomponent tasks: a holistic approach, based on an overall appraisal of student engagement in three-dimensional learning, and a disaggregated approach, which provides finer-grained information about student performance. Through our analysis, we found that these two approaches to scoring yielded closely related results; that is, in general, students scoring higher with the holistic approach also had higher overall scores on the disaggregated approach. However, we also found that for students with lower scores in the holistic approach, that were found to be performing at the lowest level of the learning progression, the disaggregated approach revealed more nuances and variations in the nature and quality of their responses. These differences were not as effectively captured when the holistic approach was applied.

These findings have key implications for teacher enactment of three-dimensional formative assessment tasks. Given the complexity of multicomponent tasks and the time-consuming approach of examining individual student responses to different elements of the task, our study suggests that taking a more holistic approach - comparing students' overall responses to a framework that includes disciplinary core ideas, science and engineering practices, and crosscutting concepts together - may be a faster way to determine what students have learned so far, and to identify next instructional steps. However, it also suggests that for students with lower-quality responses, teachers may benefit from spending more time analyzing student responses for additional patterns that could better tailor instruction to meet specific student needs.

At the same time, we note that the benefits of engaging students in complex, multicomponent tasks may far outweigh the challenges of fine-scoring these kinds of tasks. In the context of ongoing efforts to broaden engagement in science learning, particularly for those historically marginalized in classrooms, these kinds of tasks provide important space for students to show what they know and make sense of everyday phenomena. Our disaggregated approach indicated that using these tasks in combination with classroom activities that surfaced and worked with student ideas seemed to support improvement of models and explanations from the first to second part of the task. As such, our analysis indicates that teachers may not even need to closely examine formative assessment tasks such as these, especially since they consume so much time; instead, the teachers may know that the design of the tasks themselves serve a learning function. Future research may more broadly examine this possible finding across a larger range of classrooms and disciplinary contexts.

References

Bennett, R. E. (2011). Formative assessment: a critical review. *Assessment in Education: Principles, Policy & Practice*, *18*(1), 5–25.

Braaten, M., & Windschitl, M. (2011). Working toward a stronger conceptualization of scientific explanation for science education. *Science education*, *95*(4), 639-669.

Buell, J.Y., Briggs, D.C., Burkhardt, A., Chattergoon, R., Fine, C., Furtak, E.M., Henson, K., Mahr, B., & Tayne, K. (2019). A Learning Progression for Modeling Energy Flows in Systems. Boulder, CO: Center for Assessment, Design, Research and Evaluation (CADRE).

Corcoran, T., Mosher, F. A., & Rogat, A. (2009). Learning Progressions in Science: An Evidence-Based Approach to Reform. Philadelphia, PA: Consortium for Policy Research in Education.

Cowie, B., Jones, A., & Otrel-Cass, K. (2011). Re-engaging students in science: Issues of assessment, funds of knowledge and sites for learning. *International Journal of Science and Mathematics Education*, *9*(2), 347–366.

Ford, M. J., & Forman, E. a. (2006). Chapter 1: Redefining Disciplinary Learning in Classroom Contexts. *Review of Research in Education*, *30*(1), 1–32.

Furtak, E.M., Penuel, W.R., Badrinarayan, A., Patrick-Stuart, R.P. & Duwe, S. (2021). Crosscutting concepts: A sensemaking perspective. In *Crosscutting Concepts: Strengthening Science Teaching,* J. Nordine & O. Lee *(Eds).* Arlington, VA: NSTA Press.

Greeno, J. G., & Gresalfi, M. S. (2008). Opportunities to learn in practice and identity. In P. A. Moss, D. Pullin, J. P. Gee, G. Haertel, & L. J. Young (Eds.), *Assessment, equity, and opportunity to learn* (pp. 170–199). New York, NY: Cambridge University Press.

Harrison, A. G., & Treagust, D. F. (2000). A typology of school science models. *International Journal of Science Education*, *22*(9), 1011–1026.

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal for Research in Science Teaching*, *24*, 291-307.

Jin, H., Choi, J., & Anderson, C. W. (2009). Development and validation of assessments for a learning progression on carbon cycling in socio-ecological systems. *Learning Progressions in Science, Iowa City, IA*.

Kang, H., Thompson, J., & Windschitl, M. (2014). Creating Opportunities for Students to Show What They Know: The Role of Scaffolding in Assessment Tasks. *Science Education*, *98*(4), 674–704.

National Academies of Sciences, Engineering, and Medicine. 2019. *Science and Engineering for Grades 6-12: Investigation and Design at the Center*. Washington, DC: The National Academies Press.

National Research Council. (2001). *Knowing What Students Know.* Washington, D.C.: The National Academies Press.

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.: The National Academies Press.

National Research Council. (2014). *Developing Assessments for the Next Generation Science Standards*. Washington, D.C.: National Academies Press.

NGSS Lead States. (2013). Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Odden, T. O. B., & Russ, R. S. (2019). Defining sensemaking: Bringing clarity to a fragmented theoretical construct. *Science Education*, *103*(1), 187–205.

Passmore, C., Schwarz, C. V., & Mankowski, J. (2017). Developing and Using Models. In C. V. Schwarz, C. Passmore, & B. Reiser (Eds.), *Helping students make sense of the world using next generation science and engineering practices* (pp. 109–135). Arlington, VA: National Science Teachers' Association Press.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., Shwartz, Y., Hug, B., & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching*, *46*(6), 632–654.

Schwarz, C.V., Passmore, C., & Reiser, B. (2017). *Helping students make sense of the world using next generation science and engineering practices*. Arlington, VA: National Science Teachers' Association Press.

Shepard, L. A. (2000). *The Role of Assessment in a Learning Culture*. *29*(7), 4–14.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge university press.

Wertsch, J.V. (1998) *Mind as action.* New York: Oxford University Press.

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Which Motivational Factors Predict Pre-Service Teachers' Evidence-Informed Reasoning When Being Confronted With Teaching Problems?

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Abstract: Teachers are typically confronted with various classroom-related challenges every day (e.g., students might have difficulties understanding new concepts). However, they rarely reason about such challenges in an evidence-informed manner. Based on the theory of planned behavior, we examined what motivational prerequisites might facilitate pre-service teachers' engagement in evidence-informed reasoning about classroom-related challenges. $N = 157$ pre-service teachers were asked about their motivation to engage in evidence-informed reasoning and analyzed case scenarios of problematic teaching situations in an online learning environment. Structural equation modeling indicated that attainment value, descriptive normative beliefs, and self-efficacy were important prerequisites for the formation of intentions to engage in evidence-informed reasoning and the subjectively perceived behavior in order to solve classroom-related challenges. The findings suggest to help pre-service teachers carefully reflect and discuss what is part of the teacher role and their identification with this role.

Problem statement

Every day, teachers are confronted with various classroom-related challenges (e.g., students might not be motivated to learn, might not understand subject-matter information, etc). In these cases, teachers must decide how to react to these problems. In their decision-making, they are supposed to take scientific theories and evidence into account (e.g., Bauer & Prenzel, 2012). However, teachers rarely use scientific knowledge for teaching-related decisions (Dagenais et al., 2012; Demski, 2018), even though it is believed to improve the quality of their teaching. König et al. (2014) found that having pedagogical knowledge available is associated with the quality of teachers' interpretation of classroom situations. The rare use of scientific knowledge has also been demonstrated for pre-service teachers who are still in teacher training (e.g., Csanadi et al., 2020).

Among the various reasons for the inadequate use of scientific evidence (see below), we suspect motivational aspects to play an important role, especially for pre-service teachers. Thus, the main research question of the present study is: Which motivational characteristics predict pre-service teachers' engagement in evidence-informed reasoning when being confronted with classroom-related challenges?

Barriers to evidence-informed reasoning

When teachers are confronted with classroom-related challenges, scientific evidence, i.e., especially theories from educational and psychological science and corresponding empirical findings, can help to find effective solutions. However, the function of this scientific evidence is not to dictate what a practitioner should do in a specific situation, but to help to prepare for, to justify and to correct educational actions (Neuweg, 2007). Thus, we use the term evidence-informed reasoning for this kind of behavior throughout the rest of this article.

Though considered helpful, empirical evidence shows that teachers rarely apply evidence-informed reasoning when being confronted with classroom-related challenges (e.g., Dagenais et al., 2012; Demski, 2018). The literature offers a variety of reasons: Among them are limited resources (e.g., time constraints, lack of availability of scientific evidence, or lack of external support) or personal factors (e.g., ability deficits in the use of scientific knowledge, or unfavorable attitudes toward scientific theories, see Dagenais et al., 2012). In a comprehensive empirical investigation of reasons for using research-based information in teaching practice, Lysenko et al. (2014) differentiate four factors that predict the use of research-based information by teaching professionals: (a) awareness activities, i.e., being in contact with research and its application potential, (b) organizational factors, i.e., an organizational environment that supports engagement with research-based information by providing resources and structures, (c) opinions about research, i.e., thinking that research is useful and usable, and (d) individual expertise, i.e., individual skills in interpreting and using research-based information. The external factors (a and b) might be particularly relevant for in-service teachers. However, for pre-service teachers, universities should provide extensive awareness for research-based information and organizational structures and resources ideal to engage with research. In contrast, individual factors (c and d) might be relevant already in teacher education. Lysenko et al. (2014) showed that the motivational factor "opinions" (c) predicted the largest amount of variance regarding the use of research-based information. Further, pre-service teachers' abilities (d) are to be built yet and cannot be presupposed. Therefore, within these internal factors, particularly motivational factors might be crucial in understanding why pre-service teachers use scientific evidence to tackle classroom-related challenges or not.

Theory of planned behavior and evidence-informed reasoning

To conceptualize pre-service teachers' motivation to engage in evidence-informed reasoning, we use the theory of planned behavior (Fishbein & Ajzen, 2010) in the present study because the behavior that is to be predicted can be considered planned behavior. Evidence for this comes from a study by König et al. (2014), who investigated teachers' pedagogical analyses of classroom situations presented in video vignettes. They found that the quality of interpretations of these situations is strongly associated with available declarative and explicit pedagogical knowledge. Hence, the authors argued that interpreting classroom situations is a deliberate, effortful process that requires motivation, which should be especially true for beginning teachers. In addition, the theory of planned behavior is well suited to integrate several motivational predictors at the same time, which is necessary to be able to determine the relative importance of each predictor. So far, previous studies only investigated one kind of motivational predictor, or an undifferentiated mixture of several factors, which will be shown in the following.

According to the theory of planned behavior (Fishbein & Ajzen, 2010), a specific behavior is best predicted by the intention to execute this behavior and the perceived behavioral control (see Figure 1). The intention depends on the attitude toward the behavior, the subjective norm regarding the behavior, and the perceived behavioral control. The latter is to be understood as the subjective estimation of the likelihood that one is able to execute the behavior in a given situation. This corresponds to the concept of self-efficacy expectancy (Fishbein & Ajzen, 2010; Bandura, 1997). In the next sections, we will explain these concepts.

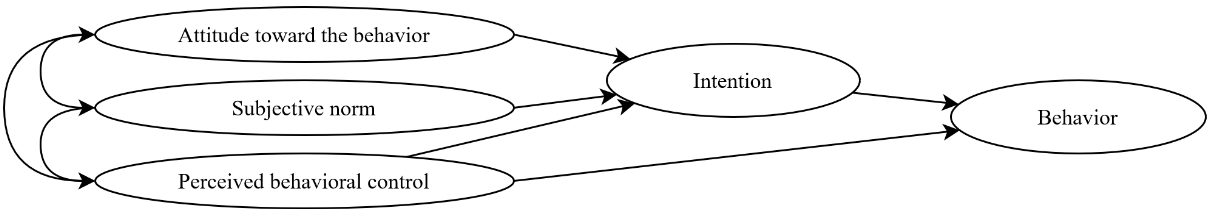

Figure 1. Theory of Planned Behavior (replicated after Fishbein & Ajzen, 2010)

Attitude toward the behavior

Theoretically, the overall attitude toward a behavior consists of various beliefs regarding this behavior, which are salient to the individual in the moment of appraisal. Each belief links the behavior to a specific attribute, e.g., an expected outcome that is a direct consequence of the behavior. Each attribute is of a certain value to the individual, and is realized with a certain likelihood in case the behavior is executed. Thus, the attitude is the sum of all salient beliefs, which in turn represent expectancy*value-interactions of attributes of that behavior.

To conceptualize the global attitude toward a behavior, we use the popular and differentiated distinction by Eccles and Wigfield (2002). The authors distinguish four dimensions of value: utility value, attainment value, intrinsic value, and costs. *Utility value* reflects the perception of the likelihood to which a behavior results in outcomes that lead to consequences positively valued by the individual. *Attainment value* represents how strongly one identifies with the behavior, i.e., perceives the behavior in question as part of one's identity or self. *Intrinsic value* does not describe the value of the consequences of a behavior, but instead the immediate effect of the behavior on oneself while executing it. For example, a behavior might be considered to be interesting or fun. At last, *costs of the behavior*, e.g., time and energy invested, have to be considered as well in order to gather a comprehensive picture of the attitude toward a certain behavior.

In an empirical study, Uhlenbrock (2019) showed that an increase in perceived utility resulted in an increase in several factors regarding the use of evidence-informed reasoning, i.e., strategic knowledge of how to prevent typical errors in evidence-informed reasoning, procedural knowledge of how to identify errors, positive attitudes toward educational science theories, subjective knowledge of educational science theories, and interest in educational science theories. However, the theoretical quality of the written case analysis itself was not influenced by the value manipulations. Kiemer and Kollar (2018) investigated the relation of general attitudes toward research on learning and instruction with actual use of scientific reasoning activities and found a small but significant relation.

Besides these studies, empirical research that investigated pre-service teachers' attitudes toward evidence-informed reasoning is quite scarce. Lysenko et al. (2014) found positive effects on teachers' use of research-based information for several heterogeneous constructs, which mirror the predictors in the theory of planned behavior: The factor "opinions about research" can be considered as an attitude factor because it contains several utility value items (4 out of 7 items). This factor positively and most strongly predicted the use of research-based information. In summary, the literature suggests that attitudes toward evidence-informed reasoning are relevant predictors of the respective intention and behavior.

Subjective norms

As depicted in Figure 1, a second predictor of behavioral intention are subjective norms. In this context, Fishbein and Ajzen (2010) distinguish injunctive and descriptive kinds of subjective norms. *Injunctive norms* reflect what relevant others think what is supposed to be done in a specific situation. *Descriptive norms* represent the perceived actual behavior of relevant others. These two kinds of norms influence behavior of an individual in different ways: While injunctive norms might induce an expectation to receive rewards or punishments when followed or disobeyed, believing that others actually behave in a certain way might offer clues on what is sensible in a specific situation (Fishbein & Ajzen, 2010).

Regarding descriptive normative beliefs, a study of Demski (2018) is informative in the context of evidence-informed reasoning. She asked 1527 teachers and principals with a questionnaire and interviewed 35 of them about reasons for or against the use of knowledge resources based on scientific evidence. The specific use of evidence in order to stimulate new pedagogical behaviors was only reported in schools with the highest average of evidence use in total teaching staff. This effect can be tentatively interpreted as an effect of a school-climate favoring evidence-informed practice: When one's teacher colleagues use evidence in their practice (= descriptive norm), one is more likely to adopt an evidence-informed practice oneself.

Also, in the study of Lysenko et al. (2014), two factors included aspects of subjective norms: In the factor "awareness activities", three out of seven items resembled descriptive normative beliefs (the rest was more about environmental conditions making transfer to practice easier). In "organizational factors", four out of eight items were related to injunctive normative beliefs (the rest was more about opportunities and resources). Both factors were positively associated with the use of research-based information. Thus, overall, the literature suggests both kinds of normative beliefs to be relevant for an engagement in evidence-informed reasoning.

Perceived behavioral control/self-efficacy

The third predictor in Fishbein and Ajzens' (2010) model is *perceived behavioral control*. Though a certain behavior might be attractive (i.e., having a positive attitude toward the behavior) and there might be social pressure to execute this behavior (i.e., strong subjective norms), individuals may still decide not to carry that behavior out. This happens when they believe that their abilities and/or the circumstances prevent successful execution of the behavior in question. Thus, perceived behavioral control is defined as believing that one "is capable of performing a given behavior" (Fishbein & Ajzen, 2010), which is identical to how Bandura (1997) defines the term *self-efficacy* (as long as self-efficacy is understood as a situational, context-specific construct, not a trait). Therefore, we use self-efficacy as the more common term throughout the rest of this article.

The general relevance of teacher self-efficacy for teaching effectiveness is already well established (e.g., Klassen & Tze, 2014). However, a specific investigation of self-efficacy regarding evidence-informed reasoning is scarce. Lawson et al. (2007) investigated self-efficacy and reasoning ability in a sample of non-major biology students, of which a high percentage were pre-service elementary teachers. The self-reported expectancy to perform well in a series of biology tasks they were asked to solve through reasoning was associated with actual reasoning ability measured by a skill test. This finding illustrates that self-efficacy regarding scientific reasoning might be related to actual scientific reasoning. With an operationalization closer to actual teaching practice, Cevik and Andre (2013) had their participants analyze cases including classroom management problems, and decide upon solutions. The quality of decisions was neither associated with self-efficacy ("expectation to do well in this class"), nor with the confidence in the adequacy of their decisions. According to the authors, this might have been due to the general, only domain- but not task-specific nature of self-efficacy measurement. At last, in the study of Lysenko et al. (2014), three out of seven items of the "opinions"-factor focused on expectancy, and the factor "individual expertise" represented abilities and skills necessary to execute evidence-informed reasoning. Taken together, these items could have constituted a self-efficacy factor, whose items are positively related to teachers' use of research-based information.

In conclusion, findings regarding the association between self-efficacy and evidence-informed reasoning about classroom-related problems are mixed: While general reasoning skills seem to be related to self-efficacy (Anderson et al., 1988; Lawson et al., 2007), reasoning in classroom situations seems not (Cevik & Andre, 2013). However, general evidence-informed practice is associated with indicators of self-efficacy (Lysenko et al., 2014). Therefore, we assume that a combination of acting in an evidence-informed way and reasoning about classroom situations is related to self-efficacy if the latter is measured in a context-specific way.

Hypotheses

In summary, a motivational perspective might be a crucial starting point to understand pre-service teachers' engagement in evidence-informed reasoning. Though most of the presented empirical evidence already justifies the expectation that the theory of planned behavior can be used to explain and predict teaching behavior, pre-service teachers' motivation to engage in evidence-informed reasoning has not yet been investigated in a systematic and comprehensive way. Either were the predictors investigated in isolation from each other, or they were grouped into theoretically heterogeneous constructs (Lysenko et al. 2014). Thus, the relative importance of different motivational predictors still needs to be determined. In addition, only a few studies investigated pre-service teachers so far. Thus, our goal was to determine which motivational factors predict pre-service teachers' engagement in evidence-informed reasoning when being confronted with classroom-related challenges.

We establish the following hypotheses:

1. Pre-service teachers' evidence-informed reasoning is predicted by their intention to engage in evidence-informed reasoning and their self-efficacy to perform this behavior.
2. The intention to engage in evidence-informed reasoning depends on various dimensions of (a) attitudes toward evidence-informed reasoning, (b) subjective norms regarding evidence-informed reasoning, and (c) the self-efficacy to perform evidence-informed reasoning.

Method

Sample

Participants were N = 157 pre-service teachers (M_{age} = 22.76, SD = 3.54, 70.1% female) enrolled in two educational psychology classes at two German universities. On average, students were in their fifth semester (M = 4.87, SD = 2.05) without substantial practical experience. Participation in the training elements of the study was a mandatory part of the classes. However, participation in the scientific data collection was voluntary, though no one opted out.

Procedure

This paper reports on data from a larger study that had five measurement points: After a pre-test (t1), in two training sessions (t2 and t3) pre-service teachers received instructional support to enhance their evidence-informed reasoning about the case scenarios. A post-test (t4) and a follow-up (t5) measured the evidence-informed reasoning skills participants acquired over the course of the sessions.

For the present paper, data from t1 (pretest) and t3 (second training session) were used because the following variables were measured at these times only to establish a longitudinal design. The order of assessments was as follows: In t1, after answering demographic items, participants analyzed the first case scenario. After that, they completed a questionnaire directed at measuring the predictor variables of the current study, i.e., attitudes, subjective norms, and self-efficacy regarding the kind of reasoning behavior they just performed. To measure the dependent variables, i.e., intention and subjective behavior, we used data from the second training session to implement a time lag of two weeks. The intentions were measured before the students analyzed the vignettes. The subjective behavior was measured afterwards. To support students in their case analyses in t3, they received evidence texts on CTML, multi-store model of memory, social-cognitive learning, and self-regulated learning, each of about 500-800 words in length, and a couple of reasoning prompts such as "Please explain the problem based on the two evidence texts".

Instruments

Attitudes toward the application of educational science knowledge

Participants indicated on twelve items from 1 (*not at all true*) to 5 (*absolutely true*) how much value they attribute to the structured application of educational science knowledge to teaching problems. The items were adapted from

Stark et al. (2018). All items were phrased using the same sentence starter: "The structured application of educational science knowledge to teaching problems…". Following the model of Eccles and Wigfield (2002), the scale consisted of the facets (three items each) (1) utility value (sample item: "… is useful to learn."), (2) attainment value (sample item "... is personally highly important to learn."), (3) intrinsic value (sample item: "... is very interesting."), and (4) cost (sample item: "... is a waste of time."). A confirmatory factor analysis yielded a good model fit ($X^2(48) = 71.62$, $p = .015$, CFI = .98, TLI = .97, RMSEA = .06, SRMR = .04, all robust estimates) for the theoretical four factor structure, which also was clearly superior to a one-dimensional solution which might have been reasonable regarding the rather high factor covariations. Cronbach's alphas were satisfactory ($\alpha = .78/.82/.85/.84$).

Subjective norms regarding the application of educational science knowledge

On six items (to be answered from 1 = *not at all true* to 5 = *absolutely true*), participants indicated their normative beliefs regarding the structured application of educational science knowledge to teaching problems. The items were specifically developed for this study. The scale consisted of the two facets (1) injunctive and (2) descriptive norms.

Three injunctive normative belief items were phrased using the same sentence starter: "People who have an influence on my later teaching behavior think that I should use educational science knowledge to…" (sample item: "... explain teaching problems."). Three descriptive normative belief items were phrased using the same sentence starter: "I believe that professional teachers use educational science knowledge to…" (sample item: "... explain teaching problems."). A confirmatory factor analysis yielded a very good model fit ($X^2(7) = 9.55$, $p = .215$, CFI = .99, TLI = .99, RMSEA = .06, SRMR = .05, all robust estimates) after inclusion of a residual covariance between the first items of each subscale which is probably due to very similar item phrasing. The two-factor-solution was clearly superior to a one-factor-solution. Cronbach's alphas were good ($\alpha = .88/.86$).

Self-efficacy regarding the application of educational science knowledge

Participants indicated on three items (to be answered from 1 = *not at all true* to 5 = *absolutely true*) their self-efficacy regarding the structured application of educational science knowledge to teaching problems. The items were adapted from the General Self-Efficacy Short-Scale (ASKU; Beierlein et al., 2014). All items were phrased using the same sentence starter: "In the structured application of educational science knowledge to teaching problems,…" (sample item: "... I can rely on my abilities in difficult situations."). Cronbach's alpha was satisfactory ($\alpha = .77$).

Intention to apply educational science knowledge

To measure participants' intention to apply educational science knowledge to teaching problems, we developed five items (to be answered from 1 = *not at all true* to 5 = *absolutely true*) that referred to the dimensions of the problem analysis students were prompted to conduct (e.g., identification of significant instances, explanation of problem). All items were phrased using the same sentence starter: "In the following case analysis, I want to structurally apply educational science knowledge to teaching problems to…" (sample item: "... explain educational problems."). Cronbach's alpha was good ($\alpha = .82$).

Subjective behavior regarding application of educational science knowledge

After the case analysis, participants indicated on five items (to be answered from 1 = *not at all true* to 5 = *absolutely true*) their perceived actual behavior while analyzing the case. The same items as for the measure of intention were used with the sentence starter: "In the previous case analysis, I structurally applied educational science knowledge to teaching problems to…". Cronbach's alpha was good ($\alpha = .84$).

Statistical analyses

To account for sample size restrictions, we used manifest factor scores and applied a stepwise approach to the statistical modeling. First, factor scores were determined by calculating confirmatory measurement models for each predictor group separately and saving the factor scores. In this way, we were able to better represent measurement error compared to an approach using simple means as factor scores. Second, we calculated three separate models predicting intention, i.e., one model with the four facets of attitude as predictors, one with the two kinds of subjective norms, and one with self-efficacy. Third, we entered the significant predictors of each group in the final model (see Figure 2). All CFA and SEM were performed using R [version 4.0.0] with the R-package lavaan [version 0.6-6].

Results

Descriptive results are shown in Table 1. The means of attitude toward the behavior were remarkably high, whereas the other constructs' means were more in the middle of the scale. As expected, correlations within predictor groups were higher than between groups. Intention was associated with almost every predictor except for injunctive norms and self-efficacy. Subjective behavior was significantly associated with every predictor variable except for descriptive norms.

Table 1: Means, standard deviations, and correlations

Variable	*M*	*SD*	1	2	3	4	5	6	7	8
1. Utility Value	4.20	0.59								
2. Attainment Value	4.07	0.63	.76**							
3. Intrinsic Value	3.73	0.74	.64**	.74**						
4. Costs	1.64	0.64	−.58**	−.64**	−.63**					
5. Injunctive Norms	3.95	0.74	.36**	.34**	.27**	−.29**				
6. Descriptive Norms	3.10	0.90	.28**	.25**	.21**	−.22**	.38**			
7. Self-Efficacy	3.62	0.60	.13	.17*	.20*	−.03	.20*	.21**		
8. Intention	4.01	0.50	.36**	.40**	.31**	−.25**	.15	.21**	.14	
9. Subjective Behavior	3.83	0.54	.38**	.37**	.32**	−.18*	.21**	.14	.23**	.50**

Note. $^{*}p < .05$. $^{**}p < .01$.

In the second modeling step, when controlling for covariation with other predictors of the same group, one predictor for each group of predictors was significantly associated with intention. Figure 2 shows the final path model with a reasonably acceptable model fit ($X^2(2) = 5.70$, $p = .058$, CFI = .96, TLI = .79, RMSEA = .11, SRMR = .04). Overall, the associations described by the theory of planned behavior were replicated. Each predictor group contributed to the explanation of intention and subjective behavior: Intention was determined by attainment value and descriptive norms, and subjective behavior was determined by intention and self-efficacy. There was only one exception: Self-efficacy was only directly related to subjective behavior, but not associated with intention.

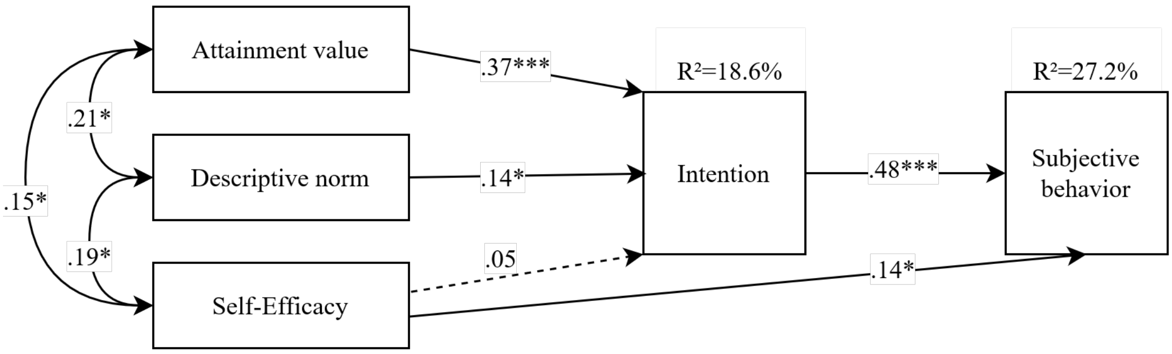

Figure 2. Final Path Model Predicting Structured Application of Educational Science Knowledge to Teaching Problems ($^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$, one-tailed; dotted line indicates non-significant effect with $p = .48$).

Discussion

Our main research question was which motivational factors would predict pre-service teachers' engagement in evidence-informed reasoning when being confronted with classroom problems. In line with the theory of planned behavior (Fishbein & Ajzen, 2010), subjective reasoning behavior was supposed to be predicted by intention to engage in evidence-informed reasoning and self-efficacy (H1). This hypothesis was confirmed by corresponding significant positive regression coefficients. Accordingly, pre-service teachers who intend to engage in evidence-informed reasoning seem to be more likely (to report) to do so when analyzing classroom situations. In addition, the more pre-service teachers feel confident to be able to engage in evidence-informed reasoning in advance, the more they (report to) engage in evidence-informed reasoning afterwards. This association of self-efficacy with subjective reasoning behavior also corresponds to the findings of Lawson et al. (2007) and Lysenko et al. (2014).

Our second hypothesis assumed that intention itself should be predicted by attitudes toward evidence-informed reasoning, subjective norms regarding evidence-informed reasoning, and self-efficacy (H2). This was partly supported in that at least one predictor per group was significantly associated with intention: Among the variables within the construct “attitudes toward the application of educational science knowledge”, attainment value turned out to be a significant predictor. Thus, pre-service teachers seem to form an intention to engage in evidence-informed reasoning especially when they find doing so personally important. Of the two variables measuring subjective norms, only descriptive normative beliefs were significant predictors of intention. This means that pre-service teachers seem to form an intention to engage in evidence-informed reasoning also when they think that (real) teachers typically do so as well. These findings reflect results from other studies that also indicate a positive relation between attitude toward evidence-informed reasoning or, more generally, practice (Uhlenbrock, 2019; Kiemer & Kollar, 2018; Lysenko et al., 2014), and between descriptive norms and evidence-use (Demski, 2018; Lysenko et al, 2014). Yet, the fact that we did not find further significant predictors is opposed to findings indicative of an association of injunctive norms with evidence-use (Lysenko et al., 2014). These findings might be explained by adopting the time perspective of a pre-service teacher: For a person still in teacher training, it might be not so relevant what one can accomplish with evidence-informed reasoning later in their professional life (utility), how much fun it will be to solve a daunting classroom problem with scientific precision (intrinsic), or if it takes a lot of effort or not to engage in evidence-informed reasoning (costs) because all these effects are still far away. In contrast, the reward of feeling like a real teacher might be immediately available just when students behave like they think a real teacher would do. The latter aspect is represented in the descriptive norm, and attainment value represents the intensity of identification with this behavior. Thus, if students think real teachers actually engage in evidence-informed reasoning and at the same time identify with this behavior, then they experience the gratification of living up to their role model as soon as they act in the same manner.

Limitations and conclusions

Of course, our study is not without limitations. Most importantly, since the data is based on self-reports, the association between intention and subjective behavior, especially, might be due to common method bias because of very similar item phrasing, memory effects, and/or social desirability because of the subjective norm to conform with one’s own previous statements. However, we argue that the almost two hours of processing time for the case analyses in between the two measurements should have reduced these effects, because participants should have forgotten what they reported. We are currently coding the participants’ case analyses, so objectively measured behavioral data will be available to corroborate our findings in the future. In general, the effects we found in this study can be considered as rather stable since there was an interval of two weeks between measurement of the predictors and intention. However, the very same interval might also be the reason why there was no effect of self-efficacy on intention: In the meantime, participants’ engagement in another training session might have changed their initially perceived level of competence, thus possibly affecting the intention to engage in evidence-informed reasoning during the next session which was measured in the present study. Finally, we did not specify the kind of teaching problem or the theoretical background useful to analyze it before we assessed pre-service teachers’ motivational predictors to engage in evidence-informed reasoning. Consequently, our measurement might not have been sensitive to moderating effects of the kind of problem or theoretical topic.

As an implication for future research, the relatively superior importance of attainment value in contrast to utility value sheds new light on the findings of Uhlenbrock (2019), who manipulated utility value to increase engagement in evidence-informed reasoning, but who did not find corresponding effects for all representations of evidence-informed reasoning: Maybe, an induction of attainment value instead of utility value might have resulted in more pronounced effects.

The present findings may also inspire the design of teacher education curricula. When aiming at motivating future teachers to make evidence-informed decisions, we empirically derived indicators where to start best. Uhlenbrock (2019) increased the utility perception of educational science theories with a value-inducing intervention. However, our results point to a different approach: As attainment value seems to be the better predictor of the intention to use and the subjective use of educational knowledge when analyzing teaching problems, and as descriptive normative beliefs also play an important role in that context, we assume that involving professional teachers in motivating pre-service teachers might be most promising: If actual teachers model evidence-informed reasoning in authentic situations, pre-service teachers should be more motivated to reason in an evidence-informed way themselves than if university instructors focus on utility or on expectations of what teachers should do that are formulated by the government or research (Bauer & Prenzel, 2012). Thus, teacher training curricula should not prescribe an engagement in evidence-informed reasoning, but should show real teachers in action as role models that are applying evidence-informed reasoning when confronted with classroom-related problems.

References

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 89–197). Academic Press.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. Freeman.

Bauer, J., & Prenzel, M. (2012). European teacher training reforms. *Science*, *336*(6089), 1642–1643. https://doi.org/10.1126/science.1218387

Beierlein, C., Kovaleva, A., Kemper, C. J., & Rammstedt, B. (n.d.). *Allgemeine Selbstwirksamkeit Kurzskala (ASKU) [General Self-Efficacy Short-Scale]*. Zusammenstellung sozialwissenschaftlicher Items und Skalen (ZIS). https://doi.org/10.6102/zis35

Cevik, Y. D., & Andre, T. (2013). Examining preservice teachers' decision behaviors and individual differences in three online case-based approaches. *International Journal of Educational Research*, *58*, 1–14.

Csanadi, A., Kollar, I., & Fischer, F. (2020). Pre-service teachers' evidence-based reasoning during pedagogical problem-solving: Better together? *European Journal of Psychology of Education*. https://doi.org/10.1007/s10212-020-00467-4

Dagenais, C., Lysenko, L., Abrami, P. C., Bernard, R. M., Ramde, J., & Janosz, M. (2012). Use of research-based information by school practitioners and determinants of use: A review of empirical research. *Evidence & Policy: A Journal of Research, Debate and Practice*, *8*(3), 285–309. https://doi.org/10.1332/174426412X654031

Demski, D. (2018). Welche Wissensbestände nutzen Akteure in der Schulpraxis? [Which knowledge assets are used by actors in school practice?]. In K. Drossel & B. Eickelmann (Eds.), *Does ‚What works' work? Bildungspolitik, Bildungsadministration und Bildungsforschung im Dialog* (pp. 101–116). Waxmann.

Eccles, J. S., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology*, *53*(1), 109–132. https://doi.org/10.1146/annurev.psych.53.100901.135153

Fishbein, M., & Ajzen, I. (2010). *Predicting and changing behavior: The reasoned action approach*. Taylor & Francis.

Kiemer, K., & Kollar, I. (2018). Evidence-based reasoning of pre-service teachers: A script perspective. In J. Kay & R. Luckin (Eds.), *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018* (Vol. 2, p. 23). International Society of the Learning Sciences.

Klassen, R. M., & Tze, V. M. C. (2014). Teachers' self-efficacy, personality, and teaching effectiveness: A meta-analysis. *Educational Research Review*, *12*, 59–76. https://doi.org/10.1016/j.edurev.2014.06.001

König, J., Blömeke, S., Klein, P., Suhl, U., Busse, A., & Kaiser, G. (2014). Is teachers' general pedagogical knowledge a premise for noticing and interpreting classroom situations? A video-based assessment approach. *Teaching and Teacher Education*, *38*, 76–88. https://doi.org/10.1016/j.tate.2013.11.004

Lawson, A. E., Banks, D. L., & Logvin, M. (2007). Self-efficacy, reasoning ability, and achievement in college biology. *Journal of Research in Science Teaching*, *44*(5), 706–724. https://doi.org/10.1002/tea.20172

Lysenko, L. V., Abrami, P. C., Bernard, R. M., Dagenais, C., & Janosz, M. (2014). Educational Research in Educational Practice: Predictors of Use. *Canadian Journal of Education*, *37*(2), 26.

Mayer, R. E. (2014). Cognitive theory of multimedia learning. In R. E. Mayer (Ed.), *The Cambridge Handbook of Multimedia Learning* (2nd ed., pp. 43–71). Cambridge University Press. https://doi.org/10.1017/CBO9781139547369.005

Neuweg, G. H. (2007). Wie grau ist alle Theorie, wie grün des Lebens goldner Baum? LehrerInnenbildung im Spannungsfeld von Theorie und Praxis. *Berufs- Und Wirtschaftspädagogik*, *12*. http://www.bwpat.de/ausgabe12/neuweg_bwpat12.pdf

Stark, L., Malkmus, E., Stark, R., Brünken, R., & Park, B. (2018). Learning-related emotions in multimedia learning: An application of control-value theory. *Learning and Instruction*, *58*, 42–52. https://doi.org/10.1016/j.learninstruc.2018.05.003

Uhlenbrock, J. (2019). *Evidenzorientiertes Lehrerhandeln [Evidence-informed teacher action]* [Dissertation]. Universität des Saarlandes.

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Growing Mindsets: Debugging by Design to Promote Students' Growth Mindset Practices in Computer Science Class

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Abstract: Mindsets play an important role in persevering in computer science: while some learners perceive bugs as opportunities for learning, others become frustrated with failure and see it as a challenge to their abilities. Yet few studies and interventions take into account the motivational and emotional aspects of debugging and how learning environments can actively promote growth mindsets. In this paper, we discuss growth mindset practices that students exhibited in "Debugging by Design," an intervention created to empower students in debugging—by designing e-textiles projects with bugs for their peers to solve. Drawing on observations of four student groups in a high school classroom over a period of eight hours, we examine the practices students exhibited that demonstrate the development of growth mindset, and the contexts where these practices emerged. We discuss how our design-focused, practice-first approach may be particularly well suited for promoting growth mindset in domains such as computer science.

Keywords: debugging, motivation, growth mindset, computer science, e-textiles

Introduction

Debugging—the process of identifying and fixing problems and errors that prevent a program from working as expected—is an inevitable and intrinsic part of learning computer programming. Furthermore, it is an essential computational thinking practice (e.g., Brennan & Resnick, 2012) that is often overlooked in K-12 classrooms (McCauley et al., 2008). As Papert (1980) remarked, "errors benefit us because they lead us to study what happened, to understand what went wrong, and, through understanding, to fix it" (p. 114). However, for some students, encountering bugs can generate emotional responses such as fear and anxiety that lead to disengagement and the avoidance of computer programming (Scott & Ghinea, 2013). Prior studies provide ample evidence of how mindsets play an important role within computer science (Burnette et al., 2020, Nolan & Bergin, 2016), as students with growth mindsets perceive bugs as opportunities for learning, and those with fixed mindsets become frustrated with failure and see it as a challenge to their intelligence. Thus, in computer science (CS), promoting growth mindset in the classroom is important since debugging is such an essential practice, and persevering through debugging is critical to students' learning.

Debugging is an area that is particularly difficult for students to learn and challenging for teachers to teach (McCauley et al., 2008). Yet, few studies provide a holistic approach to debugging that takes into account the "inextricable relationship between thinking and emotion" in learning how to persevere and handle failure (DeLiema et al., 2020, p. 210). Traditional pedagogical approaches to debugging tend to involve, highly limited, linear strategies to finding bugs in code (e.g., Silva, 2011) in constrained programming contexts that provide well-timed feedback (e.g., Luxton-Reilly et al., 2018). These approaches usually include only bugs designed by instructors, limiting students' agency over bugs. Further, they only attend to isolated, cognitive aspects of debugging in limited scenarios. In contrast, positioning learners as designers of bugs for their peers could give them greater power over bugs and allow them to be creators and not just solvers. We propose that having students design buggy (rather than functional) computational artifacts for their peers to solve may help promote students' growth mindsets in practice.

In this paper, we examine the growth mindset practices that students exhibited when creating buggy electronic textiles (hereafter e-textiles) projects for their peers to solve and, subsequently, fixing each other's projects. We report on four cases of student groups engaging in our implementation of "Debugging by Design" (DbD), an open-ended design learning activity, in a high school CS classroom over a period of eight hours (Fields & Kafai, 2020). In DbD students work with e-textiles—which involves creating wearables using programmable microcontrollers, sensors and actuators that can be sewn into fabrics (Buechley et al., 2013). Making an e-textiles project not only includes designing functional circuits but also writing code that controls interactions—thus, providing multiple opportunities for bugs in crafting physical artifacts, designing circuits and programming (Searle et al., 2018). Early evidence suggested that when students consciously created bugs, they improved their abilities to detect and fix bugs, collaboratively solved problems, and increased their confidence in debugging

(Fields et al., in press). As such, we observed students to see if and when they demonstrated growth mindset practices. Drawing on the analysis of student team interactions in designing bugs for others; we address the following research questions: (1) What practices do students exhibit that demonstrate the development of growth mindset? (2) When do growth mindset practices emerge during the DbD unit?

Background

Our work builds on longstanding motivational research on the impact of student self-beliefs in learning. Dweck (2006) organized opposing self-beliefs on the capability to develop competencies and qualities in what she calls growth and fixed mindsets. Learners with a growth mindset, those who believe their competencies and capacity can change and be developed over time, have higher resilience in challenging environments than those with fixed mindsets (Yeager & Dweck, 2012). In CS education, growth mindset has gained relevance as learning to code is challenging and encountering bugs is inevitable. For instance, Murphy and Thomas (2008) argue that in computing, while students with a growth mindset perceive bugs as opportunities for learning, those with fixed mindsets become frustrated with failure and see it as a challenge to their intelligence. This resonates with early debugging research which identified that while some learners see bugs as inherent and exciting challenges of learning to code, others become frustrated, perceiving bugs as negative reflections of their performance (Perkins et al., 1986). Indeed, among novice learners, encountering bugs and trying to fix them can generate feelings of helplessness, frustration and anxiety, and promote a fixed mindset (Scott & Ghinea, 2014; Nolan & Bergin, 2016). Furthermore, these feelings and self-beliefs can lead to disengagement, attrition, and the avoidance of computer programming (Scott & Ghinea, 2013; Margolis et al., 2017).

The existing, but limited, research on growth mindset interventions in CS education has yielded promising results that suggest that interventions seem to increase interest, particularly among novices (Burnette et al., 2019). Most of these interventions happen within learning environments, in which teachers delivered information about growth mindset research through videos, lectures, and readings followed by reflective writing and “saying is believing” exercises (Simon et al., 2008; Cutts et al., 2010; Rangel et al., 2020). Other interventions also included testimonials of professional role models that talked about growth mindset and offered tips for success (Burnette et al., 2019; Quille & Bergin, 2020). However, all of these approaches prioritize telling students about growth mindset rather than facilitating student experiences that support its development in practice. Only one intervention proposed the use of a problem-solving checklist for students to track their progress as they programmed projects (Loksa et al., 2016).

Noticeably absent from current research are interventions that actively promote and examine growth mindsets in action. Some attention has been given to how to integrate mindset research in the classroom. For instance, Campbell and colleagues (2020) identified practices, which they call behaviors, that characterize growth mindset in learning activities and situate them within larger learning theories and Haimovitz and Dweck (2017) examined how adult and socialization practices can foster growth and fixed mindsets in children. Building on these works, we investigate growth mindset in action by analyzing how students practice it while engaging in an intervention that centers around debugging. In DbD, we promote growth mindset by putting learners, rather than teachers or researchers, in charge of creating intentional problems and turning bugs into a feature of the learning product rather than a stumbling block. Our research of DbD in this paper focuses on the growth mindset practices that students exhibited when designing bugs for others and solving bugs, as well as the situations where these practices emerged.

Methods

Context and participants

We situated our DbD activities within the e-textiles unit of Exploring Computer Science (ECS), an inquiry-based CS curriculum that is committed to broadening participation in computing through a building talent approach that addresses the structural inequities and beliefs systems that limit participation from historically marginalized groups (Margolis et al., 2017). Within ECS, the promotion of a growth mindset among teachers and students plays an important role, as it puts equity first by considering that all students with access to quality education can grow in engagement and capacity (Margolis et al., 2017). During the e-textiles unit, students work on four open-ended, interest-driven physical computing projects; a paper card with circuits, a bracelet with parallel circuits, a collaborative class mural that has light patterns controlled with switches and finally a hand-crafted sensor to control light effects (see Fields & Kafai, 2020). In these open-ended physical computing activities—that integrate coding, building circuits, and crafting—facing failure and unanticipated challenges is expected and inherent in the learning process (Searle et al., 2018). Students have to think through the distributed nature of physical computing, where problems are spread across different modalities, and must iteratively identify bugs, generate solutions, and run tests (Searle et al., 2018).

DbD was intentionally situated between the third and fourth projects in the E-Textiles unit, after the collaborative class mural described above. This allowed students to bring their experiences with bugs from earlier projects to their DbD designs, and to apply any knowledge gained from DbD to their final project. The activity was designed to take place during eight 50 minutes class sessions over a period of two weeks. At the beginning of the activity students discussed with their partners and the whole class different errors and problems they encountered when working on e-textiles projects. Then, student groups came up with a list of bugs they wanted to include in their designs. After receiving approval from their teacher, students began working on their buggy designs, or DebugIts. Once they finished the buggy projects, they exchanged them with their peers and spent one class period debugging their peers' projects before presenting their solutions to the class.

In Spring 2019, Ben, a teacher with three years of experience in e-textiles that helped co-develop the curriculum, implemented DbD with his students at a high school located in a metropolitan school district in the West Coast of the United States. The class included 11 girls and 14 boys between 14 and 18 years old. Of these students, 72% spoke a language other than English at home, 80% had no previous CS experience, and 80% had family members with at least some college education. The class was ethnically and racially diverse, with 48% of students identifying as Latinx, 36% as Asian American/Pacific Islanders, 8% White, 4% other, and 4% not reporting their race/ethnicity. From the class, four collaborative groups were selected by the teacher for further study in order to represent a range of student interaction and performance including two groups of two students (Evelyn and Nicolás, and Liam and Sophia) and two groups with three students (Lucas, Emma and Lily, and Georgia, Gabriel and Camila) (all participant names in the paper are pseudonyms).

Data collection and analysis

To investigate the growth mindset practices that students exhibited and the situations, challenges or contexts where these practices seemed to emerge; data for analysis was drawn from in-class videologs and observations (recorded in daily field notes) of participants working on their projects as well as interviews (n=10 students). This multiple-source approach provides a fuller picture of what happened in the classroom and the growth mindset practices that students exhibited. Data sources were sorted by date, student group of interest and type.

Data was analyzed in two steps. First, a chronological reading of sources from two student groups focused on inductive descriptive coding (Saldaña, 2013), through which a coding scheme for moments of interest where students exhibited growth mindset practices was developed. These descriptive codes were then clustered into similar categories to detect patterns and interrelationships. This process of clustering was informed by prior theories and previous research on mindset practices and behaviors (Campbell et al., 2020; Dweck, 2006; Dweck, 2000). Following, a coding scheme was developed and discussed with two researchers familiar with the data. After receiving feedback, the coding scheme was revised. In the second round of analysis the coding scheme was applied across all groups through a deductive reading.

Findings

Our analysis in this paper focuses on the growth mindset practices that students engaged in while planning, designing, and solving their DebugIts. This allowed us to see intersections between the cognitive challenges in designing code, circuit and crafting bugs and the motivational and emotional challenges often associated with growth and fixed mindset. We identified five emergent growth mindset practices or behaviors. These practices include: 1) choosing challenges that lead to more learning, 2) persisting after setbacks, 3) giving and valuing praise for effort, 4) approaching learning as constant improvement, 5) developing comfort with failure. While the first four practices coincide with the practices proposed by Campbell and colleagues (2020), the last practice emerged inductively from videolog coding. In the following sections we introduce these five practices, providing examples for each, followed by a case study of how they emerged in the context of one team, and then conclude with an overview of how these practices were distributed across four teams of students.

Growth mindset practices

Choosing challenges that lead to more learning

Throughout DbD, students purposefully chose challenges that led them to learn new things, "throwing themselves wholeheartedly into difficult tasks—and sticking with them" (Dweck, 2000, p. 3). As an example, when making a DebugIt, Emma, a student with very little sewing experience sewing, decided to take on the challenge of sewing a complicated project that required creating one circuit across two different heart-shaped pieces of felt, with lights on one sheet and most of the sewn circuitry on the other sheet. As she struggled sewing the microcontroller on one sheet of felt and connecting it to the LED lights on the other sheet, Emma reflected, “probably I should do more craft,” a recognition of her need for more expertise in sewing (Lesson 3, Video). Yet even knowing she had little experience in this area, Emma was the one that proposed arranging the electronic components in this spatially complex way and, mischievously, to embed a short circuit between the two layers of felt. This is just one of many examples of ways that students consciously chose challenges that led them to deeper learning.

Persisting after setbacks

Setbacks are a normal part of debugging that can cause frustration and at the same time provide opportunities for students to persist. For this practice we identified two subcategories: preceding frustration and persistence. Frustration as part of the learning process is meaningful because it creates opportunities for students to persist and, as Dweck (2006) writes, “to turn an important setback into an important win” (p. 93). We observed how frustration sometimes precedes persistence and other times co-occurs in instances of persistence. As an example of frustration preceding persistence, when fixing a circuitry bug in her sewing, Evelyn exclaimed: “This is too much… I don’t know what’s wrong with it.” She was upset and frustrated. Her partner, Nicolás, encouraged her, but she insisted she didn’t know how to fix it. Nicolás offered to help, “déjame [let me] look at it” (Lesson 7, Video). Twenty minutes later, and after working on other aspects of the project, Evelyn persisted and continued folding and bending the artifact to get it to work until the lights turned on. During this process, Evelyn discovered that the problem was in loose connections of the conductive thread. “I could have fixed it a long time ago, if I knew the connections were all loose” she reflected (Lesson 7, Video). On a different instance, Evelyn seemed upset dealing with a bug and Nicolás encouraged her: “You can fix it! Fix it!” (Lesson 7, Video). In this instance, frustration and persistence co-occurred. Despite her frustration, Evelyn kept sewing and managed to get the lights to turn on. Thus, with encouragement from her partner, as Evelyn persisted, she evaluated and analyzed the problems, looking for alternative ways to solve them. These two examples illustrate the occurrence and the co-occurrence of frustration and persistence; and how setbacks, although frustrating, became opportunities for learning in the process of creating and solving bugs.

Giving and valuing praise for effort

While working on their DebugIts, students praised each other’s efforts, strategies and process. This kind of praise fosters mastery-oriented responses when facing difficult problems (Dweck, 2000). In one instance, after finding several unintentional problems in her circuit Emma reflected and suggested a possible solution: “I always forget to tie the knots, it’s so annoying, I better tie them as I go along.” Lucas praised her proposed strategy and the process of getting to it by saying, “Smart thinking!” (Lesson 3, Video). In a different instance, in Emma’s group, praising and encouraging effort demonstrated what Love (2019) calls cultural legacy, that is the traditions and customs of culture, in self-beliefs. Emma had to add a short circuit bug in which two threads intersected. Her teammates, Lucas and Lily, were worried they would finish on time. “What time is it? Do you think I’ll finish?,” Emma asked. In response, Lily and Lucas started chanting Dolores Huerta’s “¡Sí se puede!” (Yes we can) to encourage and praise Emma’s effort (Lesson 4, Video). The “¡Sí se puede!” chant, which emerged in the 1970s during the civil rights movement for farm and immigrant worker rights in the Southwestern United States, is an expression for encouraging effort and persistence with great cultural and historical significance in Latinx communities. This praise and encouragement from peers for effort promotes growth mindset by framing setbacks and challenges as inherent aspects of learning that can be overcome with persistence.

Approaching learning as constant improvement

Student teams also embraced learning as constant improvement and looked for ways to improve their projects and their competence. As Dweck (2000) argues, this reflects a desire to learn, get smarter, and acquire new skills. We see this when, after Lucas finished writing the code and reported that he had made all the suggested changes, Emma responded by saying, “let me see what other things we can do” and proposed several ways they could improve the project (Lesson 3, Video). In a complementary episode later, after Emma tested whether the stitches and knots were strong enough by turning the project upside down, Lucas suggested they checked the wires to make sure they were not touching, taking on the role of looking for opportunities for improvement (Lesson 3, Video). In these two examples we can see how students supported each other in seeking opportunities to improve their performance and saw the goal of learning as constant improvement and not just showcasing or achieving a certain level of performance.

Developing comfort with failure

Developing comfort with failure generates opportunities for learners to embrace and overcome mistakes with proper motivation and guidance (Dweck, 2000). When learners are worried about failure they are more likely to develop a fixed mindset and question their ability while learners with a growth mindset “see their own failures as problems to be solved, and they see other people's failings that way as well" (Dweck, 2000, p. 88). In DbD, we identified that students were comfortable with failure particularly by not being afraid of being wrong when: 1) asking questions and requesting feedback, 2) sharing failure with their peers, and 3) embracing failure and imperfection as part of the process. Sophia, for example, not afraid of being wrong when sewing a circuit, asked Liam "Can positive and positive cross each other?" (Lesson 1, Video). This is one of many instances in which students constantly requested feedback from peers without any fear of being wrong. Further, when learners encountered failure while working on their projects, it was not uncommon for them to openly share failure with their peers. As an example, Lucas shared his coding mistakes saying "Oh! I messed up! Wrong in the coding!" (Lesson 3, Video), while Evelyn shared "Oh my god! I was going to keep going without sewing up the light!" when she noticed a gap in sewing and laughed at her own mistake (Lesson 4, Video). These are instances of seeing failure as something worth sharing. Furthermore, students embraced imperfection and failure as a feature of their projects—separate from the intentionally designed bugs. For instance, when Emma noted that the two heart-shaped pieces of felt of the group's project were not perfectly aligned she described them as "a little bit off, but it's okay". She also went on to offer a simple, imperfect solution, saying "we'll just cut it off, it doesn't have to be perfect" (Lesson 4, Video). These are some examples of how students were not afraid of being wrong, "messing up," making mistakes and or having imperfect projects. Developing comfort with failure helped students reframe failure as a setback they could overcome and as opportunity for learning.

A case study of growing mindsets

One case study group—Georgia, Gabriel and Camila—illustrates how the five growth mindset practices described above came up in the context of the DbD unit. Growth mindset practices appeared from the very beginning of the group's work. As the group brainstormed what they wanted to make for their DebugIt and the bugs they wanted to include (see Figure 1), Camila suggested an area that went beyond the group's current expertise: making a piano and coding music. Gabriel hesitated to agree, "we've never used music before and we have two days" (Lesson 2, Video): they had not learned about coding music previously in the class and did not have much time to figure it out by themselves, but they did have access to a supplementary instructional guide on music with e-textiles. Ben, their teacher, who had overheard the conversation about coding music, encouraged the team to do it and even to create a bug related to music. They decided to play Twinkle, Twinkle, Little Star and to have Gabriel code it. This required understanding how to code notes by defining pitch and duration in numerical values with new commands in Arduino. Although Gabriel shared with his peers that he had "no clue how to code music," he took charge of this new challenge and learned about frequencies and tempo with an instructional guide. Of note, Gabriel's choosing to take on this new challenge happened in the context of both peer and teacher support.

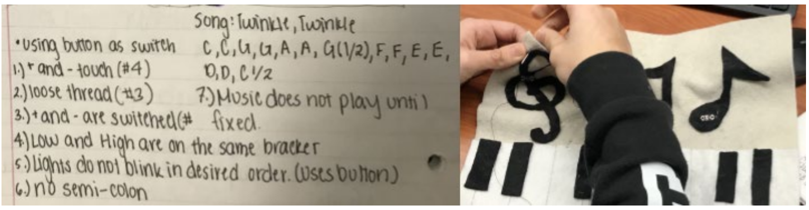

Figure 1. Georgia, Gabriel and Camila's DebugIt: (1) Left: list of bugs included in their project plus order of tones; (2) Right: Georgia sewing musical notes above the keyboard.

As Camila and Georgia worked on crafting the keyboard, Georgia became frustrated when gluing the musical notes: "I can't do this, I physically can't do this" (Lesson 3, Video). It was hard for her to calculate how much glue to apply on the felt. "I don't like glue, now it's a mess," she complained, having poured glue all over the project. Georgia's frustration created an opportunity for her to persist and overcome this setback, which she did with the support of her peers. Camila provided just-in-time praise for effort to motivate her friend to keep going: "you're almost there Georgia, that looks very good" (Video Lesson 3). Georgia persisted and tried different strategies: first using a piece of felt to apply it and then using the tip of the bottle to spread it. The latter strategy worked, and satisfied, she praised her own work "this [keyboard] looks so good!" (See Figure 1). We can see here how two mindset practices worked together: frustration generated opportunities for persistence, and just-in-time praise for effort helped reframe setbacks as inherent aspects of learning that can be overcome with persistence.

As work on the project continued, Georgia shared her mistakes when she took on a challenge that led to more learning. Georgia, who had little experience sewing and crafting, told her peers "I'm just warning you I'm not the best at sewing" as she started sewing the circuit. Not afraid of failure, Georgia shared her problems with Camila who helped her tie knots and make her connections tight. They shared their failures with each other and laughed together about the unintentional mistakes they made. Camila, for example, shared that she sewed an LED to the wrong pin of the microcontroller and Georgia shared that she sewed an LED backwards. Comfortable with failure, when students chose challenges that led to more learning, they embraced mistakes and overcame them.

When coding *Twinkle, Twinkle, Little Star*, Gabriel persisted after encountering many setbacks and frustration. He did not know how to trigger the song to play, but after fixing many unintentional bugs in his code and asking the teacher many questions he managed to make the microcontroller play music. When it worked, with frustration, he said "I have no clue why it sounds so hideous, this is devilish trap music" (Video Lesson 4). His peers agreed and did not like the sound. Yet, he persisted and continued working on improving the song and on the last day of designing he was able to play it to the teacher and his peers. The music became an Easter egg in the project: they used the light sensor on the microcontroller to trigger the song. Gabriel explained: "if you take the flash on your phone and put it on your CP [microcontroller] it'll make sounds happen." This is an example of how when students chose challenges that led to more learning, their frustration became an opportunity to overcome setbacks, persist when things do not go as expected, and approach learning as constant improvement. The team embraced learning as constant improvement in other instances as well, when they looked for ways to improve their project and their performance. When Gabriel was done with the code he insisted they had to test it to see if it worked as expected and if not to fix it. They tested several times, and every time they came up with new ideas of how to improve the project.

Growing mindsets across groups

This case illustrates how students engaged with growth mindset practices in the context of DbD. We identified 75 instances in which Georgia, Gabriel and Camila engaged with these practices. They were not the exception. The four groups we analyzed engaged in all identified growth mindset practices in 230 instances. Figure 2 shows the frequency of instances of each practice by group of interest as well as information about the context of each instance, when they occurred (e.g., when planning the project), and who was involved (e.g., teacher and learner). As we saw in our case study, students engaged with growth mindset practices through peer-to-peer and learner-teacher interactions when planning their projects (e.g., making a circuit diagram), making buggy projects, and debugging their peers' projects. Most of the instances of growth mindset practices identified (56%) occurred when learners made buggy projects for their peers to solve. Most of the instances coded (78%) occurred when peers interacted with each other, although we also identified growth mindset practices when students worked alone or in learner-teacher interactions.

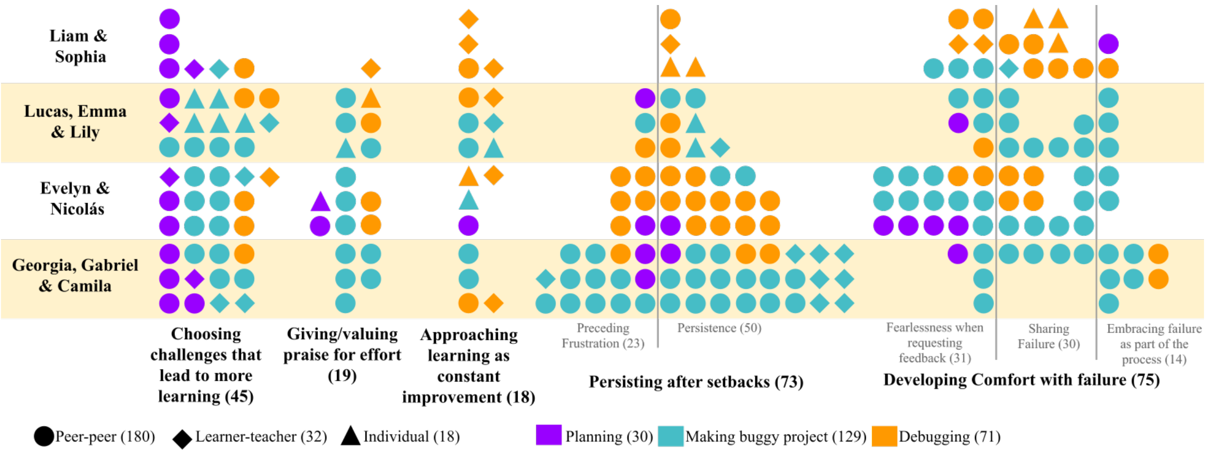

Figure 2. Visualization of instances of growth mindset practices by student group; color indicates when the instance occurred, and shape indicates who was involved.

Discussion

We analyzed the growth mindset practices that students exhibited in DbD, an intervention designed to empower learners in becoming more familiar, comfortable and capable with debugging. In the following sections, we discuss our instructional design rationale, what we learned about developing students' growth mindset practices, and directions for further research.

In designing DbD, we built on a longstanding tradition of constructionist activities that put learners in control of their own learning by designing applications for others (Harel & Papert, 1990, Kafai, 1995) and extended this concept by shifting the focus from designing functional artifacts to designing non-functional, or buggy, projects. By making learners designers rather than finders of bugs, we created an environment in which students were in control of naming and creating mistakes. DbD provides a compelling example of what Dweck and Yeager (2019) called for, “an examination of the mindsets conveyed by or embodied in the environments that students (or adults) are in” (p. 490). This proactive design approach contrasts with previous growth mindset interventions where teachers explicitly instructed students on growth mindset theory or practices (e.g., Simon et al., 2008). While explicit instruction and reflection on growth mindset can certainly help students, we suggest that our design-focused, practice-first approach may be particularly well suited to domains like CS that involve iterating, testing, and debugging. Putting students in charge of designing mistakes for their peers to solve could be applied to other areas of CS education as well other disciplines.

Furthermore, our analysis of four groups of students provided insights into how learners develop their growth mindsets and become more comfortable with debugging. Students engaged in practices such as choosing challenges that led to more learning, praising effort, approaching learning as constant improvement, persisting after setbacks, and developing comfort with failure. This last practice complements those practices mentioned in Campbell and colleagues’ (2020) framework of practices for growth mindset learning activities, acknowledging mistakes and failures as “an intrinsic part of the learning process” (Papert, 1980, p. 153). Combined, these practices promote debugging as a holistic process that involves thinking and emotion (DeLiema et al., 2020), rather than a basic skill for identifying isolated problems. Of further note are the critical roles that peer collaborations and teacher support played in the DbD unit. The development of the observed growth mindset practices mainly occurred through interactions with peers, while they made buggy projects together. But these peer-supported practices did not happen accidentally, our implementation of DbD was conducted by a highly experienced teacher that promoted a classroom culture that encouraged student collaborations, legitimized student expertise, and modeled comfort with failure (Fields et al., in press).

We reported on the first classroom-based implementation of DbD. Further studies should examine how other teachers can foster growth mindset practices when applying the unit in their classrooms. In addition, we must examine the impact of DbD on students’ continued programming efforts and compare it to students who did not engage with the unit. Furthermore, we need to examine how growth mindset practices exhibited in the classroom relate to the perceived growth mindset of students and teachers as measured in self-reported instruments. Lastly, the idea of making students designers of bugs, or mistakes, is not limited to CS education and could also be applied to other STEM contexts in which students design artifacts. Students can benefit not only from designing applications but also from designing mistakes—both are and should be an intractable part of any learning production.

References

Buechley, L., Peppler, K., Eisenberg, M., & Yasmin, K. (Eds.) (2013). *Textile Messages: Dispatches from the World of E-Textiles and Education. New Literacies and Digital Epistemologies*. Peter Lang.

Burnette, J. L., Hoyt, C. L., Russell, V. M., Lawson, B., Dweck, C. S., & Finkel, E. (2020). A growth mind-set intervention improves interest but not academic performance in the field of computer science. *Social Psychological and Personality Science*, 11(1), 107-116.

Campbell, A., Craig, T., & Collier-Reed, B. (2020). A framework for using learning theories to inform ‘growth mindset’ activities. *International Journal of Mathematical Education in Science and Technology*, 51(1), 26-43.

DeLiema, D., Dahn, M., Flood, V. J., Asuncion, A., Abrahamson, D., Enyedy, N., & Steen, F. F. (2020). Debugging as a context for collaborative reflection on problem-solving processes. *Deeper learning, communicative competence, and critical thinking: Innovative, research-based strategies for development in 21st century classrooms*, 209-228.

Dweck, C. S. (2000). *Self-Theories. Essays in Social Psychology*. Psychology Press.

Dweck, C. S. (2006). *Mindset: The new psychology of success*. Random House.

Dweck, C. S., & Yeager, D. S. (2019). Mindsets: A view from two eras. *Perspectives on Psychological Science*, 14(3), 481-496.

Fields, D. A., & Kafai, Y. B. (2020). Debugging by Design: Students’ Reflections on Designing Buggy E-Textile Projects. *Proceedings of Constructionism 2020*.

Fields, D. A., Kafai, Y. B., Morales-Navarro, L., Walker, J.T. (in press). Debugging by Design: High School Students’ Learning Experiences and Reflections about Programming Failure Artifacts. *British Journal of Educational Technology*.

Haimovitz, K., & Dweck, C. S. (2017). The origins of children's growth and fixed mindsets: New research and a new proposal. *Child Development*, 88(6), 1849-1859.

Harel, I. & Papert, S. (1990). Software design as a learning environment. *Interactive Learning Environments*, 1(1), 1-32.

Kafai, Y. B. (1995). *Minds in play: Computer game design as a context for children's learning*. Norwood, NJ: Ablex.

Loksa, D., Ko, A. J., Jernigan, W., Oleson, A., Mendez, C. J., & Burnett, M. M. (2016, May). Programming, problem solving, and self-awareness: effects of explicit guidance. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (pp. 1449-1461).

Love, B. L. (2019). *We want to do more than survive: Abolitionist teaching and the pursuit of educational freedom*. Beacon Press.

Luxton-Reilly, A., McMillan, E., Stevenson, E., Tempero, E., & Denny, P. (2018, July). Ladebug: an online tool to help novice programmers improve their debugging skills. In *Proceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education* (pp. 159-164).

Margolis, J., Goode, J., & Flapan, J. (2017). A Critical Crossroads for Computer Science for All: "Identifying Talent" or "Building Talent," and What Difference Does It Make?. In Moving Students of Color from Consumers to Producers of Technology (pp. 1-23). IGI Global.

McCauley, R., Fitzgerald, S., Lewandowski, G., Murphy, L., Simon, B., Thomas, L., & Zander, C. (2008). Debugging: a review of the literature from an educational perspective. *Computer Science Education*, 18(2), 67-92.

Murphy, L., & Thomas, L. (2008, June). Dangers of a fixed mindset: implications of self-theories research for computer science education. In *Proceedings of the 13th annual conference on Innovation and technology in computer science education* (pp. 271-275).

Nolan, K., & Bergin, S. (2016, November). The role of anxiety when learning to program: a systematic review of the literature. In *Proceedings of the 16th koli calling international conference on computing education research* (pp. 61-70).

Papert, S. A. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic books.

Perkins, D. N., Hancock, C., Hobbs, R., Martin, F., & Simmons, R. (1986). Conditions of learning in novice programmers. *Journal of Educational Computing Research*, 2(1), 37-55.

Quille, K., & Bergin, S. (2020, June). Promoting a Growth Mindset in CS1: Does One Size Fit All? A Pilot Study. In Proceedings of the 2020 *ACM Conference on Innovation and Technology in Computer Science Education* (pp. 12-18).

Rangel, J. G. C., King, M., & Muldner, K. (2020). An Incremental Mindset Intervention Increases Effort During Programming Activities but Not Performance. *ACM Transactions on Computing Education* (TOCE), 20(2), 1-18.

Scott, M. J., & Ghinea, G. (2013). On the domain-specificity of mindsets: The relationship between aptitude beliefs and programming practice. *IEEE Transactions on Education*, 57(3), 169-174.

Scott, M. J., & Ghinea, G. (2014, July). Measuring enrichment: the assembly and validation of an instrument to assess student self-beliefs in CS1. In *Proceedings of the tenth annual conference on International computing education research* (pp. 123-130).

Silva, J. (2011). A survey on algorithmic debugging strategies. *Advances in engineering software*, 42(11), 976-991.

Searle, K. A., Litts, B. K., & Kafai, Y. B. (2018). Debugging open-ended designs: High school students' perceptions of failure and success in an electronic textiles design activity. *Thinking Skills and Creativity*, 30, 125-134.

Simon, B., Hanks, B., Murphy, L., Fitzgerald, S., McCauley, R., Thomas, L., & Zander, C. (2008, September). Saying isn't necessarily believing: influencing self-theories in computing. In *Proceedings of the Fourth international Workshop on Computing Education Research* (pp. 173-184).

Yeager, D. S., & Dweck, C. S. (2012). Mindsets that promote resilience: When students believe that personal characteristics can be developed. *Educational psychologist*, 47(4), 302-314.

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Developing Progressive Knowledge Building through Idea-Friend Maps and Opportunistic Collaboration

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Abstract: We designed and examined a knowledge-building environment in which representations of a learning analytics tool called Idea-Friend Maps (IFM) and opportunistic collaboration were used to scaffold progressive knowledge building in authentic scientific practices. Fifty-two Grade-Five students in a large class in China participated and worked on *Human Input and Output*, mediated by the online platform Knowledge Forum. Student groups were provided with analytics information generated from Knowledge Forum discourse as IFM to support cross-group fertilization and progressive knowledge building. Quantitative results using social network analysis of word networks show collective knowledge advancement and changing trajectories over time. Qualitative analysis using a framework demonstrates how students pursued related ideas from other research groups, identified the current state and future direction of community knowledge, and created new knowledge by crossing boundaries with IFM and opportunistic collaboration. This study sheds light on the role of learning analytics and opportunistic groups to scaffold young children to engage in authentic scientific practices like scientists.

Introduction

How to equip learners with capacities for knowledge creation and innovation has become a great challenge facing education (OECD, 2019). *Knowledge Building* is a major model in this field, which aims to facilitate the transformation of education by introducing the concept of knowledge-creating communities (Scardamalia & Bereiter, 2014). In such a creative community, the teacher plays a facilitator's role, while the students' collective epistemic agency is stimulated to advance collective knowledge. Therefore, an online platform Knowledge Forum® was developed to allow students to post problems, co-construct explanations, and conduct sustained inquiries for collective knowledge advancement. Notably, knowledge building is premised on the notion of scientific communities (Bereiter et al., 1997). Engaging students in the kind of knowledge building just like scientists who progressively extend existing knowledge rather than seeking a static source of "truth" (Bereiter et al., 1997) is of much importance, as highlighted by recent reforms in science education (NGSS Lead States, 2013). Though this approach has attracted great interest, progressive knowledge building in scientific practice is often limited in pre-designed activities and tasks (Chinn & Malhotra, 2002).

Concerning scientific practice, Nielsen (2013) points out the role of science as a form of communicative action (scientific communication) in promoting progressive knowledge building. He further classified lab (group) communication and peer review as essential elements of scientific communication. However, how different scientist groups engage in cross-group scientific communication for progressive knowledge building in authentic scientific practices is worth further inquiry. Moreover, while flexible engagement and emergent inquiries in knowledge building are encouraged, students may feel it challenging to understand the changing status and the cutting edge of collective knowledge, similar to scientists' need to identify promising research directions. These issues bring out the questions of how to identify the promising and emergent ideas in the socio-cognitive knowledge-building environment for collective knowledge advancement. Thus, two design considerations were inspired: (1) how to design social configurations to help students engage in scientific communication like researchers; (2) how to visualize changing ideas by learning analytics so that students could identify and pursue collective ideas like researchers.

Zhang et al. (2009) examined various social configurations, including fixed groups (students working in fixed groups), interactive groups (working in fixed groups and also carrying out cross-group activities), and opportunistic groups (working temporarily in groups formulated by interests). Results indicate that opportunistic groups yielded the most creative learning outcomes. Thus, opportunistic collaboration formulated through establishing and disbanding new groups based on emergent goals is considered a promising solution to scientific communication and collective knowledge advancement.

Knowledge Building Discourse Explorer (KBDeX) (Oshima et al., 2012), a learning analytics tool, was adapted in this study, drawing upon the research on agency-driven and choice-based learning analytics in knowledge building (Zhang & Chen, 2016). It has been used in extensive research to visualize the process of knowledge-creating discourse. Specifically, this tool can visualize the changing social networks of *students*, *words*, and *discourse*, as well as their centrality metrics. To visualize the similarities and differences in ideas between students, Ma et al. (2017) adopted the betweenness centrality of the student network, coupled with the existence and mechanism regarding the connection of different ideas by rotating leaders (students with high values of betweenness centrality). To visualize collective ideas, Teo et al. (2018) used KBDeX to help teachers understand students' collective discourse and reflect on how to further the cutting edge of collective knowledge. To visualize idea boundaries, Yuan et al. (2019) used the betweenness centrality of word network to identify the new ideas developed through crossing community boundaries. Most of the current knowledge-building studies focus on the use of KBDeX by researchers, with increasing attention paid to that by students (Wise, 2020).

Accordingly, a knowledge-building environment was created using the representations of KBDeX called Idea-Friend Maps (IFM) and opportunistic collaboration to support progressive knowledge building. This paper focuses on examining a three-pronged knowledge-building framework for scientific practice, which includes: (1) how students work like researchers to pursue different but related ideas, (2) how students identify the current state and future direction of the community, and (3) how students create new knowledge by crossing knowledge boundaries. Specifically, the role of IFM and opportunistic collaboration in fostering progressive knowledge building when students were working on Knowledge Forum was examined. The research questions are: (1) Did student groups advance collective knowledge over time, and what were the different trajectories among groups? (2) What were the key areas of collective inquiry, and how did the class community make collective knowledge advancement? (3) In what ways did students engage in progressive knowledge building, supported by IFM and opportunistic collaboration?

Methods

Participants

Fifty-two Grade-Five students from a primary school in Nanjing, Mainland China, participated in the research project and worked in 12 groups, each with 4-5 students; they had previous experience working on Knowledge Forum from Grade Four. The first author served as their science teacher throughout the study period.

Design of knowledge building and the Idea-Friend Maps environment

The 12 groups of students worked on Knowledge Forum (KF) for 9 weeks, exploring *Human Input and Output* and conducting different experiments as what scientists do in their research process. They were enriched with KF activities such as posting questions, generating theories, co-constructing explanations, revising theories, and collaborating with other groups. We designed the *Idea-Friend Maps* tool to provide students with analytics information from KF discourse. KBDeX is a social network analysis tool from which the word networks were extracted and provided as diagrams for students. The circles are all the keywords in KF writings: the red and yellow circles denote keywords having or having not been discussed. Students were also provided with prompt sheets with scaffolds (e.g., What are your group's idea friends? What topics do they come from? What questions you want to research now?) to support cross-group fertilization.

We designed three levels of IFM (i.e., the group, community, and knowledge building) and combined them with different social configurations in three phases (Figure 1). IFM diagrams (KBDeX word network of their KF writings) were provided to help students work on (a) problems across groups (group), (b) problems for the class (community), and (c) a rise-above *Progressive Knowledge Building* view on emerging new problems in different phases. Initially, they worked as interactive groups to explore different but related ideas, and then as opportunistic groups to conceptualize the current state and future direction of community knowledge, as well as to identify new gaps by crossing boundaries. Table 1 depicts the three-levels of IFM, including challenges, types, key features, as well as examples of how to use them.

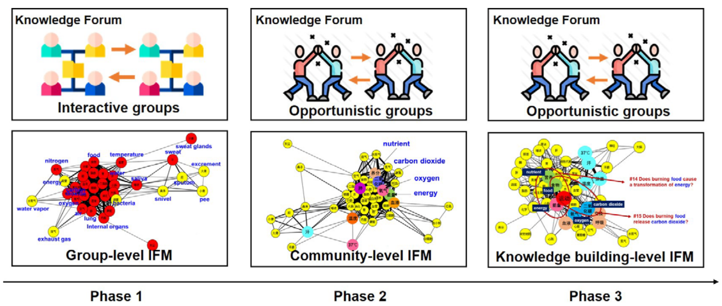

Figure 1. The combination of IFM and social configuration design

Table 1. The framework of the three-level Idea-Friend Maps

Challenge	Type	Key feature	Example
How to work like researchers as a community to pursue different but related ideas?	Group-level	Distinguishing ideas from other groups	Students work in *interactive groups* to identify group problems first and then bring new concepts and promising ideas from related groups.
How to identify the current state and future direction of community knowledge?	Community-level	Highlighting key problems in the community knowledge	Students work in *opportunistic groups* to conduct meta-discourse to criticize and synthesize different theories, identify connections between problems, and create new promising ideas.
How to sustain progressive knowledge building by crossing knowledge boundaries?	Knowledge building-level	Highlighting key problems in each research area to clarify knowledge boundaries	Students work in *opportunistic groups* to identify new gaps and propose higher-level ideas by crossing knowledge boundaries.

In Phase 1, using the group-level IFM, students conducted cross-group interactions to explore 8 research fields (views), including *Food Input*, *Excreta Output*, *Gas Input*, *Gas Output, Digestive System*, *Respiratory System*, *Cardiovascular System* and *Others* (Figure 2(a)). In Phase 2, they used the community-level IFM to research the community's key problems and worked in opportunistic groups on the *Community Building* view (Figure 2(b)). In the last phase, using the knowledge building-level IFM, they conducted sustained inquiries on the *Progressive Knowledge Building* view (Figure 2(c)). After identifying new gaps, putting forward theories, and finding evidence, they researched conclusions and pointed out future directions.

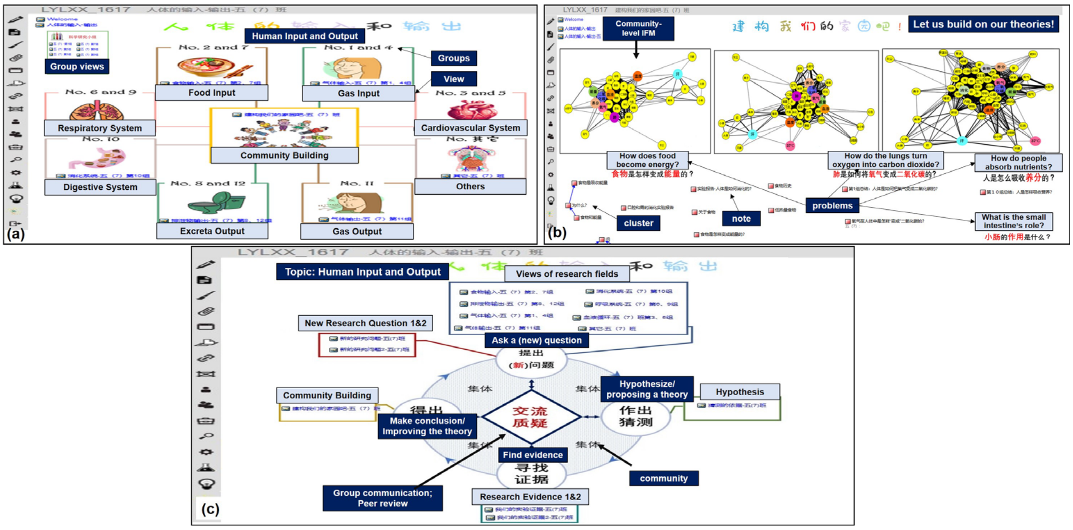

Figure 2. Research field views (a); *Community Building* view (b); *Progressive Knowledge Building* view (c)

Data sources and analyses

Data sources include KF writings, videos of classroom discourse, and knowledge artifacts. Pre- and post-tests of scientific understanding changes and the role of IFM have been reported previously (Feng et al., 2020). This paper focuses on knowledge-building dynamics supported by IFM and assesses collective knowledge advancement using Total Degree Centrality (TDC). Based on knowledge-building research on KBDeX (Oshima et al., 2012), a higher TDC means a denser social network of domain keywords and discourse, denoting more collective knowledge advancement (Oshima et al., 2017). Using the KBDeX networks, we can track how different groups evolved in their collective KF work across phases and studies. Additionally, qualitative analyses were conducted to investigate the key areas of collective inquiry, the developmental trajectory of collective inquiry and collective knowledge advancement, and in what ways students worked like scientists to engage in progressive knowledge building.

Results

RQ1: Did student groups advance collective knowledge over time, and what were the different trajectories among groups?

The changing word networks of different contributing groups exported from KBDeX are depicted in Figure 3, where red and yellow circles represent the keywords having or having not been discussed. Overall, there is an upward trend in TDC and network density across 3 phases (42.76 in Phase 1, 61.84 in Phase 2, and 67.81 in Phase 3). As a higher TDC score means more collective knowledge advancement (Oshima et al., 2017), this finding suggests group advancements in the collective knowledge of *Human Input and Output* over time.

We also identified three contributing groups (i.e., high, medium, and low) and tracked their trajectories in relation to different levels of IFM and social configurations. High/medium/low contribution group refers to the extent to which their KF notes added value to the TDC of the whole class. With the intervention of the *group-level IFM* and *interactive groups* in Phase 1, the high-contribution group presented a centralized network of red circles, demonstrating the ability to connect different subtopics. In contrast, the medium and low-contribution groups showed different locations of red circles, indicating the ability to conduct interactive activities to explore ideas from different subtopics but with limited connections of those subtopics. Moreover, the high-contribution group's contribution to collective knowledge advancement was two times more than that of the medium and low-contribution ones. In Phase 2, with the intervention of the *community-level IFM* and *opportunistic groups*, both medium and low-contribution groups doubled their contribution to collective knowledge advancement compared with Phase 1. Furthermore, the medium-contribution group showed a much more centralized network of red circles, comparable to that of the high-contribution group. In Phase 3, with the intervention of the *knowledge building-level IFM* and *opportunistic groups*, both the medium and low-contribution groups showed comparable group contribution and centralization of red circles to the high-contribution group. These results suggest the role of different levels of IFM and social configurations in scaffolding different contributing groups for collective knowledge advancement.

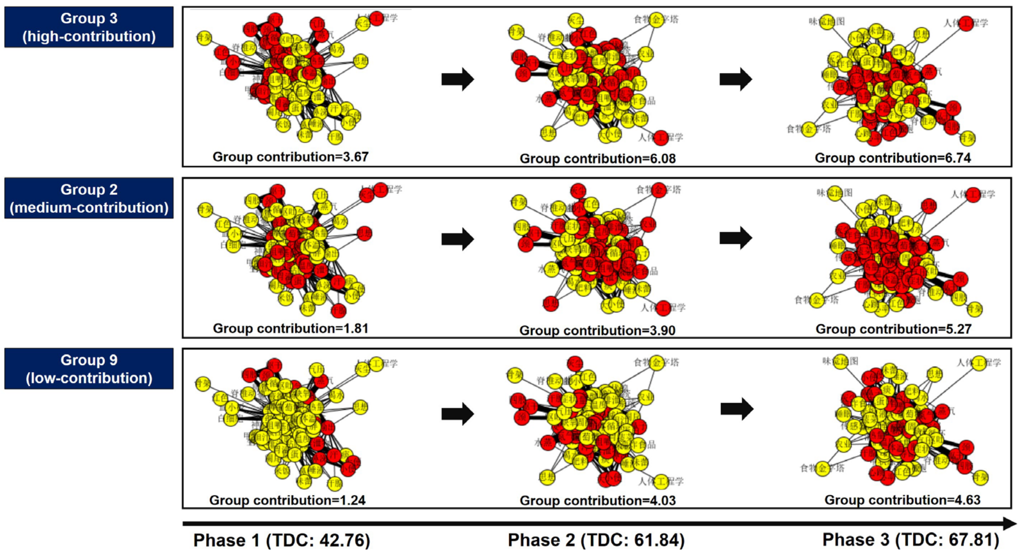

Figure 3. Changing networks and group contributions to collective knowledge advancement over phases

RQ2. What were the key areas of collective inquiry, and how did the class community make collective knowledge advancement?

Key areas of collective inquiry of class community

Figure 4 shows the socio-cognitive community dynamics of how student groups engaged in progressive knowledge building towards collective knowledge advancement under three levels of IFM and social configurations, akin to how scientist groups work, focusing on different topics but also culminating in different foci. Overall, the *Human Input and Output* developed from 8 fields in Phase 1, including *Food Input*, *Excreta Output*, *Gas Input, Gas Output*, *Digestive System*, *Respiratory System*, *Cardiovascular System*, and *Others*. Later, these fields were synthesized into 4 in Phase 2, including *Food Input and Digestive System*, *Gas Input/ Output and Respiratory System*, *Cardiovascular System*, and *Excreta Output*. Each covered several problems. For instance, in the research field of *Food Input and Digestive System,* problems of "What is the small intestine's role (Problem #1)?" "How do people absorb nutrients (Problem #2)?" and "How does food become energy (Problem #3)?" were targeted. In Phase 3, all the research fields rose above to one primary research field of *Food/Gas*

Input/Output: Reactants and Products of Digestion. Finally, this problem moved forward to the future direction of *Metabolism*, to explore problems such as "Where does the food turn into energy (Problem #19)?"

Developmental trajectory of collective inquiry and collective knowledge advancement

In Phase 1, students conducted interactive collaboration with other groups. For example, Group 2 took the research field *Food Input* and interactively explored other fields. In Phase 2, students first identified seven key problems of the four research fields from IFM diagrams and posted those problems on KF. For instance, "How do the lung turn oxygen into carbon dioxide (Problem #4)?" was identified in the *Food/Gas Input/Output* field. After tackling those community problems, they proposed new problems. Afterward, students worked in opportunistic groups joining different members to solve those key problems and propose new questions. In Phase 3, working in opportunistic groups, members from Group 2 first came to *Food Input and Digestive System* to explore the problems of "How do people absorb nutrients (Problem #2)?" "How do people feel food (Problem #8)?" and "What changes in body temperature after eating food (Problem #9)?" Later, they worked at the cutting edge and crossed boundaries of food and gas fields, solving Problems #14 to #16, such as "Does burning food cause a transformation of energy?" Finally, they proposed rising-above problems of *Human Input and Output*, pointing to the future direction of *Metabolism.* With the use of different levels of IFM and scaffolds (e.g., where would you move next?), students were able to have cross-group fertilization and synthesis for collective knowledge advancement.

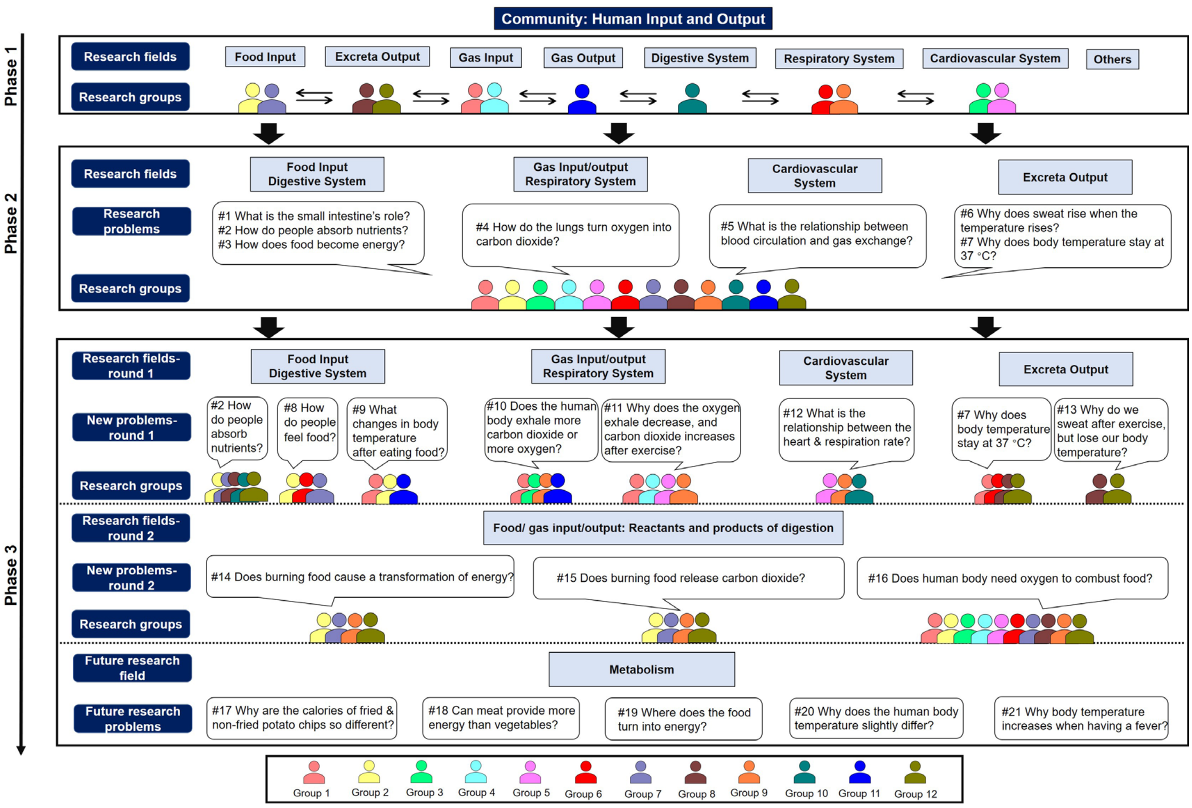

Figure 4. Socio-cognitive community dynamics for progressive knowledge building

RQ3. In what ways did students engage in progressive knowledge building supported by IFM and opportunistic collaboration?

Using the framework (Table 1), we explored in what ways students worked like scientists, including pursuing different but related ideas, identifying the current state and future direction of community knowledge, and creating new knowledge by crossing boundaries supported by IFM and opportunistic collaboration.

How to work like scientists as a community to pursue different but related ideas?

A group-level IFM of Group 2 (generated from KBDeX) is depicted in Figure 5(a), where the red and yellow circles denote those keywords on KF used and not used by Group 2, respectively.

Among the circles, yellow circles near the red ones represent "idea friends." The "friendship" among ideas is analogous to the proximity of scientific ideas in research. As described in Figure 5(a), students in Group

2, who were responsible for *Food Input*, first identified “bacteria,” “energy,” and “excrement” as idea friends, and then moved to *Excreta Output* for relevant information on KF. Furthermore, they also proposed new connections under the group-level IFM. For instance, after identifying “bacteria” as an idea friend and proposing a new keyword of “Escherichia coli,” they made a focus and constructed connections among other idea friends. Notably, after comparing and combining what they identified from IFM with their knowledge, they drew a flow map (Figure 5(b)) to visualize their theory of “How bacteria help digestion in intestines, release energy, as well as absorb nutrients and release useless materials.” These results suggest that students with the support of the group-level IFM could identify important gaps to pursue different but related ideas.

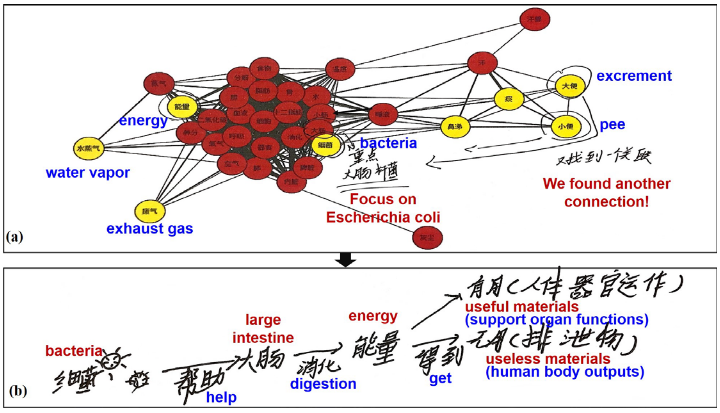

Figure 5. Examples of writings and drawings from Group 2 on the prompt sheet of the group-level IFM

How to identify the current state and future direction of community knowledge?

A *community-level IFM* is presented in Figure 6(a), in which the key problems were identified by the community and marked by *colored* circles (except yellow ones that represent potential explanations of the key problems). For instance, the pink circle “oxygen” presents the key problem “How do the lungs turn oxygen into carbon dioxide (Problem #4 in Figure 4)?” It can be synthesized by students in opportunistic groups with the surrounding yellow circles.

Supported by the community-level IFM that shows different problems and gaps, students started exploring the class community’s key problems. Then, they worked in opportunistic groups to reframe the collective ideas and propose new questions on the KF. For instance, from the perspective of the transformation of food/gas inputs to outputs by human organs, an opportunistic group synthesized the questions “How do people absorb nutrients?” and “How do the lungs turn oxygen into carbon dioxide?” They selected and referenced some related KF notes from the whole community, proposing a new theory of “Oxygen supports breathing, food provides energy, and water maintains human health,” and then completing a new KF synthesis note, as shown in Figure 6(b). These results indicate the process of students identifying the current state and future directions with the support of the community-level IFM.

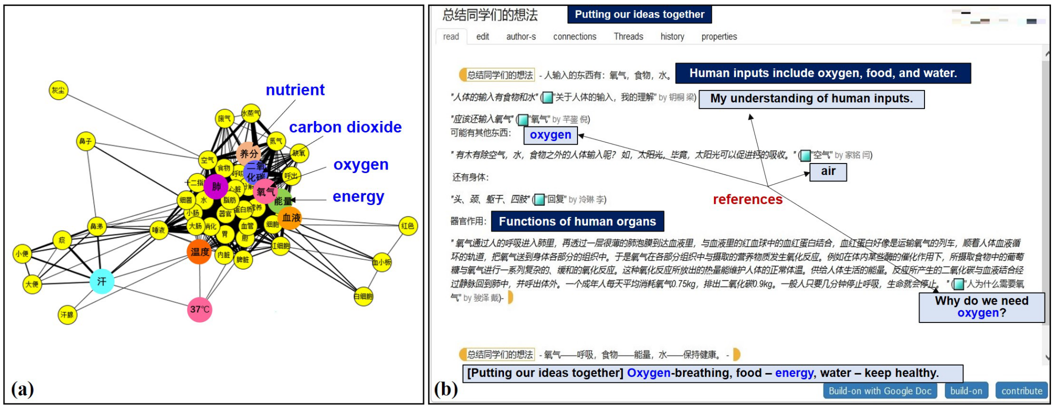

Figure 6. Example of an opportunistic group’s conceptualization of the community state

How to create new knowledge by crossing knowledge boundaries?

Figure 7 displays a *knowledge building-level IFM*, where circles with the same color (except some yellow ones as they might be bridging ideas for different research fields) refer to the key ideas identified from the same research field. For instance, the new problem “Does burning food cause a transformation of energy (Problem #14 in Figure 4)?" is incurred by the connection of the green circle "food" and the pink circle "energy." The new problem, "Does burning food release carbon dioxide (Problem #15 in Figure 4)?" comes from the connection of the green circle "food" and the dark-blue circle "carbon dioxide."

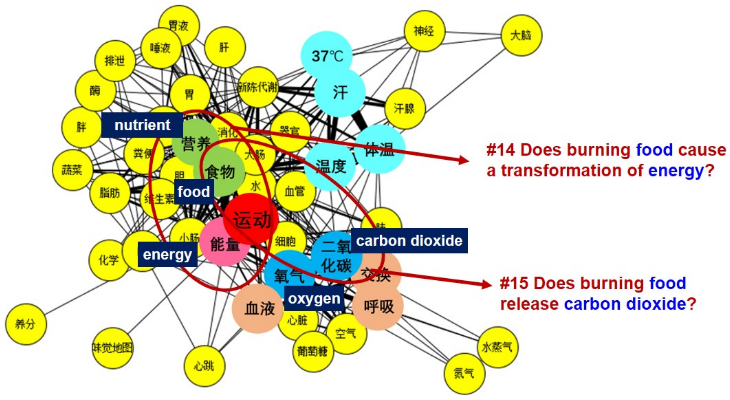

Figure 7. The knowledge building-level IFM used to visualize idea boundaries

After identifying and exploring the current community's key problems on *Human Input and Output*, students worked in much more in-depth opportunistic groups to conduct sustained inquiries of new research problems. Here, students c736, c742, and students from other groups as a new opportunistic group are taken as an example. With the knowledge building-level IFM, this opportunistic group observed the close distance between "food" and "energy" and then proposed the new problem of "Does burning food cause a transformation of energy?" They measured the water temperature with a temperature sensor before and after heated by the burning potato chips (Figure 8(a)). They found that even 0.3 g fried potato chips could boil 5 ml of water, indicating the release of energy from food burning. Later, they found the close distance from the blue circle "carbon dioxide" in the research field of *Gas Output* to the green cycle of "food" in *Food Input*. Then they proposed a new problem by crossing the two research fields: "Does burning food release carbon dioxide?" Using the carbon dioxide sensor, they found that potato chips consume oxygen while releasing carbon dioxide and energy during burning process (Figure 8(b)). Knowledge building is progressively deepened as problems solved and new ones emerged - students rose above to the higher research field of reactants and digestion products, eventually proposing the concept of metabolism and identifying new problems for future direction. Surprisingly, students c736 and c742 came from Group 9, which was a low-contribution group identified in RQ1. However, results from RQ1 also show their improved group contribution over time and comparable contribution to the high-contribution group in the final phase. These findings suggest that with the support of the knowledge building-level IFM and opportunistic collaboration, young children can engage in progressive knowledge building through crossing boundaries.

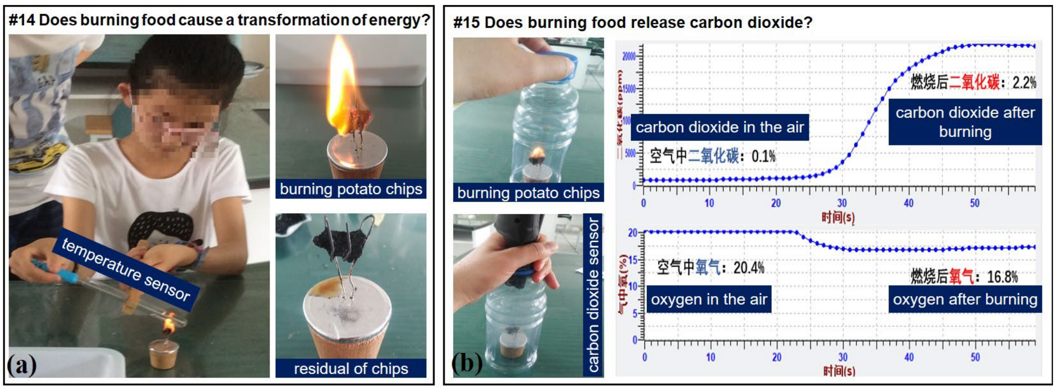

Figure 8. Experiments for examining whether food combustion releases energy (a) and carbon dioxide (b)

Conclusion and discussion

This study contributes to the literature of scientific practice and knowledge building - by investigating how young children were supported by the innovative design of learning analytics representations (IFM) and opportunistic collaboration to work as a community just like scientists. Results show how elementary-school children engaged in progressive knowledge building, specifically pursued different but related ideas, identified the current state and future direction of community knowledge, and created new knowledge by crossing boundaries with the support of IFM and opportunistic collaboration. This study suggests engaging students in deep social-community interaction such as authentic scientific practices, just like researchers involved in intentional scientific communication. The analogy to scientists' working practices presented in the framework of IFM (Table 1) will help educators scale such social configurations for innovative knowledge building. Theoretically, the framework can be examined for the socio-community dynamics of knowledge emergence. Additionally, it can also guide students to engage in fixed groups, interactive groups, and opportunistic groups for deepening inquiry into specific topics gradually. Their knowledge-building process can be sustained through collective inquiry, just like how researchers work on innovative projects.

References

Bereiter, C., Scardamalia, M., Cassells, C., & Hewitt, J. (1997). Postmodernism, knowledge building, and elementary science. *The Elementary School Journal*, *97*(4), 329-340. https://doi.org/dg498w

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175-218. https://doi.org/b24g7f

Feng, X., van Aalst, J., Chan, C. K. K., & Yang, Y. (2020). Co-designing a collective journey of knowledge creation with Idea-Friend Maps. In M. Gresalfi & I. S. Horn (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020* (Vol. 3, pp. 1429-1436). International Society of the Learning Sciences. https://bit.ly/3rjhqIE

Ma, L., Tan, S., Teo, C. L., & Kamsan, M. A. B. (2017). Using rotating leadership to visualize students' epistemic agency and collective responsibility for knowledge advancement. In B. K. Smith, M. Borge, E. Mercier, & K. Y. Lim (Eds.), *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017* (Vol. 1, pp. 455-462). International Society of the Learning Sciences. https://bit.ly/2FW4GFP

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. The National Academies Press. https://doi.org/drgp

Nielsen, K. H. (2013). Scientific communication and the nature of science. *Science & Education*, *22*(9), 2067-2086. https://doi.org/f5bd4d

OECD. (2019). *Fostering students' creativity and critical thinking: What it means in school*. OECD Publishing. https://doi.org/d9vr

Oshima, J., Ohsaki, A., Yamada, Y., & Oshima, R. (2017). Collective knowledge advancement and conceptual understanding of complex scientific concepts in the jigsaw instruction. In B. K. Smith, Borge, M., Mercier, E., and Lim, K. Y. (Ed.), *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017* (Vol. 1, pp. 57-64). International Society of the Learning Sciences. https://bit.ly/2RRp1id

Oshima, J., Oshima, R., & Matsuzawa, Y. (2012). Knowledge Building Discourse Explorer: a social network analysis application for knowledge building discourse. *Educational Technology Research and Development*, *60*(5), 903-921. https://doi.org/f39tjb

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 397-417). Cambridge University Press. https://doi.org/d9tv

Teo, C. L., Chan, C. K. K., & Ng, D. (2018). Engaging teachers in discussions around temporality measures from analytics to inform knowledge building discourse. In J. Kay & R. Luckin (Eds.), *Rethinking learning in the digital age: Making the learning sciences count, 13th International Conference of the Learning Sciences (ICLS) 2018* (Vol. 3, pp. 1677-1678). International Society of the Learning Sciences. https://bit.ly/33Tur1W

Wise, A. F. (2020). Educating data scientists and data literate citizens for a new generation of data. *The Journal of the Learning Sciences*, *29*(1), 165-181. https://doi.org/d9tx

Yuan, G., Zhang, J., & Chen, M.-H. (2019). Cross-boundary interaction for sustaining idea development and knowledge building with Idea Thread Mapper. In K. Lund, Niccolai, G., Lavoué, E., Hmelo-Silver, C., Gweon, G., and Baker, M. (Ed.), *A wide lens: Combining embodied, enactive, extended, and embedded learning in collaborative settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019* (Vol. 1, pp. 456-463). International Society of the Learning Sciences. https://bit.ly/2RXGPYV

Zhang, J., & Chen, B. (2016). Analytics for knowledge creation: Towards epistemic agency and design-mode thinking. *Journal of Learning Analytics*, *3(2)*, 139-163. https://doi.org/d9t3

Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge-building communities. *The Journal of the Learning Sciences*, *18*(1), 7-44. https://doi.org/b6tvkk

Playful Discourse Practices in Guided Play Learning Environments

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Abstract: This paper examines how teacher guided play can support inquiry while learning science. Guided play has been positioned as a balanced approach to supporting learning in ways that value the curious, playful, and child-directed characteristics of play. We present interaction analysis of two cases of teacher guided play, where we examine how teachers guide students in ways that not only lead to instructional goals but support the playful exploration that is important in students' learning experiences. Findings in this paper reveal how guided play changes participation and discourse practices as teachers incorporate these open forms of learning into classroom spaces.

Introduction

In recent years, there has been a growing interest in the importance and potential of young students learning through play (Hirsh-Pasek, et al., 2009; Papademetri & Louca, 2020; Youngquist & Pataray-Ching, 2004). This work has provided evidence that play can support the development of young learners' creativity, engagement, socio-emotional competence, and cognitive development (Ashiabi, 2007; Nicolopoulou, Barbosa de Sá, Ilgaz, & Brockmeyer, 2009; Pyle, DeLuca, & Danniels, 2017; Saracho, 2012). Within learning contexts, particularly in schools and classroom settings, there has been a focus on *guided play*, where teachers and educators can engage in play to guide young students in learning. Our study blends adult guidance, the investigation of complex scientific phenomena, and opportunities for young students to playfully explore these science concepts.

While recent literature on guided play shows how it can scaffold and lead to learning (Fisher et al., 2011), we further unpack how play—specifically how *paidia play* can be guided in ways to support students in investigating conceptual ideas. We do this by examining how guided play transforms what participation and discourse can look like as students engage in more playful and spontaneous forms of learning and sensemaking. This paper will examine how guided play can function as an agentic space where students have access and opportunities to participate, explore, and learn science in different ways. We ask: *How does guided play support students' participation and discourse while learning science?*

Theoretical framework

Play

Although there is little consensus on how to define play, one broad distinction relevant to our analysis is Caillois' (1961) concept of paidia play. Paidia play is characterized by its spontaneity, with any rules for the play arising from within the play activity itself. Examples include playing in a jungle gym, rolling down a hill, or wrestling with a friend. Unlike games (often called *ludus* play) there are no pre-established winners or losers, nor any one right way to play. One way to think about paidia play is as an orientation towards one's activity, rather than any defining characteristic of the activity itself. As Bateson (1955, pp. 41) put it, play is a "meta-communicative stance" towards one's own activity where the meaning of actions is flexible and negotiable. For example, in a play fight, a punch is meant to stand in for a real punch, but it does not mean the same thing as it would in a real conflict. Colloquially, we might say that paidia is a term that emphasizes the 'playfulness' dimension of play. For our analysis, we examine interactions where students are taking a playful, paidia stance towards their science inquiry, and how teachers guide students within this playful frame to support learning.

Socio-dramatic play

While some contend that socio-dramatic play and paidia play are synonymous (Frasca, 2003), it is important for our analysis to distinguish how socio-dramatic play is often structured and governed by implicit socio-cultural rules. For example, children who play house might take on the role of "parents" by pretending to drive to the store, hold a baby, or make dinner. We think of socio-dramatic play as a subset of paidia play in the sense that it can also unfold spontaneously in playful ways, but the addition of explicit socio-cultural roles and rules shifts how it influences and organizes children's activities and learning.

For young children, play serves as one of many cultural tools that provides access to participation in cultural practices mediated by social norms, rules, and histories. During socio-dramatic play, a young child can negotiate the cultural rules and roles that may not be accessible to them in their everyday lives. For example, Vygotsky (1980) described two sisters who play "sisters" together. Typically, being sisters is in the background of their every experience—rarely do they make visible the meaning of their relationship. However, playing "sisters" foregrounds the rules of sisterhood (e.g., dressing and talking alike or sharing parents). Thus, playing as "sisters" transforms sisterhood from an implicit relationship to an explicit social role with corresponding rules and norms. These rules that ground sisterhood provide these young children with an opportunity to socialize in culturally relevant ways. That is, making the rules explicit in play reflects how they perceive sisters should behave in the real world. The importance of socio-dramatic play is therefore not only for fun and whimsy, but the opportunity to reflect, re-enact, and explore experiences rich with shared sociocultural rules, roles, and norms.

Socio-dramatic play also gives children the opportunity to explore imaginary situations that are not a part of their everyday lives. In order to help them gain access to an imaginary situation that they otherwise would not be able to explore, children use familiar objects and ideas in new ways. For example, in socio-dramatic play a signifier (e.g., a stick) can be used to represent the meaning of the signified (e.g., a horse) (Vygotsky, 1967). Vygotsky described this process as a pivot, where children could attach abstract meaning to known objects in order to satisfy the imaginary situation in play. Thus, when a child plays "horsie," they can imagine and use the stick to represent the horse. This expands the possibilities of their immediate environment and provides opportunities to use everyday experiences to help investigate the rules of a situation that they are not yet able to fully understand. In this way, play acts as a leading activity of childhood, driving the development of new and more complex cognitive processes in young children as they enact playful versions of situations that are just beyond their reach (Duncan & Tarulli, 2003).

Teacher guided play

Guided play differs in that the goals of the play activity include adult-driven learning goals. It "melds exploration and child autonomy with the best elements of teacher-guided instruction" (Weisberg et al., 2016, pp. 1). Research on guided play activities have shown to be effective and promising for education, including positive learning outcomes in literacy, math, and science learning (Bellin & Singer, 2006; Enyedy, et al., 2017; Sarama & Clements, 2002). When learning through guided play, students can gain agency, control, and choice in their learning experiences (Jensen, Pyle, Alaca, & Fesseha, 2019; McInnes, Howard, Crowley, & Miles, 2013). This is what makes guided play a powerful learning and sensemaking experience that connects with students' lived experiences and provides them with opportunities where we can playfully challenge and build on their ideas and thinking.

During guided play, the role of the teachers and how teachers provide guidance can differ and vary based on classroom and student needs. For example, a common method of guiding play is when teachers provide materials and set up the classroom environment for children to play in (Neuman & Roskos, 1992). Relevant to our analysis, teachers can also provide guidance by participating *with* students in the play activity; "teachers enhance children's exploration and learning by commenting on children's discoveries; by co-playing along with the children; through asking open-ended questions about what children are finding; or exploring the materials in ways that children might not have thought to do" (Fisher, et al., 2011, pp. 343). This version of guided play, where teachers actively co-participate alongside students in the activity, is an untraditional way of participating in classroom discourse and disciplinary work.

In this paper, we question how participation and discourse in inquiry learning can shift and transform as a result of both teachers and students co-participating in a playful learning environment. Our paper presents analysis of two cases of paidia play, where teachers guided learning within these playful environments in different ways. In the first case, we present an example of paidia play where the teacher suggests an emergent and playful goal that fluidly becomes part of inquiry. In the second case, we present an example of socio-dramatic play, a version of paidia play where students spontaneously organize their actions according to the implicit socio-cultural rules of a role. In both cases, we analyze how teachers balanced students' agency while working towards broader curriculum goals and examine how guided play shifts disciplinary discourse, participation, and learning.

Science through technology enhanced play

To set up the classroom environment in ways that promote playful activity within scientific inquiry, we leverage technology developed for the Science through Technology Enhanced Play project (Danish, et al., 2015; 2020). The project is a mixed reality learning environment that uses motion tracking cameras (labeled K1, K2, & K3 in Figure 1) to allow students to playfully embody and explore science concepts. For this study, students engaged in guided play as water particles. The environment tracks and transforms students' movements into a digital simulation of water particles moving on a screen (Figure 1). We first fostered playfulness by asking our students to imagine themselves shrinking down to the size of microscopic water particles. Guided by their classroom teacher, students took on these microscopic roles to discover the rules that governed changes in states of matter as they moved in coordination with their peers. The mixed reality technology also guided students' play by providing real time feedback to students about how their different movements can create and change the states of matter represented on the shared screen.

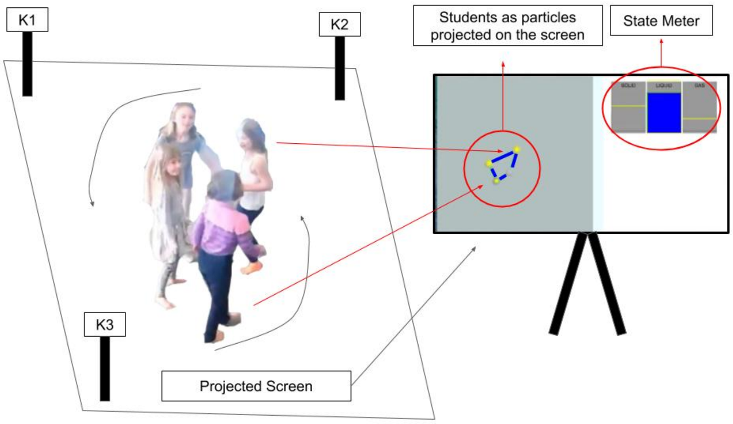

Figure 1. Students in the mixed reality environment

The facilitators used the mixed reality environment and playful prompting (e.g., having students crawl through a hula hoop dubbed the "Particle Shrink o Rator") to set up an imaginary situation in which students can investigate the rules of particle behavior, such as how speed, distance, and energy impact the way that matter changes into different states. Across the unit, students explored both macroscopic (e.g., observable properties such as solids keep their shape) and microscopic features of states of matter (e.g., particles in a gas move quickly). Students spent the majority of the unit exploring how water particles change at the microscopic level and describing the rules for each state in terms of the speed and the distance between particles. Students were given agency to explore the simulation and notice different aspects of state change as they interacted in fairly freeform ways. As the unit progressed, the teachers added increasing amounts of structure to students' play in order to move them towards more formal modeling practices.

In both their play and modeling, students were encouraged to move in ways that reflected how water particles behave in solid, liquid, and gaseous states. Through their explorations, they uncovered the underlying rules that created each state of matter in the simulation by using the visualizations of the technology, namely the color of the bond or a state meter. To create a solid, students moved slowly (often vibrating in place) while spreading out to have some distance in between peers. This created white colored particles on the screen. To create a liquid, students slowly weaved around the play space while keeping a closer distance to create blue particles (see Figure 1). Finally, to create a gaseous state of matter, students ran around the play space at a fast speed with plenty of distance between peers to create red particles in the simulation.

Methods

Students in this study were from five mixed-aged classrooms of 1st and 2nd graders (ages 6-8) from two different sites in the United States. Three of the classrooms were from a large city on the west coast (site 1), while two classrooms were from a smaller midwestern city (site 2). The focus of our analysis was how teacher guided play provided students with new and unique opportunities to participate in science learning.

Using interaction analysis (Jordan & Henderson, 1995), we analyze and present the data in detail to explore the mechanisms through which teachers noticed and supported playful interactions to guide students towards scientific inquiry. We first reviewed and content logged the larger video data corpus across all five classrooms, which consisted of 24 classroom videos of approximately 45-60 minutes in length. Based on our initial video viewing, two classrooms were selected for more detailed analysis, one from Site 1 and one from Site 2, because the teachers in these classrooms engaged in the most amount of paidia play. We then marked moments in these classrooms to create a collection of teacher-guided paidia play— including both spontaneous playful moments (e.g., moving like a caterpillar) as well as more structured versions of paidia play (socio-dramatic play). Within these moments, we focused on episodes where teachers guided and used these playful moments to build towards scientific learning goals. These episodes were transcribed using the Jeffersonian transcription system (Jefferson, 2004) and analyzed through multiple rounds of video viewing with the research teams at both sites to examine the ways in which the different teachers guided students' play. We present our analysis to illustrate the potential of guided play that we found to be reflective of the larger corpus of data. Each case examines ideas that were proposed during paidia play that resulted in teachers guiding students towards greater understanding of the scientific phenomena.

Findings

Case 1.

In our first case we present analysis of discourse from an example of teacher guided paidia play at site 1, where the teacher (Ms. Jones) guides her students in inquiry by spontaneously pitching a playful idea to encourage her students to explore science concepts. The analysis details how students used the colors that were represented in the visualization (Figure 1) to make observations, conjectures, and conclusions on how speed and distance between particles result in each state of matter. Students often associated their body movements with colors before connecting the movements to more abstract representations of their activity, before finally connecting these abstractions to the states of matter. For example, students would first discover that moving fast around the room caused themselves to turn red on the screen, before concluding that spreading out and moving in faster speeds represented gas particles.

In the following transcript, students had yet to make observations on how to create blue (liquid). However, instead of suggesting a direct curricular goal such as, "let's make blue," Ms. Jones suggests trying something they had done before, to hold hands and walk in a circle. The decision to guide students towards playing in a circle was interesting because the shape she suggests does not have any scientific relevance—it doesn't represent any of the structures of solid, liquid, or gas particles. However, for the students it is a spontaneous, yet clear and understandable rule that Ms. Jones uses to guide inquiry.

1	Ms. Jones	One of the *things* that we did *before* to try and make the different colors (0.2)
2		was we all got in a circle and we moved in different ways. Could we try that?
3	Students	Yea::
4	Student 1	LET'S TRY TO MAKE A GINORMOUS CIRCLE AND SEE IF IF (0.1) if...one side is
5		blue and one side is red
6	Ms. Jones	Oh so you're looking at *where* we are in the space?
7	Student 2	EVERYBODY GET IN A CIRCLE!
8		((Students all gather in a circle))
9	Student 3	HOOK UP! HOLD EACH OTHER'S HANDS!

Figure 2. Students and Ms. Jones play in a circle

What made this example significant was not only that Ms. Jones didn't specify a science goal (line 1), but *how* the students took up her idea (line 4). In lines 3-5, we see how students are engaged in paidia play as they excitedly and fluidly build on her idea. We see evidence of this as students responded to Ms. Jones' by suggesting to make the circle more extreme and "ginormous", and by elaborating on her bid to focus on observing what happens next (Figure 2). This allowed Ms. Jones in line 6 to offer more guidance by re-phrasing and abstracting the students' idea of looking at spatial relations. Although we are focusing on the teacher's guidance, it is important to note that in lines 7-9, it is the students who take the agency to organize each other to carry out the play. After playing in the circle, a few students broke away and began to make further observations.

10	Student 1	And when we were spread out it was white and I think white was the *longest* and then
11		blue is the *shortest* because we were together and then the yellow is the shortest
12	Ms. Jones	So it goes white is long, blue is medium, and yellow is the shortest?
13	Student 4	What's red?
14	Ms. Jones	*Oooo* Student 4 wants to know how you make red

After walking in a circle, Student 1 (lines 10-11) observed and hypothesized the importance of distance when creating each color. While Student 1 was not completely accurate, it was the first time the students had made the conceptual connection between the distance between particles and different colors/states. Further, Ms. Jones was able to use her ideas to guide the class towards a crisp description of the role distance plays in making different colors and states of matter (line 12). The exchange ends, with the students specifying a goal for their next exploration--making red (line 13). This short exchange shows how the teacher's guiding moves of bringing spontaneous goals through paidia play can still benefit students with greater knowledge of the science content. Ms. Jones was able to guide student thinking to be more abstract and precise while still allowing the students the agency to set their own goals. The significance of this example is how Ms. Jones guided her students by bringing paidia play to life. She spontaneously pitched a seemingly unscientific goal to inspire her students to explore being particles together. Her guiding moves in paidia play led to students exploring the movements of a circle, and explore with whether these familiar sets of movements can help them create and embody states of matter. Here, teacher guided paidia play offers students opportunities to bring in these familiar everyday ideas to use as metaphors or starting points for investigating these concepts during scientific inquiry.

Case 2.

In our second case, we examine an example of student-initiated socio-dramatic play and how teacher guidance shaped the interactions for inquiry. While we consider socio-dramatic play to be a subset of paidia play, we make this distinction because of how students in this example move and interact according to the rules governed by a social role (or in this case, a student's exaggerated parody of a social role). Here, the students take on the role of an "old man" in order to establish both the goals and rules of their play and inquiry activity. Our analysis focuses on the discourse that unfolded while the teacher (Ms. Wilson) guides students' socio-dramatic play of being an old man towards the larger science learning goals. In the following transcript, the students were initially engaged in unstructured paidia play, with students running in circles and moving in exploratory ways to see how the simulation might change in response. Student 1 then proposes a goal for their play, and with the teacher's support, the activity begins to shift into more structured socio-dramatic play (line 1).

1	Student 1	Guys let's all be water! Guys-
2	Ms. Wilson	Oh (.) I kind of like Student 1's suggestion can you all try to be um (.)
3	Student 2	Liquid
4	Ms. Wilson	Yes (.) try to be liquid
5	Student 1	Student 3! Get clo- start moving like an old man
6	Ms. Wilson	So [look at the screen]
7	Student 4	[Old granny walking] [through!]
8	Student 1	[OH!] (.) we were just all
9	Student 4	Old granny moving through!
10	Student 1	OH! It's [doing it]
11	Student 3	[We're all-]
12	Student 4	Will you help me [please young lady]
13	Ms. Wilson	[Oh my gosh! (.) ((gasp))] (1) I have seen success
14	Student 4	[Young] lady (.) would you [please help me]
15	Ms. Wilson	[How] (.) [what am I] seeing to show that you are all
16		water what am I seeing [on the screen]

17	Student 4		[I need a cane]
18	Student 3	[Blue]	
19	Student 1	[It's] blue	

Figure 3. Students moving like "old people"

The role of being an old man is a clever way to communicate, embody, and self-regulate students' movements to move slowly, get close, and become liquid (Figure 3). The movement of an "old man" is parallel to moving like liquid particles in the mixed reality environment; in that liquid particles move slowly and closer together. As the students use the idea of the old man to slow their movement and arrange themselves together, the teacher guides the effects of the socio-dramatic play and tries to guide students' attention to the screen (line 6 & lines 15-16). In line 6 she says, "look at the screen" to guide students' attention towards the effects of their "old man" movements on the digital representation of particles. Since the screen (Figure 1) provides information on how students' movements create each state of matter, Ms. Wilson's guiding move to draw attention to the screen verifies that moving within the rules of an old man results in embodying liquid particles. In line 13, she states she has "seen success", and in line 15 she asks them to see what she sees on the screen. As a result, the students consistently look back to the screen to check for the creation of liquid while playing as old people. With his hand still clutching his back, Student 1 notices that they've successfully formed liquid particles with a shout of "Oh! It's doing it!" (line 10), and later notes that the particles have turned blue (line 19).

Within this guided socio-dramatic play space, the rules of embodying and pretending to be an old man were set by students as part of the imaginary situation. These rules and role of the old man were then guided by Ms. Wilson so that the socio-dramatic play would connect back to inquiry; making the scientific rules of being liquid visible. By calling attention to the technology, Ms. Wilson's guiding discourse helped organize the class to collectively work together in creating and verifying how to embody liquid particles.

Conclusions

The imagination of shrinking and pretending to be microscopic particles opened opportunities for students to enact, explore, and question the rules of matter in a variety of playful ways. We detailed in both of our examples how teachers and students engaged in play; where students maintained both a playful agency to their learning while still engaged in inquiry. In the first example, we see how Ms. Jones guided students' exploration of abstract scientific phenomena by spontaneously engaging her students in play. Here, the fluidity and emergent rules and goals of paidia play became tools for inquiry that Ms. Jones used to explore the significance of space and distance relevant to states of matter. In the second example, Ms. Wilson guided students' socio-dramatic play, where students collectively played the role of an old man in order to embody liquid particles. The significance of this example is that Ms. Wilson guided students' socio-dramatic play by connecting the embodied outcome of the imaginary roles and rules of the old man back to tools for inquiry. Across both examples, we saw how teachers led or responded to these varying kinds of play, guiding students towards the goals of inquiry while simultaneously valuing and building on students' agency and playful ideas. The teachers blend the exploratory benefits of children's play with the structure and content richness of formal classroom learning, creating a playful scientific inquiry space to encourage sensemaking.

Playful discourse for learning science

In both examples of teacher guided play, we primarily attend to the discourse, or talk that occurs as teachers guide and navigate students' interactions. These moments of teacher guided play reveal the unique opportunities for students to engage in alternative discourse and participation practices to help them learn and understand science. As a result, the discourse of participating and engaging in science is inherently different from traditional forms of learning, opening up what counts as learning and redefining how disciplinary discourse can look like in guided play. A commonality across the two types of guided play is how ideas and interactions that would typically be categorized as “unscientific” or “irrelevant” became powerful resources. Through guided play, students can draw from the known world around them to build an understanding of unobservable abstract scientific concepts in ways that blend ideas and behaviors from informal play with the concepts and questions of formal science.

Additionally, teachers in guided play took up students’ ideas and made them objects of inquiry for the whole class. In the second case, the concept of the old man was accepted by the teacher as a valid form of participating in classroom science learning. Here, the teacher’s response to students’ playful performance of being an old man was to guide and connect their movements back to the movements of liquid particles in the simulation. Similarly, in the first case, we saw how students built on the teacher’s suggestion to get into a circle by questioning spatial placement as a potential method of creating different states of matter. These ideas were a valued part of participating and engaging in scientific practices. In this way, guided play offers a way for students and teachers to navigate the sometimes uncomfortable territory of blending dominant school scripts with children’s play. Integrating students’ play into science learning allows students and teachers to have a more dialogic conversation about science, in which these unconventional, playful ideas are taken up as a valuable resource for doing science.

References

Ashiabi, G.S. (2007). Play in the preschool classroom: Its socioemotional significance and the teacher’s role in play. *Early Childhood Education Journal, 35*(2), 199-207. https://doi.org/10.1007/s10643-007-0165-8.

Bateson, G. (1955). A theory of play and fantasy. P*sychiatric Research Reports*, *2*, 39-51.

Bellin, H.F. & Singer, D.G. (2006). My magic story car: Video–based intervention to strengthen emergent literacy of at-risk preschoolers. In D.G. Singer, R.M. Golinkoff, & K. Hirsh-Pasek, (Eds.), *Play=Learning: How Play Motivates and Enhances Children’s Cognitive and Social-emotional Growth* (pp. 101–123). Oxford University Press.

Caillois, R. (1961). Man, play, and games. Translated by Meyer Barash. Free Press.

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: A sociocultural framework for embodied cognition. *International Journal of Computer-Supported Collaborative Learning, 15*(1), 49-87. https://doi.org/10.1007/s11412-020-09317-3.

Danish, J. A., Enyedy, N., Saleh, A., Lee, C., & Andrade, A. (2015, June 7-11). Science through technology enhanced play: Designing to support reflection through play and embodiment [Paper presentation]. In O. Lindwall, P. Hakkinen, T. Koschman, P. Tchounikine, & S. Ludvigsen (Eds.). Exploring the Material Conditions of Learning: Proceedings of the 11th International Conference on Computer Supported Collaborative Learning, Gothenburg, Sweden (pp. 332–339). International Society of the Learning Sciences.

Duncan, R. & Tarulli, D. (2003). Play as the leading activity of the preschool period: Insights from Vygotsky, Leont'ev, and Bakhtin*. Early Education and Development, 14*(3). 271-292. https://doi.org/10.1207/s15566935eed1403_2.

Enyedy, N., Danish, J., DeLiema, D., Saleh, A., Lee., C., Morris., N., & Illum., R. (2017). Social affordances of mixed reality learning environments: A case from the science through technology enhanced play project (STEP) [Paper presentation]. In Proceedings of the 50th Hawaii International Conference on System Sciences (HICSS).

Fisher, K., Hirsh-Pasek, K., Golinkoff, R. M., Singer, D. G., & Berk, L. (2011). Playing around in school: Implications for learning and educational policy. In A. D. Pellegrini (Ed.), *The Oxford Handbook of the Development of play* (pp. 341–360). Oxford University Press.

Frasca, G. (2003). Simulation versus Narrative: Introduction to Ludology. In M. J. P. Wolf & B. Perron (Eds.) *The Video Game Theory Reader* (pp. 221-235). Routledge.

Hirsh-Pasek, K., Golinkoff, R. M., Berk, L. E., & Singer, D. G. (2009). A mandate for playful learning in preschool. Oxford University Press.

Jefferson, G. (2004). Glossary of transcript symbols with an introduction. In G.H. Lerner (Ed.). *Conversation analysis: Studies from the first generation* (pp.13-23). John Benjamins.

Jensen, H., Pyle, A., Alaca, B., & Fesseha, E. (2019). Playing with a goal in mind: Exploring the enactment of guided play in Canadian and South African early years classrooms. *Early Years*, https://doi.org/10.1080/09575146.2019.1619670.

Jordan, B. & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences*, *4*(1), 39-103. https://doi.org/10.1207/s15327809jls0401_2.

McInnes, K., Howard, J., Crowley, K., & Miles, G. (2013). The nature of adult-child interaction in the early years classroom: implications for children's perceptions of play and subsequent learning behaviour. *European Early Childhood Education Research Journal*, *21*(2), 268–282. https://doi.org/10.1080/1350293X.2013.789194.

Neuman, S., & Roskos, K. (1992). Literacy objects as cultural tools: Effects on children's literacy behaviors during play. *Reading Research Quarterly*, *27*(3), 202-225. https://doi.org/10.2307/747792.

Nicolopoulou, A., Barbosa de Sá, A., Ilgaz, H., & Brockmeyer, C. (2009). Using the transformative power of play to educate hearts and minds: From Vygotsky to Vivian Paley and beyond. *Mind, Culture, and Activity*, *17*(1), 42-58. https://doi.org/10.1080/10749030903312512.

Papademetri, C. & Louca, L. (2020). Developing a learning culture of play for young children through math and science. In M. Gresalfi, M. & I. S. Horn (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020*, Volume 1 (pp. 59-66). Nashville, Tennessee: International Society of the Learning Sciences.

Pyle, A., DeLuca, C., & Danniels, E. (2017). A scoping review of research on play based pedagogies in kindergarten education. *Review of Education*, *5*(3), 311-351. https://doi.org/10.1002/rev3.3097.

Saracho, O. N. (2012). *An integrated play-based curriculum for young children*. Routledge.

Sarama, J., & Clements, D. H. (2002). Building blocks for young children's mathematical development. *Journal of Educational Computing Research*, *27*(1), 93–110. https://doi.org/10.2190/F85E-QQXB-UAX4-BMBJ.

Vygotsky, L. S. (1967). Play and its role in the mental development of the child. *Soviet Psychology, 5*(3), 6-18. https://doi.org/10.2753/RPO1061-040505036.

Vygotsky, L. S. (1980). Mind in society: The development of higher psychological processes. Harvard University Press.

Weisberg, D.S., Hirsh-Pasek K., Golinkoff, R.M., Kittredge, A.K., & Klahr, D. (2016). Guided play: Principles and practices. *Current Directions in Psychological Science*, *25*(3), 177-182. https://doi.org/10.1177/0963721416645512.

Youngquist, J., & Pataray-Ching, J. (2004). Revisiting "Play": Analyzing and articulating acts of inquiry. *Early Childhood Education Journal*, *31*, 171–178. https://doi.org/10.1023

Refining Student Thinking through Computational Modeling

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Abstract: Scientists systematically refine their thinking through theory-building practices. Computational modeling is a key mode of theory building in the 21st century. This study investigates how engagement in the construction and refinement of computational models helps students refine their thinking. Specifically, it presents a microgenetic analysis of an episode during which a student refined their understanding of how disease spreads by building and refining a computational model of an Ebola epidemic. The analysis decomposes the episode into nine theory-building steps and locates the shifts in the student's thinking that occur in each step. It draws connections between these shifts and the theory building activity.

Introduction

In recent years there has been a shift, in science education, toward engaging students in epistemic practices (Ford & Foreman, 2006; Osborne, 2016). This builds on the perspective that students should construct scientific understanding through the kinds of knowledge-building practices scientists use to make sense of the world (Schwarz, Passmore, Reiser, 2017). Theory building is a central epistemic practice of science (Suppe, 1974). We define theory building as a family of practices through which scientists and students systematically refine theoretical knowledge artifacts, including explanations and models (Swanson, 2019). We further posit that as artifacts are refined, thinking is refined. This aligns with empirical work from sociology and cognitive psychology, which shows that scientists build knowledge by refining artifacts and existing ideas (Dunbar, 1997; Latour, 1999), and Einstein's (1936) notion that "the whole of science is nothing more than a refinement of everyday thinking."

Today, many scientists build theory by constructing computational models that, when run, produce outcomes that can be explored and compared with experimental findings (Weintrop et al., 2016; Foster, 2006). A number of research programs have designed and investigated ways of engaging students in theory building through computational modeling. diSessa (1995) used the Boxer computational modeling environment to help high school students articulate and refine their ideas about Newtonian dynamics. Sherin (2001) looked broadly at the possibility of using programming as a language for expressing simple physical ideas. Wilensky and colleagues have investigated student engagement in computational modeling of complex systems phenomena across domains using NetLogo (Wilensky, 1999; Wilensky & Reisman, 2006). More recently, Wilensky and colleagues have examined student model construction using NetTango (Horn, Baker, & Wilensky, 2020), a block-based interface to NetLogo. These studies examine the development of both scientific understanding and computational thinking that result from student engagement in computational modeling (Horn et al., 2014; Wagh & Wilensky, 2017).

Building on this tradition, the present research investigates how computational modeling helps students refine their thinking by driving them to refine a computational model. Specifically, we examine how one student refined her understanding of disease spread as she refined a computational model of the Ebola virus. We identify the smaller shifts in thinking that resulted from her engagement in constructing, testing, debugging, and making sense of the computational model.

Developing an understanding of the complex dynamics of disease spread is of particular relevance today, given the COVID-19 pandemic. At the writing of this paper, COVID-19 has infected approximately 48 million people worldwide and killed 1.2 million ("WHO Coronavirus Disease Dashboard," 2020). In addition to factors such as symptom-free carriers and a long incubation period, the success of the disease can also be attributed to the fact that it is just fatal enough to kill a percentage of those who are infected, but not fatal enough that those people become obviously sick and die before interacting with, and potentially infecting, many other people (Murray & Mearns, 2020). This quality of the coronavirus is at odds with commonsense conceptions about the fatality of a disease, which is that a disease that is very deadly to an individual must be very deadly to a population (Wilensky & Abrahamson, 2006).

This is a good example of what Wilensky and Resnick (1999) refer to as *levels slippage*. Levels slippage is a common error in novice reasoning about complex systems phenomena, whereby a characteristic at the individual level is mapped directly to the aggregate-level. In reasoning about disease, levels slippage occurs when a disease that is deadly to an individual is assumed to be deadly to a population. In reality, as our student learns, a disease that is very deadly to an individual may not be deadly to a population (without additional interacting factors), because it will sicken and kill its carriers before they have the opportunity to infect others. Understanding this complex dynamic between individual and aggregate levels is one of the key understandings that results from our focal student's engagement in computational modeling.

Theoretical foundations

Our analysis is founded on the basic premise of constructivism, which holds that new knowledge is built on the foundation of prior knowledge (Piaget, 1971). A constructivist epistemology known as knowledge-in-pieces (KiP) (diSessa, 1993), characterizes the process of knowledge construction as a refinement of a complex system of existing knowledge elements. The elements are cued variously for sensemaking, depending on a person's level of expertise. For the novice, the elements are loosely interconnected and employed in a manner that is highly context-dependent. For the expert, the elements are more reliably connected and cued more consistently in contexts where they are productive. Learning (or the movement from novice to expert) occurs through the reorganization and refinement of the networks of elements in the knowledge system. For this reason, the naïve knowledge system is viewed as a resource rich with potentially productive ideas for the construction of more expert knowledge networks (Smith, diSessa & Roschelle, 1994). This stands in contrast with the "misconceptions" perspective which regards naïve knowledge as incorrect knowledge structures that need to be removed and replaced (Chi, 2008).

KiP instruction focuses on eliciting students' ideas and refining those that are productive with respect to the context at hand. The construction of computational models provides an opportunity for students to articulate and refine their ideas. This aligns with constructionism (Papert, 1980), which argues that learning happens best through the construction of public artifacts, such as computational models. We posit that the systematic refinement of artifacts that is accomplished through scientific theory building, and in particular, computational modeling, affords and supports a refinement of thinking. This study seeks to understand how computational modeling supports learning. KiP views learning as the sum over smaller shifts, or refinements, in thinking over time. To understand how the construction and refinement of computational models supports refinement of thinking, we examine a case where learning occurred, looking for shifts in the student's thinking over time and connections between those shifts and the student's theory-building activity.

Methods

This paper presents the results of an analysis of data taken from a larger study. The goal of the larger study is to understand how to engage middle school students in different approaches to scientific theory building, including the construction of computational agent-based models. To lower the threshold for participation in computational modeling, we are designing block-based computational modeling microworlds using the NetTango platform (Horn and Wilensky, 2011). NetTango integrates the computational power of NetLogo (Wilensky, 1999) with the accessibility of block-based modeling languages. NetTango blocks are not a full programming language, but domain-specific blocks relevant to a domain that is modeled. Previously called *semantic blocks (*Wilkerson-Jerde & Wilensky, 2010) and now called *domain blocks* (Wagh, Cook-Whitt & Wilensky, 2017) the blocks are primitive elements of code that represent agents' actions and can be combined to model a specific phenomenon. We are designing domain-block libraries for simulating complex systems phenomena and studying how children use the blocks to build and refine computational models, and how their thinking is refined as a result. The present study seeks to characterize, at a fine grain-size, how theory building supports refinement of thinking and asks the question: *How does building and refining a computational model of the Ebola epidemic refine a student's thinking about the spread of disease?*

To address this question, we designed a NetTango modeling microworld that enables a user to build a model of the spread of disease. We tested the microworld with four students during individual 1.5-hour interviews. During the interviews, each student was seated at a desk that displayed a laptop featuring the computational modeling microworld. The student had full command of the laptop. The interviewer sat at the student's left and guided them through tasks and questions contained in a semi-structured interview protocol. The protocol began with an introduction to the study, its purpose, and the overall timeline of the interview. It then probed for students' background in computing and asked a few basic content-related questions (e.g., Do you know what the word epidemic means?). The protocol then moved on to introduce the student to the modeling microworld interface and specific blocks for programming procedures. It then prompted students to use the existing blocks to model diseases (e.g., Ebola). Data was collected during each interview in three forms: video, screen capture, and audio recordings.

The present report focuses on results from an interview with a student we call Sage. Sage was 13 years old and had just started the 8th grade at the local public middle school in her small Midwestern city. She had been introduced to block-based programming when her 7th grade science class participated in *Hour of Code*, an event hosted by schools all over the world to encourage students' interest in computing. The present report focuses on an excerpt from her exploration of the *Spread of Disease* modeling environment.

The *Spread of Disease* modeling environment is pictured below (Figure 1). The screenshot shows the modeling environment with a model that has been built and initialized. The black box to the left is the *world* which depicts the activity of the agents that are programmed to behave according to the rules specified by the model. The *setup* and *go* buttons are controlled by *setup* and *go* procedures (red blocks) that the user must drag from the block library (far right) into the modeling field (middle) and then define by connecting with blocks (purple, grey, and green) defined by specific commands, such as *move*, *if contact person*, and *infect*.

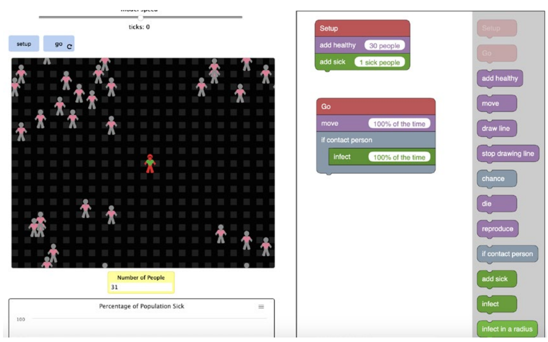

Figure 1. Screenshots of the *Spread of Disease* modeling microworld.

An audio recording of the interview with Sage was transcribed. Both screen capture (with audio recording) and transcript were analyzed to look for evidence of learning. A shift in thinking was identified during an activity in which she attempted to build a model of an Ebola epidemic. A microgenetic analysis (Siegler, 2007) of the episode was conducted to understand the smaller shifts through which her thinking was refined. The episode was ultimately divided into nine steps, each of which featured engagement in aspects of the theory-building process. These included building, testing, and debugging the computational model, and making sense of its simulated outcomes. Having created a temporal decomposition of the episode into these steps, the shifts in thinking that occurred during each were characterized and connected with the theory-building activities.

Findings

We present an episode from Sage's interview to illustrate how she refined her thinking as she refined her model. Ultimately, she developed a sense that a disease that was very deadly to an infected individual can actually be less deadly to a population. In this way, she may have ameliorated a common instance of levels slippage and developed a more sophisticated understanding of the complexity of the phenomenon.

Modeling the Spread of Ebola

Sage is seated at a desk in an office, the interviewer sits at her left. She is looking at a laptop screen on which the *Disease Spread* modeling microworld is open. She has been exploring the microworld for the last 25 minutes, trying out combinations of blocks and watching the resulting activity in the *world*. The interviewer wants to focus Sage on the task of modeling an epidemic and asks: "What if we were to try to make a model of the Ebola epidemic?" The steps below represent a temporal decomposition of Sage's trajectory through the modeling activity, highlighting her shifts in thinking.

Step 1: Building an Initial Model

Sage drags blocks into the programming field, specifying agent rules and constructing her initial model of how Ebola spreads through a population. To aid her design, she browses the internet for information on Ebola, including rates of transmission and death. Turning back to her model, she purposefully selects parameter values that align with what she has found.

> Sage: If sick die 50%, I'll have that, but maybe infect like 10% 'cause like I bet 10% of the time you're like, you accidentally like cough on someone and get their like your saliva in their mouth or something. And like that's, that's gross to think about it but um, infect, well yeah, infect like 10%. […] And then if you're sick, then you die. Let's say 50% 'cause that about ....

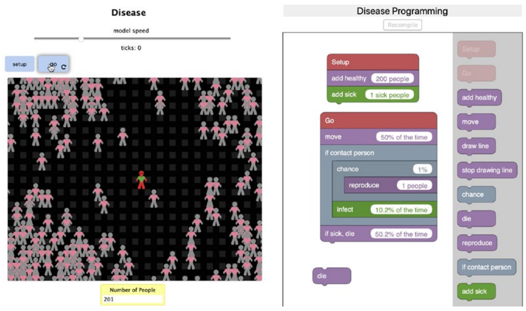

Figure 2. Sage's initial model of Ebola, before she presses "go."

As shown in Figure 2, Sage has set the model to initialize with 200 healthy people (grey bodies, pink hearts) and one sick person (red body with a green heart). With each tick of the clock, each person in the world will move with a 50% probability. If they contact another person, there is a 1% chance they will reproduce, and if they are sick, a 10% chance they will infect the person. If they are sick, there is a 50.2% chance they will die.

Step 2: Testing the Initial Model

Sage runs her model and observes as the single green person in the world disappears almost instantly.

Step 3: Making Sense of the Initial Model

Sage laughs, suggesting she is surprised by the outcome of the model-run. This is evidence that she expects a disease that is very deadly to infected individuals to be deadly to a population. She tries to understand what is happening at the agent level that would have caused the aggregate-level outcome, namely, why the sick person has disappeared, and why the disease did not spread and diminish the population.

Sage: What happened?!
Interviewer: And the number of, what's it look - what happened? Oh the number-
Sage: He died probably.
Interviewer: Oh yeah
Sage: 'Cause, 'cause it's like a 50, 50
Interviewer: Yeah. Yeah. Yeah. And he was already sick. So.

Sage reasons that the single infected person died quickly because they had a 50% chance of dying each tick of the clock.

Step 4: Debugging the Initial Model

Sage's first reaction is that there may indeed not be a way to program the model so that Ebola will spread as she expects. On second thought, she corrects herself, deciding that she could remedy the problem by adding more people.

> Sage: Hmm. Maybe, I don't, I don't think there really is a way to like, do, to do that, if that, because no, no, I could have more people. Um, I'm being ridiculous. Let's have 20 sick people, 21.

She attempts to debug the model by changing a parameter value, increasing the initial number of sick people in the world from 1 to 21. It appears she is testing an extreme value, thinking that it will surely help the disease to spread among the population.

Step 5: Testing the Revised Model

Sage runs her revised model to test the effect of her modified parameter and observes as the sick people (the 21 initially infected people and the people they infected) die within six ticks, leaving only healthy people, as before.

Sage: Then maybe they'll, Oh wait, no they all died.

Sage appears to be surprised by this result. This is evidence that the outcome of the model-run does not match her expectations. It suggests that she may expect a disease that is very deadly to infected individuals to be similarly deadly to a population.

Step 6: Making Sense of the Model Outcome

In an attempt to get Sage to make sense of the relationship between agent- and aggregate-level in this complex-systems phenomenon, the interviewer asks Sage what she thinks is happening.

Sage:	Um, epidemics are hard to start.
Interviewer:	Well, yeah. Well, when, what's hard to start about this one, do you think?
Sage:	Well, I think because, um, that it has a high fatality rate.
Interviewer:	Yeah
Sage:	And well maybe because the infectivity is so low, 'cause then if, um-

Sage appears to have drawn an important conclusion about complex-systems dynamics in the context of the spread of disease. This is that a high fatality rate will cause the carriers of a disease to die before they have a chance to spread it, making it in fact *less deadly* to the population. In arriving at this conclusion, Sage is beginning to construct a more accurate understanding of the connection between agent and aggregate levels. At the same time, she may be holding onto an intuition that the disease *should* be more deadly to the population, as she tries to think of another aspect of the model she could modify so that it produces the aggregate-level phenomenon she expects.

Step 7: Debugging the Model

In an attempt to debug the model and cause the disease to be more deadly to the population, Sage purposefully modifies a parameter setting, increasing the rate of infection.

Interviewer:	Do you want to change that and
Sage:	Yeah, let's, maybe people in this fictional city really like spitting in each other's mouth.
Interviewer:	OK
Sage:	Like maybe, maybe, maybe they're just like kissing everyone and that makes them more infectious.

Sage increases the probability of infection from 10.2% to 50.2% and recompiles the code.

Step 8: Testing the Revised Model

Sage runs her revised model to test the effect of her modified parameter. She observes as the sick people (the 21 initially infected people and the people they infected) die within 14 ticks, leaving only healthy people, as before. This outcome matches those of the previous runs, where the sick people die relatively quickly, leaving the world filled with only healthy people.

Sage:	Setup. Go. They're still all...

As before, Sage appears to be surprised by this outcome. Again, this suggests that she may expect a disease that is very deadly to infected individuals to be similarly deadly to a population.

Step 9. Making Sense of the Model Outcome

The interviewer engages Sage in making sense of the outcome of the model run. She wants Sage to consider what it would mean if her model were actually not flawed, but rather, a good approximation of a disease that is very deadly to individuals. In reality, the model is not a good approximation of Ebola, as that disease is very deadly to individuals yet has succeeded as an epidemic due to factors that are not representable by the block-based modeling infrastructure (e.g., healthy care-givers tending to their dying and deceased loved ones) (Hewlett & Hewlett, 2008).

Interviewer:	Wow. Is that what you expected to happen?
Sage:	No
Interviewer:	Well, what if you assume that your model is actually a good approximation of Ebola?
Sage:	Yeah
Interviewer:	What, what conclusion would you
Sage:	Well, like highly deadly diseases are hard to start epidemics, but when you do, they like really, really start 'cause, um, like, and like maybe, Hmm. I wish you could have like a, like there's, I don't know, like, 'cause like everyone's touching each other and they're like making people, let's take this out right now. Um, but, um- [...] they're reproducing and um, I don't know. It just, like, it, epidemics are hard to start. Um, even if you have people infecting each other like all the time, like they, like all of those people just died.

Sage compares the outcome of the model-run with her expectations and admits that the two do not align. She reflects on what she can learn from the model outcome and further expresses the notion that it is hard to get an epidemic to start when a disease is very deadly to an infected individual. It appears that she is clinging to an intuition that if such diseases do manage to spread, “they really start.” Still trying to find a way to build the model of Ebola so that it wipes out the population (aligning with what she has learned about the disease through the media) Sage removes the “reproduce” command from the “go” procedure.

Discussion

Analysis of this episode shows that Sage refined her understanding as she refined her model. She initially expected Ebola to spread and kill a larger percentage of the population. When her initial model did not produce her expected result, Sage modified parameter values (e.g., the initial number of sick people in the world and the probability of infection on contact) in an attempt to debug her model so the disease would spread. On testing her revised models, she found they still produced the same result. On reflection, she noted that “highly deadly diseases are hard to start epidemics” because their high fatality rates quickly wipe out the infected individuals who would otherwise spread them. In this way, by revising and testing her model, Sage refined her understanding. It is also apparent that her intuitions about disease are appealing and difficult to let go of, as evinced by her statement near the end of the activity “when you do [start an epidemic], they like really, really start.”

Her intuitions about Ebola are not unfounded, as she knows that the disease has indeed been an epidemic in Africa, and continues to be a risk. Ebola was able to become an epidemic despite its deadliness, however, because of other factors (e.g., family members caring for their dying and mourning their deceased) that were not represented in the model. Therefore, the important learning that occurred for Sage was a more nuanced understanding of the dynamics of disease spread as a complex-systems phenomenon, where the deadliness of a disease at the individual level does not directly correspond to the deadliness at the level of the population. In the activity that followed this episode, Sage constructed and refined a model of the flu. The activity helped to further refine her understanding, and she arrived at the conclusion “If [a disease] is like super, super fatal then it won't spread because like it will be super, super rare because like, um, then they let it, we'll just kill out all its carriers.”

The shift in Sage’s thinking over the course of the activity appears to be a correction of a classic case of levels slippage whereby a person determines that a phenomenon occurring at one level is directly caused by the same phenomenon at another level. In this case, a slippage between levels would be attributing the deadliness of a disease at the population level to the deadliness of a disease at the individual level. As Sage learns, however, just because a disease is deadly to an infected individual does not mean that it is deadly to a population.

Taking a step back and looking at what the analysis tells us about Sage’s learning, we see that refining the model helped Sage to refine her thinking. We postulate that all kinds of theory building engage students in refining artifacts that represent their knowledge, therefore helping them refine their thinking. It is important to acknowledge that this particular approach to theory building - building a *computational agent-based model* - afforded particular refinements in Sage’s thinking.

The fact that Sage was building a *computational* model meant that she could test her theory of how disease spread by clicking “go” and simulating what would happen in a world that was set up according to the initial conditions she selected, and behaved according to the rules she had specified. Had Sage not been able to test her revised models, she would not have seen that her modifications did not yield her intended results. She might have continued to think that a disease that was deadly to an individual was similarly deadly to a population, if one starts with enough sick people, or if the probability of infection is high enough. Testing out these agent-level modifications may have helped Sage see that they in fact had no significant impact on the phenomenon. Revising and testing her model helped her to see that regardless of the number of people initially sick or how infectious the disease was, if it was quite deadly to an individual, it would die out before it could spread, producing the opposite of what many people intuitively expect. The computational nature of her model supported refinement through *debugging*, whereby Sage was able to make small corrections to the model and test them, iteratively refining her model and her thinking.

The fact that the computational modeling microworld was *agent-based* meant that her model would be well-suited to simulating complex-systems phenomena. This, in turn, would help her more clearly see relationships between agent and aggregate levels, potentially clearing up any slippage between levels. Furthermore, the model was built using a block-based interface to the underlying computational agent-based modeling language, NetLogo. The blocks both afforded and constrained Sage's theory building. They afforded her entry into computational agent-based modeling, an activity which would otherwise have been inaccessible without some training in the language. It constrained her theory building because there were only particular commands available. Sage noted a number of times, during the interview, that she wished there had been ways of accomplishing something that was not currently afforded by the block-based modeling infrastructure (e.g., making the person infect a certain number of people before they died).

In addition to making a contribution to work concerned with engaging students in science practices, this work makes an empirical contribution to literature on conceptual change, by offering a microgenetic account of how one student's thinking changed as a result of engagement in theory building. Microgenetic accounts of learning are few and necessary for understanding the finer mechanics of learning (diSessa, 2014). Finally, our work makes a contribution by demonstrating an important connection between knowledge-in-pieces and constructionism: that through the refinement of a physical and publicly shareable artifact, students can refine their thinking.

References

Chi, M.T.H. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *Handbook of research on conceptual change* (pp. 61-82). Hillsdale, NJ: Erlbaum.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and instruction*, *10*(2-3), 105-225.

diSessa, A. A. (1995). Designing Newton's laws: Patterns of social and representational feedback in a learning task. In R.-J. Beun, M. Baker, & M. Reiner (Eds.), *Dialogue and Interaction: Modeling Interaction in Intelligent Tutoring Systems.* Berlin: Springer-Verlag, 105-122.

diSessa, A. A. (2014). The construction of causal schemes: Learning mechanisms at the knowledge level. *Cognitive science*, *38*(5), 795-850.

Dunbar, K. (1997). How scientists think: On-line creativity and conceptual change in science. In *Conceptual structures and processes: Emergence, discovery, and change.* American Psychological Association Press.

Duschl, R. A. (2008). Science education in 3-part harmony: Balancing conceptual, epistemic and social goals. Review of Research in Education, 32, 268 – 291.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8* (Vol. 500). Washington, DC: National Academies Press.

Einstein, A. (1936). Physics and reality. *Journal of the Franklin Institute*, *221*(3), 349-382.

Ford, M. J., & Foreman, E. (2006). Redefining Disciplinary Learning in Classroom Contexts. *Review of Research in Education*, *30*(1), 1–32.

Foster, I. (2006) 2020 computing: a two-way street to science's future. Nature 440(7083):419

Hewlett, B. S., Hewlett, B. L. (2008). Ebola, culture, and politics: the anthropology of an emerging disease. United States: Cengage Learning.

Horn, M.S., Brady, C., Hjorth, A., Wagh, A., & Wilensky, U. (2014). Frog Pond: A code first learning environment on natural selection and evolution. Proceedings of IDC 2014.

Horn, M.S., Baker, J. & Wilensky, U. (2020). NetTango Web [Computer Software]. Evanston, IL: Center for Connected Learning and Computer Based Modeling, Northwestern University. https://netlogoweb.org/nettango-builder

Latour, B. (1999). *Pandora's hope: essays on the reality of science studies*. Harvard university press.

Osborne, J. (2016). Defining a knowledge base for reasoning in science: the role of procedural and epistemic knowledge. In R. A. Duschl & A. S. Bismack (Eds.) Reconceptualizing STEM education: The central role of practices. New York: Routledge.

Murray, A., & Mearns, E., (2020, April 29). Understanding the disease: Why is COVID-19 so successful? Retrieved from https://newseu.cgtn.com/news/2020-04-29/pandemic-playback-2-understand-disease-PIHbaLQN8Y/index.html

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc.

Piaget, J., (1971). *Psychology and Epistemology: Towards a Theory of Knowledge*. New York: Grossman.

Schwarz, C. V., Passmore, C., & Reiser, B. J. (2017). *Helping students make sense of the world using next generation science and engineering practices*. NSTA Press.

Sherin, Bruce L. "A Comparison of Programming Languages and Algebraic Notation as Expressive Languages for Physics." *International Journal of Computers for Mathematical Learning* 6, no. 1 (2001): 1–61.

Siegler, R. S. (2007). Microgenetic analyses of learning. In *Handbook of child psychology* (Vol. 2). https://doi.org/10.1002/9780470147658.chpsy0211

Suppe, F. (1974). The search for philosophic understanding of scientific theories: Introduction. In Kuhn, T. S., & Suppe, F. (Eds.), *The structure of scientific theories* (p.244-254). Chicago: University of Illinois Press.

Swanson, H. (2019, April). *Cultivating a theoretical turn-of-mind.* Paper presented at the annual meeting of the American Educational Research Association, Toronto, Canada.

Wagh, A., & Wilensky, U. (2017). EvoBuild: A Quickstart Toolkit for Programming Agent-Based Models of Evolutionary Processes. Journal of Science Education and Technology, 1-16.

Wagh, A., Cook-Whitt, K., & Wilensky, U. (2017). Bridging inquiry-based science and constructionism: Exploring the alignment between students tinkering with code of computational models and goals of inquiry. *Journal of Research in Science Teaching*, *54*(5), 615-641.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127-147.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Wilensky, U. (1998). NetLogo Virus model. http://ccl.northwestern.edu/netlogo/models/Virus

Wilensky, U., & Abrahamson, D. (2006). *Is a disease like a lottery? Classroom networked technology that enables student reasoning about complexity*. Paper presented at the annual meeting of the American Educational Research Association, San Francisco, CA.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—an embodied modeling approach. *Cognition and instruction*, *24*(2), 171-209.

Wilensky, U., & Resnick, M. (1999). Thinking in levels: A dynamic systems approach to making sense of the world. *Journal of Science Education and technology*, *8*(1), 3-19.

Wilkerson-Jerde, M., & Wilensky, U. (2010). *Restructuring Change, Interpreting Changes: The DeltaTick Modeling and Analysis Toolkit*. Paper presented at the Constructionism 2010 Conference, Paris.

WHO Coronavirus Disease Dashboard (2020, November 5). Retrieved from https://covid19.who.in

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Computational Thinking through Body and Ego Syntonicity: Young Children's Embodied Sense-Making Using A Programming Toy

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Abstract: Papert's concept of body syntonicity (how an experience aligns with learners' sense and knowledge about their own bodies) has been embraced by learning scientists; however, his notion of ego syntonicity (how an experience aligns with children's sense of self as people with intentions, goals, desires, likes/dislikes) is less discussed. We argue body syntonicity (BS) and ego syntonicity (ES) are both critical dimensions for understanding how young children learn abstract concepts and skills as part of embodied computational thinking (CT) with tangible programming toys. Using multimodal interactional analysis, we demonstrate how a preschooler (aged 4) used both physical enactment (BS) and intense emotional involvement (ES) with precisely coordinated response cries (e.g., collaborative cheering, gasping) to make sense of how a continuous spatial route can be decomposed into discrete programmable steps. We discuss implications for learning sciences at large and for supporting young children's learning of decomposition and other CT practices.

Introduction

Viewed as "the new literacy of the 21st century," computational thinking (CT) is the systematic analysis, exploration, and testing of solutions to open-ended and often complex problems (Wing, 2011). In addition to its direct application for computer science or programming, CT is also essential to a broad range of planning, critical thinking, and problem-solving situations in other domains such as reading, writing, and arithmetic (Wing, 2006). Given its importance, there are burgeoning, albeit, limited efforts to explore and promote CT in early childhood (ages 0-8; Çetin & Demircan, 2018; Jung & Won, 2018). However, the majority of these studies focus on the feasibility of introducing CT to young children or effectiveness of such efforts (Wang & Choi, under review). As a result, we still have limited understanding of the *processes and mechanisms* through which young children acquire abstract CT concepts and practices.

To address this gap, we investigate how young children (ages 3-4) can participate in the CT practice of *decomposition,* and we adapt Papert's (1980) concepts of body syntonicity and ego syntonicity to make sense of this process. As one of the foundational components of CT, decomposition is defined as breaking down a complex problem into smaller or more manageable parts (Shute et al., 2017; Wing, 2006). For example, in this paper, the participating children were engaged in decomposing a continuous spatial route (moving from "Start" to "Home" and avoiding an obstacle in the path) into discrete programmable steps (attaching different body segments with commands such as go straight, turn left, and turn right) using a programming toy. Decomposition is an important research focus for understanding young children's CT thinking because dealing with different parts of a complex problem all at once may be especially difficult for young children considering their still limited although fast developing memory capacity.

Theoretical framework and relevant literature

Papert (1980) defines body syntonicity as aligning learning tools and experiences with learners' "sense and knowledge about their own bodies" (p. 63), while "ego syntonicity" as aligning learning tools and experiences with learners' "sense of self as people with intentions, goals, desires, likes and dislikes" (p. 63). Embracing Papert's idea that model of learning should "draw on our own behaviors *(i.e. sense of self)*, our own bodies." (p.64), we argue both body syntonicity (BS) and ego syntonicity (ES) are critical dimensions for understanding how young children learn abstract concepts and skills. Both BS and ES can be considered forms of embodied understanding that children have access to.

In the larger learning sciences community, there is broad support for the notion that the body can serve as a key resource for programming and engaging in CT practices. It has been exemplified by the early work of Papert with Turtle Geometry (1980) and the more recent Maker Movement that emphasizes making learning visible and tangible by designing and physically making robotics, textiles, videogames, etc. (Peppler, Halverson, & Kafai, 2016). There are also concerted research efforts to understand how body syntonicity supports and scaffolds learning. For example, Fadjo et al. (2009) found that elementary school children instructed to use their bodies to act out Scratch programming statements outperform those who merely imagine the statements.

Capitalizing on body syntonicity, Berland et al. (2011) developed IPRO "Programming Standing Up," a mobile programming environment where learners use their bodies to simulate and program a robot to play soccer. In this embodied educational programming environment, students overcome impasses by physically acting out their programs and collaboratively debugging them in ways that are not possible with traditional "seated" programming environments. However, while these studies provide useful insights on how body can be used as *physical problem-solving tool*; they have not explored the role of ego syntonicity in students' *affective embodied sense-making.*

There is growing recognition and interest in the broad role of ego syntonicity (ES) plays in the learning sciences. For example, some researchers have foregrounded students' science identity and sense of belonging in the community of practice, and examined how they are developed and how they shape and support science learning (e.g., Kim, Sinatra & Seyranian, 2018; Barton & Tan, 2010; Varelas, Martin & Kane, 2012). Other researchers have zoomed in on how embodied emotion can be a resource for sense-making at a micro moment-to-moment level. In science education, a number of scholars have demonstrated that students' intense affective experiences (e.g., vexation, wonder) can play a central role in driving their engagement and motivation to solve difficult problems both alone and together (e.g., Engle & Conant, 2002; Jaber & Hammer, 2016). In mathematics, Nemirovsky (2011) has demonstrated that episodic feelings (e.g., surprise, enthusiasm, esthetic appreciation) can help learners narratively make sense of and connect together distinct learning experiences. Notably, Nemirovsky argues that embodied experiences of learning cannot be fully understood without attending to their entangled emotional and affective character. Drawing on these studies collectively, we adopt the position that moment-to-moment emotional responses and experiences are likely fundamental to the ways that leaners make sense of STEM practices and their sense of self in relation to the learning tasks and subject areas at hand (i.e., identity). Currently, research on children's emotional engagement and experiences in CT learning (ES at a micro level) or how learner identity (ES at a meso or macro level) is related to CT learning is sorely lacking.

Addressing this gap, our study explores the role of both body syntonicity and ego syntonicity in young children's CT learning. Specifically, we ask the following research question: how can preschoolers use both physical enactment (BS) and intense emotional involvement (ES) to make sense of decomposition in a teacher-guided group coding session? We focus on a classroom's use of a tangible programming toy, and how a focal child first physically enacts a continuous spatial route but misses some steps, and later is able to decompose it into accurate, discrete programmable steps, after he collaboratively narrates the route and engages in precisely coordinated response cries (e.g., collaborative cheering, gasping) with his group. Response cries are "exclamatory interjections that are not full-fledged words" (Goffman, 1978, p. 800) and are used to display emotion in interaction (For example, like surprise (e.g., Oh!) or revulsion (e.g., Ew!)). Response cries can also be used as interactional resources for drawing joint attention to objects and processes (Streeck et al., 2011). In this study, we show how coordinated response cries help the children perceive and recognize a continuous spatial trajectory in terms of discrete programmable steps in order to navigate the tangible programming toy (i.e., in the process of decomposition).

Significance

Understanding the process of how children use decomposition to solve spatial problems can have important implications. Theoretically, by adopting both body syntonicity (BS) and ego syntonicity (ES), our study brings the affective embodied dimension of learning to bear along with the physical body. Thus, our study embraces learner-centered philosophy in its fullest sense. Practically, we argue that understanding how to support both BS and ES may help teachers and parents strengthen young children's learning of CT concepts and practices by leveraging children's knowledge and sense of their body (both emotionally and physically) and motivating them with connections to their own desires and emotions.

Methods

Our present study emerged as part of a larger investigation examining young children's CT learning with a commercially available programming toy at a University-affiliated preschool in the United States. Children worked with Fisher-Price's Think and Learn Code-a-pillar (Code-a-pillar for short) (https://www.youtube.com/watch?v=3d4zXauy6EM) in small groups once or twice a week (average 15 minutes per session) for over 12 weeks. Twenty-two children and two teachers participated in the study. As shown in Figure 1, the Code-a-pillar is shaped like a caterpillar but has interchangeable body segments that program the caterpillar to move and behave in multiple ways. Each body segment represents a different command (e.g., turn right, turn left, go straight, play music). In a purposefully-designed introductory session, children named the Code-a-pillar 'Rapunzel' through a process of brainstorming and voting, decorated a house (a box) for Rapunzel, and learned rules for taking care of her. Each week, children engaged in new programming challenges that often-involved imaginative stories about Rapunzel and required "helping" her navigate to desired locations in the room by programming her. With the teacher's guidance, children engaged in various forms of CT thinking and were encouraged to empathize with the caterpillar's goals (e.g., going home, escaping a toy wasteland). All sessions were video recorded, creating a corpus of about 15 hours.

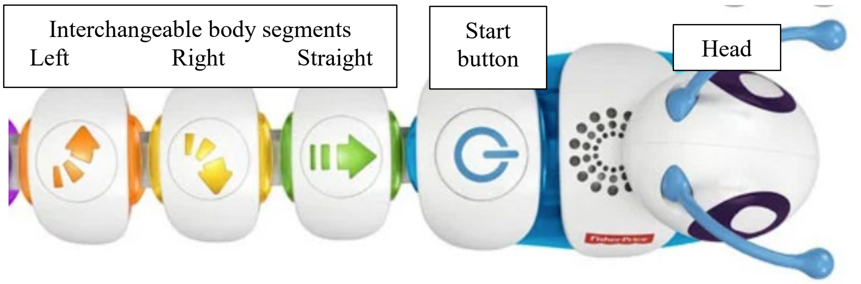


Figure 1. Code-a-pillar (named "Rapunzel" by the children in the present study)

We selected the case we present here because it illustrates how ego syntonicity and body syntonicity can be tightly interwoven as part of children's computational thinking. The session of interest occurred during the ninth week as Mr. Samuel worked with three children, David, Ned, and Peter (all names are pseudonyms) (see a screenshot of the video recorded session in Figure 2). David (aged 4) was Korean-American and an English language learner, Peter (aged 3) and Ned (aged 4) were Caucasians. Mr. Samuel, African American, had been teaching at the pre-school for 7 years.

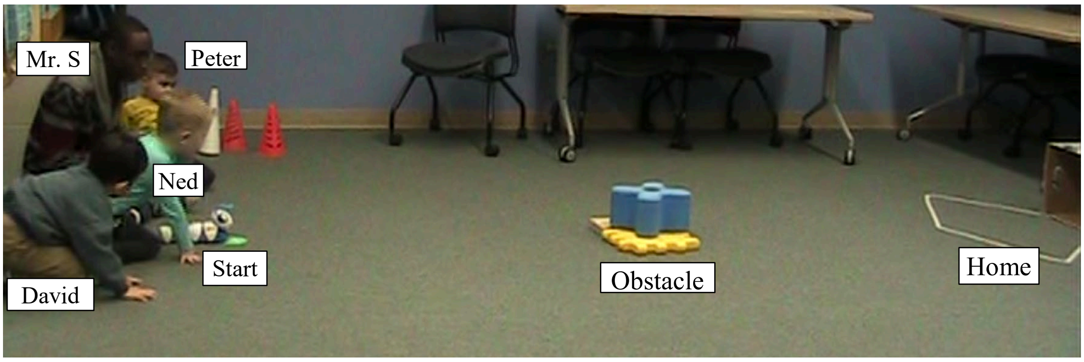


Figure 2. Mr. Samuel and the children in the focal session

Our analysis highlights how Ned's description of the route became more sophisticated over the episode, and the role that body and ego syntonicity played in this process. To understand the progression of Ned's idea about the route Rapunzel should take, we conducted a multimodal analysis of the group's interactions (Jordan & Henderson, 1995; Streeck et al., 2011) during the session. We transcribed participants' speech, facial expressions, vocalizations (e.g., response cries), body movements, and gestures. We also treated Rapunzel as a participant, and her actions were also transcribed. Our close attention to detail revealed the refinement in Ned's understanding of the Code-a-pillar's steps before and after a collaborative narration of its route. Our careful analysis of intense displays of emotional involvement during the collaborative narration revealed how these displays punctuated the Code-a-Pillar's trajectory in space to make it perceivable as a discrete sequence of steps (a form of decomposition).

Findings and discussion

During the session of interest, Mr. Samuel presented the children with a new task: Help Rapunzel, the Code-a-pillar, navigate around an obstacle (a pile of foam objects that the children imaginatively decided to be a snow mountain with a popular cartoon villain on top) and reach her home (the decorated cardboard box) on the other side of the room, about six feet away (see Figure 2). Solving the problem of getting Rapunzel from "Start" to "Home" around the obstacle required the children to break a relatively complicated continuous spatial route down into a sequence of discreet programmable steps using the commands they had available: body segments that make the Code-a-pillar (1) turn right, (2) turn left, or (3) go straight.

To program this route, the children must make sense of and comprehend (1) the continuous trajectory through space (the path or route) that will achieve the goal of getting Rapunzel from Start to Home and (2) how to organize and translate this path into a language the Code-a-pillar understands: a sequential series of commands (turn left, turn right, go straight) dictated by the segments that must be attached to her body. Translating the spatial route into a sequence of steps requires engaging in the important CT practice of *decomposition*. In addition, the children also need to engage in *debugging* to identify and rectify errors in the series of commands they choose (another important CT practice). There are two viable options: passing to the left of the obstacle or passing to the right. If passing to the left, the series of steps could be (a) straight, (b) left turn, (c) right turn, (d) straight, (e) straight, (f) right turn. This is the solution that the group eventually settled on.

In their first attempt, the children only attached two movement segments (one straight and one left turn) to Rapunzel, and as a result, Rapunzel stopped in front of the obstacle as shown in the screenshot (Figure 4). After this failed trial, Mr. Samuel asked them to stop and think.

In response, Ned mapped out a proposed trajectory and series of steps for Rapunzel (Figure 3). Using his finger on the floor to trace a route, Ned crawled from Start to Finish around the obstacle to the left. As he traced and crawled, he named the series of commands he thought would achieve this route (see Table 1)—straight (02), straight (04), left turn (05), right turn (08), and straight (12). The screenshot in Figure 4 captures the next-to-the last step (line 12) when he almost reached Home and the diagram in Figure 3 shows where each of his speech/action lines occurred as he mapped out the route.

By physically enacting (both moving the finger on the floor and crawling forward) Rapunzel's route, Ned was using his body to both plan the path and break the path down into steps. Interestingly, although his audience was at Start, Ned faced Home and crawled with his back toward them the whole time as if he was moving as Rapunzel would. He both simultaneously adopted a *character view point* with his body (facing the direction Rapunzel faced, moving through the space as if he was Rapunzel) and an *observer view point* (using just his finger to trace the route Rapunzel would take). Crowder (1996) has demonstrated that when students adopt a character view point to use their bodies to represent ideas, they are often still in the process of making sense of scientific explanations, and when they adopt observer view-points (such as pointing), they are often relaying already thought-through responses. Here, we argue Ned's blended view point suggests he was both (1) using his body to think through the route, a form of body syntonicity, while (2) simultaneously attempting to illustrate this route for the others by using his finger.

Table 1: Ned plans out Rapunzel's route on the floor

	Ned's Speech	Ned's Action/Gesture
01	I think, we have to go	
02	straaaight, ((pause))	((Drags right finger forward across the floor toward the obstacle as he crawls forward.))
03	and then	((Pauses))
04	straaaight, ((pause))	((Sweeps finger and entire arm backward. Pauses))
05	turn. ((pause))	((Sweeps right finger forward across the floor toward the obstacle as he crawls forward.))
06	And then ((pause))	((Drags right finger slowly to the left. Pauses, then draws a left turning path .))
07	then ((pause))	((Slight pause. Traces finger on floor to go straight forward.))
08	It turns	((Traces to the right toward the home box while crawling forward))
09	This way	((Continues forward tracing a straight line with his finger as he crawls.))
10	and	((Veers to the right with his finger, around the obstacle.))
11	then	((Readjusts, moves his finger and body path straight))
12	straight	((Continues across the floor tracing a straight path into the home box.))

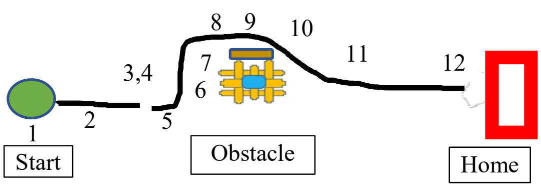


Figure 3. Diagram of Ned's route for Rapunzel

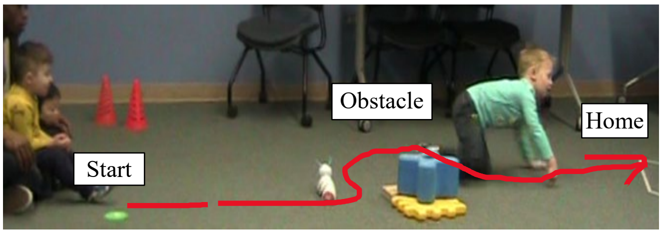


Figure 4. Screenshot of Ned planing Rapunzel's route

Although the path Ned embodied and traced could achieve the goal, he had not fully decomposed it into programmable steps that would work, particularly towards the end of the path. He would need a second right turn to properly line Rapunzel up with her "Home" (although he does embody the continuous curve of the path to get her there) and he also was missing an additional straight command to get her far enough to make it all the way home (although again he traced it). His proposed programming steps would result in Rapunzel ending up short about 2-3 feet and too far to the left of the goal.

Based on Ned's proposed route and steps, the group programmed Rapunzel by attaching five movement segments (a. straight, b. left, c. right, d. straight, e. straight). But Rapunzel stopped short to the left outside of her home. Mr. Samuel took another student, Peter, by the hand, and together they found the solution by walking the final step for Rapunzel. As a result, the group decided that they needed one last piece (f. right turn). A third student, David, attached the final piece and pressed "start."

Together, the Mr. Samuel and the group of children observed Rapunzel's "run" to see what would happen with this new revision. However, the group did not just passively watch Rapunzel progress, instead engaged in an emotionally charged collaborative narration of each step along the way. The diagram in Figure 5 shows how participants' vocalization and action lines (01-22) correspond to Rapunzel's movement (a-f) and Table 2 also uses alternative background colors (red and blue) to correspond to the color of Rapunzel route in the diagram.

Table 2: The group observes Rapunzel's home run

	Participants' Speech and Vocalization	Participants' Action	Rapunzel's Movement
01	Mr. S: Maybe some popcorn she'll have	((Children giggle))	Rapunzel starts moving forward (a)
02	when she gets home. I don't [know.		
03	Children: [OOHhhhh]	((Children lean forward))	Rapunzel continues forward (a)
04	Mr. S: Now, okaaay, now	((N puts hands over mouth))	Rapunzel begins left turn (b)
05	Mr. S: she turnnns		Rapunzel continues turning left (b)
06	Mr. S: Peter, watch, look	((Mr. S points at Rapunzel))	Rapunzel begins turning right (c)
07	Mr. S: And then a riiight turn[nnnnn]		Rapunzel continues turning right (c)
08	D&P&N: [nnnnn]		
09	Mr. S: And then a ST[raaaaaight]		Rapunzel straightens out (d)
10	D&P&N: [Straaaight]		Rapunzel moves forward (d)
11	D: anoder stre[eeeeeee]		
12	Mr. S: And then another stra[aaaight]	((N puts his hands on his mouth and sits up))	Rapunzel starts the next forward command (e)
13	D: [aaNAAHaha!	((D crawls forward))	
14	N: [Nnnnnnnnnn	((N sits further up on knees))	Rapunzel continues straight (e)
15	Mr. S: And THEN	((N inches forward))	
16	(pause)		
17	P: Mmmm[mmmmmmmmmmm		Rapunzel finishes the forward (e)
18	D: [RAAAAIGHTT]		
19	Mr. S: [AND THEN A T]URRN Aaaaaaaah]		Rapunzel begins to turn right (f)
20	Children: [mmmmmmmmmmmmmmmmmmm]		Rapunzel enters the target zone, continuing to turn right (f)
21		((Mr. S throws his arms in the air and then starts clapping))	Rapunzel stops
22	D: Yeah!	((Mr. S, D, P, and N clap, and children start to dance))	

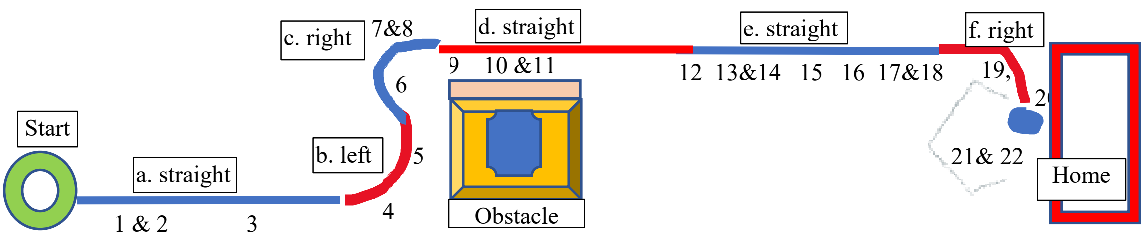


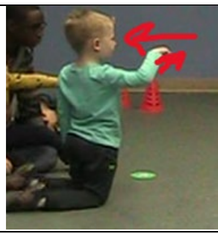
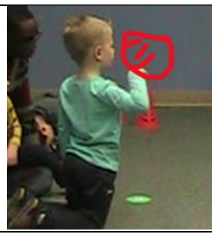
Figure 5. Diagram of Rapunzel's home run

As the run occurred, Mr. Samuel acted like a sports announcer by setting up the scene (01) and detailing Rapunzel's each step (05, 07, 09, 12, 19). The children were intensely engaged and their actions showed intense focus: leaning or inching forward (03, 15), sitting up straight (12, 14), and crawling forward (13), and holding back vocalization by covering their mouth (04, 12) at each consequential step. In addition, the group's collective response cries were precisely coordinated to respond to Rapunzel's movement. Along the way, they gasped, laughed, used elongated sounds, and engaged in playful screams and shrieks. For example, for Rapunzel's fifth movement (e. straight), the children started with intense focus (Ned sitting up with hands covering his moth in 12 and David crawling forward in 13) and cried out in excited anticipation (David uttering intensely excited noises, nearly screaming, in 13). As Rapunzel continued going straight, the children audibly lowered the volume of their response cries, e.g., Ned sat further straight and uttered "Nnnnnn" displaying nervousness (14). Finally, when Rapunzel completed this turn (e. straight), children let out louder joyful shrieks to release the tension until her next new turn started again. To coordinate their collective response cries with Rapunzel's movements and Mr. Samuel's narration, the children had to attune their attention to each place where Rapunzel's continuous spatial trajectory was broken down into the discrete steps they had programmed for her. The range of strong emotions that they performed together showed that they were deeply invested in Rapunzel's success. Overall, the children's intense embodied emotional involvement with the toy's route and programmed steps constitutes a form of ego syntonicity that appears to help them recognize how the continuous spatial trajectory was decomposed into discrete steps.

After this final run, and the body syntonicity (Table 1) and ego syntonicity (Table 2) experiences discussed above, Ned demonstrated a more sophisticated understanding of the decomposition of the route by accurately describing the steps needed to bring Rapunzel to her home (see Table 3). Ned's answer now contained the missing steps he omitted before (e, and f) as he successfully decomposed the whole route into programmable steps. Instead of describing the path through space (which was part of his first explanation in Table 1), he now only seemed to be recounting a list of the discrete programming steps. Each statement corresponded to Rapunzel's segmented movements. There were also less pauses and disfluencies (Crowder, 1996) in his recount compared to his initial planning, and he was more fluent as he described the entire route, suggesting that he was no longer thinking it through how to map the continuous trajectory to the steps, but could just see it as a list of steps. In addition, Ned's gestures were no-longer in character view point (he was only using his hand, and not his whole body), which also suggests he had made sense of the route, and was narrating what he already understood (Crowder, 1996). This is a stark contrast to the first attempt at decomposition, when he was working out the turns, as he went, with his body. Further evidence of Ned's improved competency in regards to decomposition is illustrated by the absence of gesture toward the end of his explanation. Ned did not completely gesture the last two-three steps and relied more on speech to complete the idea.

<u>Table 3: Ned recounts Rapunzel's route</u>

	Ned's Speech	Ned's Gesture
01	We had ta straight	((Moves right arm straight out, pointing finger straight.))
02	turn	((Moves right arm toward his left.))
03		((Makes a slight point forward.))
04	turn	((Extends arm back to the right and forward.))
05	straight	((Retracts arm closer to body.))
06	straight	((Slightly moves finger.))
07	and then- and then- turn.	((Moves finger slightly three times.))

01 & 02	03	04	05	07
				

Throughout Ned's participation, character view point and gestures served as an important stepping stone to developing a more sophisticated computational way of analyzing a situation, and they eventually give way into a more sophisticated description of the decomposition in words. This aligns well others' findings in math and science that that gestures can help reify and objectify abstract patterns (e.g., Radford, 2003) and play an important role in developing technical language (e.g., Roth & Lawless, 2002). However, we argue that Ned's experience is irreducible to just physical bodily activity (in this case body syntonicity). Instead, our study shows the equally important role of intense emotional engagement in learning (ego syntonicity). Collective response cries drew the children's attention to the relationship between the spatial trajectory and discrete programmable steps, and thus likely deepened Ned's understanding of the decomposition in this case.

Conclusion

As an exploratory study, we used a small group of preschoolers' embodied CT learning to illustrate how body syntonicity (BS) and ego syntonicity (ES) can both support children's' sense making of the CT practice of decomposition. While the connection between Ned's BS experience and his learning of these CT concepts and practices is well supported by other embodiment research (e.g., Crowder, 1996; Radford, 2003; Roth & Lawless, 2002), our study highlights the equally important role of ES in children's learning. Although we only focus on the role that intense emotional engagement plays (ES at a moment-to-moment micro level) through the focal session in the findings, we have noted myriads ways the children's ES are being supported. For example, the Code-a-pillar design (life-like features and actions), the curriculum design (naming Rapunzel in the introductory session – see Methods for detail), the teacher's guidance (designing tasks related to Rapunzel's needs), and children's collaboration all contributed to ES at a broader level. Overall, we argue that leaving out ES would result in an incomplete picture of Ned's embodied sense making of the decomposition of the route. Like Papert, we argue that the emotional body and the physical body both play a key role in learning to program. Therefore, we strongly advocate learning sciences communities to pay attention to both BS and ES in their examination of learning processes as well as their design of learning experiences and tools. In practice, teachers and caregivers should consider allowing and supporting children to leverage their knowledge of their body, their sense of self, and their emotions in making sense of CT concepts and practices.

By revisiting *both* of Papert's classic notions of the embodied dimensions of programming – body and ego syntonicity – and bringing them to bear in the case of young children's experiences with a new, tangible programming toy, we embody this year's conference theme by reflecting the past and embracing the future. In particular, our findings lend additional support to Papert's assertions that ego syntonicity plays an important role in how children make sense of tangible programming toys, and warrants further investigation and attention in the design of future learning experience as well as tangible programming toys for young children.

Moving forward, we are planning to extend this research in several directions. First, we will investigate the role body and ego syntonicity plays in supporting students' engagement in other aspects of CT learning. Our data already hinted at some potential effects of ES on debugging, another key CT practice. We also believe ES is particularly well suited to foster desired CT attitudes and perspectives (e.g., collaboration and communication, perseverance, productive failures, tinkering spirit) because its explicitly connects to one's sense of self. Second, we plan to further unpack the social dimensions (e.g., peer collaboration, and teacher scaffolding) of integrating BS and ES to better understand how "'making sense' is a social process" (Bruner & Haste, 1987, p. 1). Third, we will examine the affordances and constraints of tangible programming toys such as Code-a-pillar for young children's BS/ES in their sense making of CT. For example, we have noticed that Code-a-pillar's life-like features lend themselves well for children to project and to align with their own desires, needs and emotions. Code-a-pillar's interchangeable body segments can be attached and detached, which also provides an intuitive way to decompose a continuous route into discrete steps. Finally, we will also explore potential connections between the moment-to-moment emotional and embodied experiences in CT learning (i.e. BS and ES at a micro-level) and the broader macroscale processes of developing learner identities related to computer science (BS and ES at a meso or macro level). Challenging the Cartesian dualism of emotion (body) and knowledge (mind), we believe this integrated BS/ES-based approach to understanding and supporting CT learning may be especially valuable for helping make CT more inclusive for children from non-dominant communities with non-Western epistemologies.

Endnote: Transcript conventions

(1) Brackets [] show overlapping speech or vocalization that occurs at the same time.
(2) ((Double parentheses)) denote nonverbal activities and embodied actions such as gesture.
(3) CAPITALS denote loud speech.
(4) Nnnnnnnnnn extended letters show elongated sounds and cries.

References

Barton, A., & Tan, E. (2010). We be burnin'! agency, identity, and science learning. *Journal of the learning Sciences, 19*(2), 187-229. http://dx.doi.org/10.1080/10508400903530044

Berland, M., Martin, T., Benton, T., & Petrick, C. (2011). Programming on the move: Design lessons from IPRO. In *CHI'11 Extended Abstracts on Human Factors in Computing Systems* (pp. 2149-2154).

Bruner, J., & Haste, H. (1987). Introduction. In J. Bruner & H. Haste (Eds). *Making sense: The child's construction of the world* (pp. 1-26). New York: Routledge

Çetin, M., & Demircan, H. O. (2018). Empowering technology and engineering for STEM education through programming robots: A systematic literature review. *Early Child Development and Care, 190* (9). https://doi.org/10.1080/ 03004430.2018.1534844

Crowder, E. M. (1996). Gestures at work in sense-making science talk. *Journal of the Learning Sciences*, *5*(3), 173–208.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction, 20*(4), 399–483. https://doi.org/10.1207/S1532690XCI2004_1

Fadjo, C. L., Lu, M. T., & Black, J. B. (2009). Instructional embodiment and video game programming in an after-school program. In *EdMedia+ Innovate Learning* (pp. 4041-4046). Association for the Advancement of Computing in Education (AACE).

Goffman, E. (1978). Response cries. *Language, 54*(4), 787–815. https//doi.org/10.2307/413235

Jaber, L. Z., & Hammer, D., (2016). Learning to feel like a scientist. *Science Education, 100*(2), 189–220. https://doi.org/10.1002/sce.21202

Jordan, B., & Henderson, A. (1995). Interaction analysis: foundations and practice. *Journal of the Learning Sciences*, *4*(1), 39–103.

Jung, S. E., & Won, E. (2018). Systematic review of research trends in robotics education for young children. *Sustainability, 10*(4), 905. https://doi.org/10.3390/su10040905

Kim, A., Sinatra, G., & Seyranian, V. (2018). Developing a stem identity among young women: A social identity perspective. *Review of Educational Research, 88*(4). 589-625. https://doi.org/10.3102/0034654318779957

Nemirovsky, R. (2011). Episodic feelings and transfer of learning. *Journal of the Learning Sciences, 20*(2), 308-337.

Papert, S. (1980). *Mindstorms: Children, computer, and powerful ideas.* New York: Basic Books

Peppler, K., Halverson, E. R., & Kafai, Y. (Eds.). (2016). *Makeology.* New York: Routledge. https://doi.org/10.4324/9781315726519

Radford, L. (2003). Gestures, speech, and the sprouting of signs: A semiotic-cultural approach to students' types of generalization. *Mathematical Thinking and Learning*, *5*(1), 37–41.

Roth, W. M., & Lawless, D. (2002). Scientific investigations, metaphorical gestures, and the emergence of abstract scientific concepts. *Learning and Instruction*, *12*(3), 285–304.

Shute, V. J., Sun, C., & Asbell-Clarke, J. (2017). Demystifying computational thinking. *Educational Research Review, 22*, 142-158. https://doi.org/10.1016/j.edurev.2017.09.003

Streeck, J., Goodwin, C., & LeBaron, C. (2011). Embodied interaction: language and body in the material world. In J. Streeck, C. Goodwin, & C. LeBaron (Eds.), *Embodied Interaction language and body in the material world* (pp. 1–28). Cambridge University Press. http://books.google.com/books?id=vJlSewAACAAJ&pgis=1

Varelas, M., Martin, D. B., & Kane, J. M. (2012). Content learning and identity construction: A framework to strengthen African American students' mathematics and science learning in urban elementary schools. *Human Development, 55*(5-6), 319-339. https://doi.org/10.1159/000345324

Wang, X. C., & Choi, Y. (under review). Fostering children's computational thinking in early childhood: A systematic review. *Review of Educational Research*.

Wing, J. M. (2006). Computational thinking. *Communications of the ACM, 49*(3), 33–35. https://doi.org/10.1145/ 1118178.1118215

Wing, J. M. (2011). Computational thinking—What and why? *The Link Magazine*. Pittsburg, PA: Carnegie Mellon University. https://www.cs.cmu.edu/link/research-notebook-computational-thinking-what-and-why

Model-Based Reasoning with Immersive VR Simulations: Patterns of Use Grounded in Time and 3D Space

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Abstract: This paper explores the affordances of virtual reality (VR) simulations for model-based reasoning. Thirty-four undergraduate students engaged with simulated scientific models in head-mount displays in either a seated or standing position. To examine how simulation and learning activity supported model-based reasoning, we coded facilitator-participant interactions using the Structure-Behavior-Function framework and inductively analyzed the exchanges for key themes relating to *how* students interrogated the model. Findings showed that students examined the model's function most frequently, followed by structure then behavior. They spontaneously observed the model's structural components, which at times led to more in-depth student-driven inquiries. Students attended to components' behavior in the form of immediate situated feedback while demonstrating their conceptual understanding. Students compared and contrasted the multiple simulated states to elaborate on the model's function. However, mental workload and prior knowledge were mediating factors. Lastly, predictions about the model's function drew upon structure and behavior 'levels' in student reasoning.

Understanding dynamic systems with simulations

It is well understood that different external representational forms can influence how people think about a phenomenon (Wilkerson-Jerde et al., 2015). For instance, dynamic visualizations (or animations) of molecular processes and mechanisms depict change over time particularly well, engaging learners with temporal dimensions of phenomena (Tversky et al., 2002). On the other hand, agent-based models (Wilensky & Reisman, 2006) afford learners to explore underlying rule-sets of a complex phenomenon through experimentation (Levy & Wilensky, 2009). A wealth of research in the learning sciences, representing well over two decades of effort, has examined in-depth how computational tools can engage learners with complex concepts in a multitude of scientific domains (for a summary, see Yoon et al., 2018). Nevertheless, certain scientific concepts remain challenging for learners to learn with deep understanding.

Complex phenomena with multilevel organization, interconnections, and emergent properties that are invisible, dynamic, and interdependent are particularly prone to misconceptions (Chi et al., 2012; Hmelo-Silver et al., 2007). According to research comparing novice and expert understanding of complex systems using the Structure-Behavior-Function (SBF) framework, Hmelo-Silver and colleagues (2000) found that novices tended to focus on visible structures rather than the behaviors of components or functioning of the overall system. Meanwhile, Chi and colleagues (2005; 2012) hypothesized that novice learners misinterpret the emergent and dynamic properties of scientific models as sequential processes because they lack the schema required to interpret non-sequential processes. Authors suggest that an emergent schema may be taught to students with instructional material that incorporates dynamic computer simulations. The increasing availability of immersive virtual reality (VR) offers promise as a form factor for "experiencing" typically unobservable phenomena, including those at non-tactile scales that students found challenging to perceive (Tretter et al., 2006). VR simulations can also be designed to include properties of dynamic visualizations and computational models. However, we are just beginning to understand how VR simulations can help learners develop appropriate schemas while interrogating complex systems models.

Embodied simulation environments

Based on the embodied cognition theory, how we create and recall mental constructs is influenced by the way we perceive our surroundings and move our bodies (Barsalou, 2008; Shapiro, 2014). Some theorists suggest that "activity in sensorimotor cortices causes conceptual activity (because they are substantially the same) and conceptual activity causes sensorimotor activity (for the same reason)" (Johnson-Glenberg et al., 2015, p. 181). Recent research examining the impact of experimenting with agent-based computational simulations on student explanations (of gold nanoparticles) found that the desktop simulations offer an embodied learning experience (Lai et al., 2018). Viewing videos of dynamic visualizations, however, did not produce evidence of an embodied experience. Authors posit that interacting with the simulation helped students construct new schema about nanoscale target structures, which they incorporated into mental simulations and called upon when asked to explain their understanding. Computer simulations are believed to present certain advantages over traditional abstract representations (e.g., seen in textbook diagrams) by providing “a perceptual grounding for concepts that might otherwise be too abstract to readily comprehend” (Goldstone & Son, 2005, p. 72). Interestingly, prior research suggests that agent-based computational modeling environments present unique perspective-taking challenges for learners (Sengupta & Wilensky, 2009) — which point to a need for additional research in this area. Unlike conventional desktop simulations, VR simulations allow users to move freely and interact with objects, opening up opportunities to ground abstract concepts into concrete manipulatable representations for the learner.

Early explorations of VR simulations, such as the ScienceSpace project by Dede and colleagues, show promise for supporting students to learn complex scientific concepts of mechanics, electromagnetism, and chemistry (Dede et al., 1996). More recent VR designs for addressing scientific understanding focus on storytelling approaches (Ba et al., 2019; Zhang et al., 2019). This paper examines virtual reality as a form factor for supporting model-based understandings and makes the case that VR simulations *can be designed* for learners to construct new schema relating to the structure, behavior, and function of complex systems. By examining the affordances of an immersive VR simulation to support university students as they explore a complex genetic regulation model, this study considers virtual reality simulations as an external representational form for thinking about complex phenomena.

In our previous work, we conducted a study that examines the use of a VR simulation and learning outcomes with students from a microbiology course (Lui et al., 2020). We compared students’ conceptual understanding between students who experienced a VR simulation in either a sitting down or standing up position (to examine gross motor effects), along with a group of students that did not experience the simulation. We found that students who engaged with the VR simulation performed significantly better on a concept inventory test than students who did not. Our findings, which examine the VR experience from a psychophysiological perspective, point to a connection between sensorimotor engagement and learning but do not address *why* or *how*.

Further explorations require an in-depth examination of the learning involved. The current study extends our prior work by examining *how* students engage with the VR simulation in model-based reasoning. We seek to identify the patterns students use to interrogate the simulation model and how their strategies connect to perceptual affordances in virtual reality.

Method

This project is based on a design-based research methodology (The Design-Based Research Collective, 2003), following a co-design process (Penuel, 2019). Researchers collaborated with a science instructor to develop the VR simulation in Unity 3D to address a topic her students had difficulty understanding. The topic was introduced to course students in two 80-minute lectures using an active learning approach. The VR simulation was tested with a subset of her students in the Winter term of 2019.

The VR simulation environment & model-based reasoning activity

The subject of the simulation is a foundational but complex model of gene regulation in the bacteria known as the *lac operon*, or simply put, how a set of genes are turned on and off to regulate lactose metabolism in the E. Coli bacteria. Part of the difficulty in constructing a complete understanding of the lac operon is that it has two interconnected controlling mechanisms (negative feedback and rate of metabolism) that respond “intelligently” to fluctuating environmental conditions (Cooper, 2015).

Within the simulation, learners build the lac operon model and reason about its function under various conditions (e.g., high glucose levels). The model has 18 components, grouped into three types according to their role in the simulation: structural components, mechanistic components, and system-automated components (Table 1). The learning activity was facilitated by the lead researcher and consisted of the following phases:

Phase 1 – Learners completed the model by placing or throwing elements (structural elements) in their designated location along a placeholder DNA strand (similar to a “drag-and-drop” interaction but in 3D space; Figure 1).

Phase 2 – Learners explored how the model’s components behave by interacting with mechanistic elements to create new molecular and protein elements, effectively “running” the simulation (e.g., transcription with RNA polymerase, translation with ribosome).

Phase 3 – Once system-automated elements appeared, learners were prompted to reason about how the model functions (e.g., “What is happening here?”, “Why do you think…”). Since it was important for learners to notice certain interactive features and inter-level attributes of emergent processes in dynamic simulations, prompts were used as a scaffolding device to supplement the simulation (Chi et al., 2012). Feedback and prompts were consistent with facilitator-participant interactions in related studies (Roussou & Slater, 2020; Wilkerson-Jerde et al., 2015).

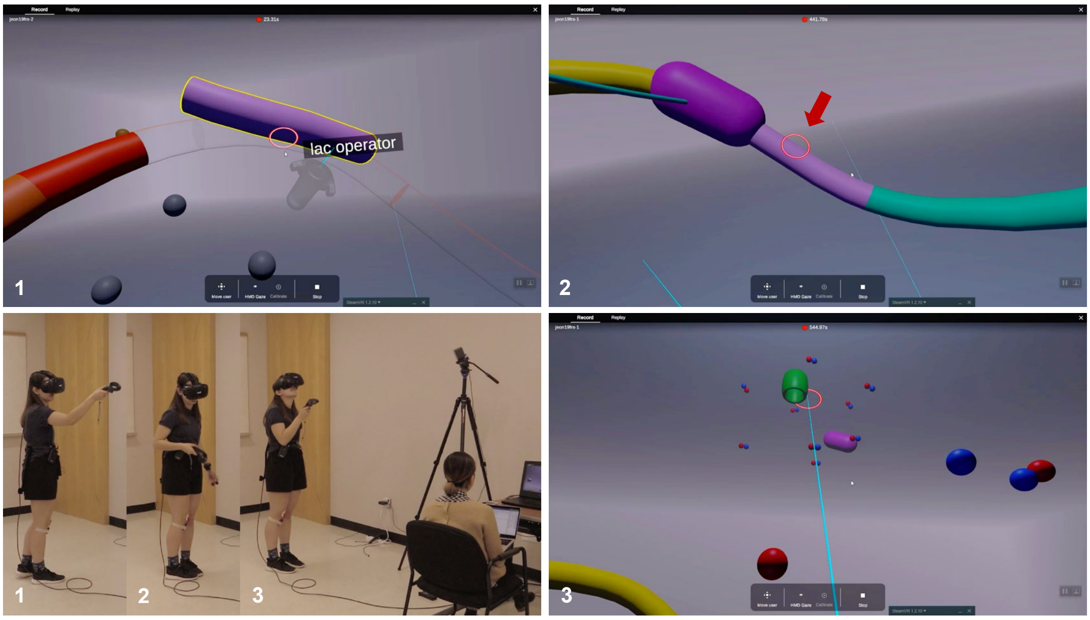

Figure 1. Images from the VR simulation, phases 1–3. Clockwise from top left: 1) Moving operator gene to DNA, 2) RNA polymerase transcribing the DNA to mRNA, 3) Permease protein transporting lactose into the cell. Bottom left: Participant positions in corresponding phases. Red circles indicate participant gaze fixations.

Table 1: Component types in the VR simulation and their relationship to the scientific model

Type of VR object	Description	Model component
Structural	Learner-controlled objects that form model structure	Individual genes (e.g., operator)
Mechanistic	Learner-controlled objects requiring interaction to modify simulated states of the model	RNA polymerase, ribosome, mRNA
System-automated*	Objects generated automatically by the simulation as a result of user interaction with mechanistic elements	Molecules (e.g., lactose, cAMP), proteins (e.g., beta-galactosidase, acetyltransferase)

**Two mechanisms involve system-automated elements that impact the model's function. One relates to a negative (–) feedback loop (stops function), and another relates to a positive (+) feedback loop (accelerates effects).*

Participants
Thirty-four students from an undergraduate microbiology course participated in the experiment (5 males, 29 females). Participants were recruited through class announcements and randomly assigned to either a seated or standing condition. The average age was 21.2 years; 15 did not have prior experience with immersive technology.

Procedure
Prior to the experience, participants completed a pre-activity questionnaire consisting of nine multiple-choice questions based on a concept inventory about the *lac* operon (Stefanski et al., 2016). As well, the questionnaire included questions about learners' prior experience with immersive environments and spatial ability. An HTC Vive head-mounted display retrofitted with integrated eye tracking (Tobii Pro VR, Tobii Group) was used. The VR experience itself was approximately 30 minutes long. Participants in the seated condition sat in a swivel chair, while participants in the standing condition freely moved within a 2.5 m^2 space. All participants held a controller in their dominant hand only. Audio, video, and screen recordings were captured, in addition to physiological sensing data. The lead researcher took field notes during the data collection period. Afterward, participants completed a post-questionnaire, which included a posttest (identical to the pretest) and questions about their experience. The entire session lasted approximately one hour, and participants were given a gift card as a token of appreciation.

Data sources and analysis

The primary data source for this study were video recordings of the VR sessions, which were transcribed by a text-to-speech service (https://otter.ai/) and corrected by two researchers. Other data sources collected provided contextual information about the learner and perceptions of their learning experience. To analyze the data, we first coded the content of facilitator-participant interactions (Chi, 1997) using the structure-behavior-function framework (Hmelo-Silver & Pfeffer, 2004). For example, exchanges coded as structure may begin with "What do you think *that* is?" (referring to the objects participants were looking at). Exchanges coded as behavior may begin with "What do you think beta-galactosidase does?" Those stemming from prediction questions such as "What do you think will happen?" and "Why did the repressor release from the *lac* operon?" were coded as function. Two researchers coded the exchanges, with the codebook established collaboratively from coding one transcript together. After coding slightly over 20% of the transcripts separately and achieving over 85% agreement (with all differences reconciled), the remainder of the transcripts were divided between the two researchers. The exchanges underwent further coding with an inductive approach following the constant comparative method (Gibson & Brown, 2009). Open coding on the exchanges was performed to examine how learners interrogated the model in VR. The researchers shared and discussed the codes and explored proto-themes. Finally, these codes coalesced as a set of four themes that described learners' patterns of use (Thompson & Reimann, 2010). Particular attention was paid to the affordances of the VR environment for supporting learners to reason around models.

Results and discussion

SBF model engagement with VR simulations

This study seeks to uncover patterns of use when students are engaged in a model-based reasoning activity with VR simulations. However firstly, we needed to establish *which* aspects of the model students engaged with. The content analysis of facilitator-participant interactions found that students engaged with the function of the lac operon model most, taking up 50% of exchanges that belonged to the SBF framework. This was followed by the model's structural features, which comprised 26% of facilitator-participant interactions, and then behavior of individual components at 24%. In some ways, the analysis of facilitator-participant interactions from an SBF perspective speaks to how well a VR simulation can support students' conceptual engagement about the lac operon model. We demonstrate that the activity maintained a strong focus on the model's function, which was crucial for students to develop a deep conceptual understanding of the phenomenon (Hmelo-Silver et al., 2007). Because VR simulations offer highly tangible representation embedded in the learner's perceptual view, one might suggest that learners in VR simulations are at risk of focusing on structural features too much simply because they are easier to attend to visually. This study offers preliminary evidence that it does not have to be the case and that novices, such as the students in the foundational biology course, can be prompted through the design of the learning activities to engage with the VR simulation for examining the behaviors and functions of a system.

Other researchers have also explored ways in which an SBF framing of embodied activity can lead to shifts in explanations about superficial structures to the system's behaviors and functions (Danish, 2014). However, they caution that design decisions can influence whether learners' attention is directed toward or away from a complex system's key behaviors. More work is needed to understand how specific design features may cue learners' attention to complex phenomena in VR simulations.

Patterns of use in model-based reasoning with VR simulations

In this section, we present *how* learners engaged with the VR simulation. Below, we describe four themes regarding the patterns of use in a VR-mediated experience during a model-based reasoning activity. We also discuss the affordances of VR simulations for supporting each pattern.

Theme 1: Spontaneous, direct observations of model structural features

While interacting with the simulation, students noticed certain visual aspects of the model and wondered about them. Although many such comments were of surface-level features of the model, this seemed to motivate students' questions about their behavior. In S32 @ 13:24 she noted: "What is that blue thing on top of this? Is it Allolactose? … It just stays there?" and S12 @ 23:23 "Oh, what's this? Galactose acetyltransferase [aiming and pointing to the object to reveal its text label, reading aloud] … Where did that come from? … oh, there's another one." Instead of continuing to the next task as planned, the facilitator guided S12 to transcribe the lac operon again. She carefully observed the proteins that were produced as a result, which included acetyltransferase.

For students learning about complex phenomena with computational models, direct observation offers one method for grounding abstract scientific knowledge in the model (Markauskaite et al., 2020). Similarly, the learners in this study were attending to structural elements they see, drawing from lower-level perceptual inputs, but the nature of their verbal observations was unprompted. An important distinction of the student observations in this theme from other inquiries about the model's structural components is that the exchanges were driven by the learner's own curiosity. Importantly, they (sometimes) led to deeper level investigations about the components, such as neighboring structures, interrelationships, and mechanisms involved. We posit that being perceptually situated in the molecular-scale of the model in 3D space facilitated students' spontaneous, direct observations, which in turn encouraged self-directed questions and deeper reasoning beyond surface-level features of the model. The unprompted observations and curiosity about model elements also relate to a correlation between positive emotions (e.g., motivation, enjoyment) and learning in VR (Makransky & Lilleholt, 2018).

Theme 2: Immediate situated feedback of model processes

Throughout the VR session, students were asked about the behavior of objects they interacted with. Students answered verbally and were then prompted to replicate their answers' through interaction with the simulation. In this way, student feedback was situated in experiencing the model's processes, such as in S10 @ 17:42. When asked, "What does [the repressor] do?" she answered, "It can bind to the operator to stop transcription?" When prompted to demonstrate this, the episode continued:

> S10: OOoo allolactose bound…the repressor…now is binding
> R: It wasn't binding before. Why is that?
> S10: Because the allolactose bound to it, so we have conformational change…cool.

S10 answered correctly but did not appear confident. Having "seen" the process validated her thinking and completed her understanding of the repressor's role in regulating the lac operon (i.e., negative feedback loop).

When students did not know how to respond to questions about the model, they were guided in the simulation to discover the answer. For example, when S28 @ 28:40 was asked, "What does allolactose do?" she responded with, "It allows lactose…is it? I can't remember…" S28 was guided to create a copy of the repressor. At that point, she observed allolactose binding to the repressor @ 30:15 "So the mRNA was put into the ribosome, created lac I repressor…and then attached to it is the allolactose." She successfully identified the structure in a new context. Upon observing the weak transient intermolecular attraction between the lac operon and the repressor, S28 initially (erroneously) conjectured that the repressor could indeed bind to the operator. However, as soon as the allolactose molecule bound to the repressor, S28 saw that the repressor detached from the DNA @ 30:48. She observed, "So when the repressor is attached, allolactose is not." Throughout the above episode, S28 explored the model intending to understand the role of allolactose. With each interaction, she attended to the subsequent dynamic behaviors of related structural components and directly observed the emergent nature of intermolecular attraction.

Episodes related to this theme were typically related to students' answer-seeking efforts or to demonstrate their understanding of model component behaviors. It is thought that our vestibular and proprioceptive senses (unconscious sense of body position, movement, and acceleration) are involved in the encoding, storing, recognizing, embodying, and recalling of spatial information about our environment and of our orientation within immersive VR (Krokos et al., 2019). The immediacy of "experiencing" dynamic feedback as students interacted with structure components likely supported the construction of embodied mental models that are situated in the first-person perspective (Glenberg, 1999). In cases where the learner's verbal response 'matched' what they saw, the experience validated their own mental model. Verbalizations may be encoded along with memory traces of their virtual reality experience. Conversely, in cases where the outcome is unexpected, learners were afforded an opportunity to confront their erroneous and fragmented understanding, allowing them to recognize the need to construct a more complete mental model.

Theme 3: Immersion of multiple simulated states in sequence

Students examined the simulated model under several distinct conditions. They began with the most basic variation with no external lactose or glucose molecules and culminated in a simulation version with high levels of lactose and glucose. Between "variations" of the model, students were asked to describe differences between the current version and the previously examined simulation. For example, after exploring a model with glucose present but not lactose (2^{nd} variation), S9 was presented with a version of the simulation with lactose only (3^{rd} variation). When asked to examine the differences between the two environments @ 21:29, S9 immediately noticed, "The cAMP is back…Okay, so before there's no CAP proteins associated, there's no cAMP bound to the CAP protein." Upon further prompting @ 21:48, he continues to recall details about the positive feedback mechanism:

R: And what else is different about the CAP protein?
S9: There's two of them bound together.
R: Yeah…what do you think will happen when the DNA is built?
S9: CAP protein should bind to the C site.

Later once the DNA was completed, when asked, "Did something happen on the DNA strand?" S9 comments @ 23:51, "Same thing as before the cAMP protein bind to the C site." In which he referred to the first variation of the simulation. He recalled elements of the positive feedback regulatory mechanism. He later made causal connections between the presence of glucose, the absence of cAMP, lack of CAP protein dimerization, and binding to the DNA — this ultimately suppressed the model's efficiency to metabolized lactose.
Presenting variations of the model in a sequential manner fostered the cyclical nature of the discovery process and supported a natural affordance of virtual reality to immerse students in a single alternate reality one at a time. Akin to using a compare and contrast strategy to examine epistemic frames (Collins & Ferguson, 1993), students recognized how the model might function under different circumstances and began to appreciate the model's emergent properties. Exploring increasingly complex variations allowed students to gradually develop progressively more sophisticated mental models and reason about the model as a dynamic system.

A drawback to this approach became apparent when a few students had difficulty recalling variations of the simulation. For instance, S7 acknowledged that something looked different but could not pinpoint exact details @ 14:48 "Oh, there's no um…the proteins look different here, but there's no inhibitor, the red thing is gone." Furthermore, S7 did not recognize that the red repressor was produced from interacting with the simulation (rather than appear at the outset). When students experienced difficulty recalling recent events and showed physiological markers of stress (from sensor data), it suggested that they were experiencing cognitive overload. Making connections amongst different aspects of a complex system taxes one's working memory (Perkins & Grotzer, 2000). At the same time, there are additional perceptual and proprioceptive processing demands in VR, which further limits working memory capacity. The issue of cognitive overload presents a fundamental design consideration, particularly for learners sensitive to simulator sickness and who have less prior domain knowledge.

Theme 4: Inquiry across structure, behavior, and function of the simulated model

In many instances, when students were asked to predict how the model would function, student responses spanned scalar levels, characteristic of mechanistic reasoning (Krist et al., 2019). For example, the facilitator posed to S1 @ 29:21 "What happens when you try to transcribe the repressor?" S1 responds, "Right…it will produce the repressor now. I don't think it will bind. The lactose can be broken down by the (beta-)galactosidase, and we have allolactose present, and it will bind to the repressor…it will remove it from the operator." S1 accurately identifies each of the elements (lactose, beta-galactosidase, allolactose) in the causal chain and the necessary behavior for the event to occur (beta-galactosidase breaks down lactose into allolactose and galactose).

Several episodes began as examinations in one of the SBF components but later spanned across the other categories. For example, S12 @ 19:36 noticed that the repressor was disassociated from the DNA ("Oh, yeah, it's already off"). Upon prompting, "What made [the repressor] come off?" S12 attended to the interrelationships between the structures around the repressor and reasons about them to discover the answer:

> Now it's back on there. Oh, there's a… it's a… it's one of the sugars that is broken down like glucose, right? What are the blue ones? It's a blue one. I'm not sure which one that is. There. Oh, allolactose…And that one's lactose. So, it's taking the lactose from that comes through the membrane, and then the beta… the B-gal [beta-galactosidase] separates it into galactose and allolactose and then…oh where did it go? Oh there. Okay. And then it binds to the repressor. And then it's not…

The episodes above illustrate the VR simulation's affordance to act as an experimental 'sandbox' by offering several decision paths for the learner to engage with various aspects of the model from the same perceptual context. Beyond interacting with the model in designated environmental conditions, the variables can be manipulated from within any scenario (i.e., increasing/decreasing glucose and lactose levels). These and other features opened up possibilities for supporting student-interest-driven inquiries in an uninterrupted, natural interaction flow. Future designs can draw on work with multiple representations for supporting more abstract reasoning. One argument that concrete materials can support abstract reasoning is connected to how well external representational forms can be designed—to explicitly promote inferences from perceptually salient features to correspond to abstract concepts (Goldstone & Son, 2005). Investigating design features in VR simulations for bridging concrete and abstract understandings of complex phenomena is an exciting direction for future research and serves as a promising area for understanding embodied cognition in learning contexts.

Conclusions

This paper offers preliminary support for the use of VR simulations to facilitate model-based learning activities for novices to understand complex phenomena. Although certain simulation affordances discussed are tied to the learning activity design, we suggest that the activity and form factor together confer advantages for novices to understand complex phenomena by grounding conceptually abstract entities (like negative feedback loops) into concrete 3D representations for observation over time. Learners not only focused on functional features of the model more frequently than structural or behavioral mechanisms, but they also exhibited patterns of use that were conducive to interrogating deeper interrelations of a complex genetic regulation system.

References

Ba, R., Xie, Y., Zhang, Y., Taib, S. F. B. M., Cai, Y., Walker, Z., Chen, Z., Tan, S., Chow, B. H., Lim, S. M., Pang, D., Goei, S. L., Matimba, H. E. K., & van Joolingen, W. R. (2019). Virtual Reality Enzymes: Interdisciplinary and international project towards an inquiry-based pedagogy. In Y. Cai, van Joolingen, Wouter, & Walker, Zachary (Eds.), *VR, Simulations and serious games for education* (pp. 45–54). Springer Nature.

Barsalou, L. W. (2008). Cognitive and neural contributions to understanding the conceptual system: *Current Directions in Psychological Science*, *17*(2), 91–95.

Chi, M. T. H. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences*, *14*(2), 161–199.

Chi, M. T. H., Roscoe, R., Slotta, J. D., Roy, M., & Chase, C. C. (2012). Misconceived causal explanations for emergent processes. *Cognitive Science*, *36*(1), 1–61.

Collins, A., & Ferguson, W. (1993). Epistemic forms and epistemic games: Structures and strategies to guide inquiry. *Educational Psychologist*, *28*(1), 25–42.

Cooper, R. A. (2015). Teaching the big ideas of biology with operon models. *The American Biology Teacher*, *77*(1), 30–39.

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. *Journal of the Learning Sciences*, *23*(2), 100–148.

Dede, C., Salzman, M. C., & Bowen Loftin, R. (1996). ScienceSpace: Virtual realities for learning complex and abstract scientific concepts. *Proceedings of the 1996 Virtual Reality Annual International Symposium (VRAIS 96)*, 246.

Gibbs, J., Raymond W. (2005). *Embodiment and Cognitive Science*. Cambridge University Press.

Gibson, W., & Brown, A. (2009). *Working with Qualitative Data*. SAGE Publications, Ltd.

Glenberg, A. (1999). 4 Why mental models must be embodied. In G. Rickheit & C. Habel (Eds.), *Advances in Psychology* (Vol. 128, pp. 77–90). North-Holland.

Goldstone, R. L., & Son, J. Y. (2005). The transfer of scientific principles using concrete and idealized simulations. *Journal of the Learning Sciences*, *14*(1), 69–110.

Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *Journal of the Learning Sciences*, *9*(3), 247–298.

Hmelo-Silver, C. E., Marathe, S., & Liu, L. (2007). Fish swim, rocks sit, and lungs breathe: Expert-novice understanding of complex systems. *Journal of the Learning Sciences*, *16*(3), 307–331. https://doi.org/10.1080/10508400701413401

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science*, *28*(1), 127–138.

Johnson-Glenberg, M. C., Birchfield, D. A., Megowan-Romanowicz, C., & Snow, E. L. (2015). If the gear fits, spin It!: Embodied education and in-game assessments. *International Journal of Gaming and Computer-Mediated Simulations (IJGCMS)*, *7*(4), 40–65.

Krist, C., Schwarz, C. V., & Reiser, B. J. (2019). Identifying essential epistemic heuristics for guiding mechanistic reasoning in science learning. *Journal of the Learning Sciences*, *28*(2), 160–205.

Krokos, E., Plaisant, C., & Varshney, A. (2019). Virtual memory palaces: Immersion aids recall. *Virtual Reality*, *23*(1), 1–15.

Lai, P., Jacobson, M., & Goldwater, M. (2018) Learning nanoscience concepts through a nanoscale experience. *Proceedings of the 13th International Conference of the Learning Sciences (ICLS) 2018 (Volume 1)*, pp. 200-207. International Society of the Learning Sciences, Inc.

Levy, S. T., & Wilensky, U. (2009). Students' learning with the Connected Chemistry (CC1) curriculum: Navigating the complexities of the particulate world. *Journal of Science Education and Technology*, *18*(3), 243–254.

Lui, M., McEwen, R., & Mullally, M. (2020). Immersive virtual reality for supporting complex scientific knowledge: Augmenting our understanding with physiological monitoring. *British Journal of Educational Technology*, *51*(6), 2181–2199.

Makransky, G., & Lilleholt, L. (2018). A structural equation modeling investigation of the emotional value of immersive virtual reality in education. *Educational Technology Research and Development*, *66*(5), 1141–1164. https://doi.org/10.1007/s11423-018-9581-2

Markauskaite, L., Kelly, N., & Jacobson, M. J. (2020). Model-based knowing: How do students ground their understanding about climate systems in agent-based computer models? *Research in Science Education*, *50*(1), 53–77.

Penuel, W. R. (2019). Co-design as infrastructuring with attention to power: Building collective capacity for equitable teaching and learning through Design-Based Implementation Research. In J. Pieters, J. Voogt, & N. Pareja Roblin (Eds.), *Collaborative Curriculum Design for Sustainable Innovation and Teacher Learning* (pp. 387–401). Springer International Publishing.

Perkins, D. N., & Grotzer, T. A. (2000). *Models and moves: Focusing on Dimensions of Causal Complexity To Achieve Deeper Scientific Understanding*. https://eric.ed.gov/?id=ED441698

Roussou, M., & Slater, M. (2020). Comparison of the effect of interactive versus passive virtual reality learning activities in evoking and sustaining conceptual change. *IEEE Transactions on Emerging Topics in Computing*, *8*(1), 233–244.

Salzman, M. C., Dede, C., Loftin, R. B., & Chen, J. (1999). A model for understanding how virtual reality aids complex conceptual learning. *Presence: Teleoperators and Virtual Environments*, *8*(3), 293–316.

Sengupta, P., & Wilensky, U. (2009). Learning electricity with NIELS: Thinking with electrons and thinking in Levels. *International Journal of Computers for Mathematical Learning*, *14*(1), 21–50.

Shapiro, L. (Ed.). (2014). *The Routledge Handbook of Embodied Cognition*. Routledge.

Stefanski, K. M., Gardner, G. E., & Seipelt-Thiemann, R. L. (2016). Development of a Lac Operon Concept Inventory (LOCI). *CBE Life Sciences Education*, *15*(2). https://doi.org/10.1187/cbe.15-07-0162

The Design-Based Research Collective. (2003). Design-Based Research: An emerging paradigm for educational inquiry: *Educational Researcher*, *32*(1), 5–8.

Thompson, K., & Reimann, P. (2010). Patterns of use of an agent-based model and a system dynamics model: The application of patterns of use and the impacts on learning outcomes. *Computers & Education*, *54*(2), 392–403.

Tretter, T. R., Jones, M. G., & Minogue, J. (2006). Accuracy of scale conceptions in science: Mental maneuverings across many orders of spatial magnitude. *Journal of Research in Science Teaching*, *43*(10), 1061–1085.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies*, *57*(4), 247–262.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—An embodied modeling approach. *Cognition and Instruction*, *24*(2), 171–209.

Wilkerson-Jerde, M. H., Gravel, B. E., & Macrander, C. A. (2015). Exploring shifts in middle school learners' modeling activity while generating drawings, animations, and computational simulations of molecular diffusion. *Journal of Science Education and Technology*, *24*(2), 396–415.

Yoon, S. A., Goh, S.-E., & Park, M. (2018). Teaching and learning about complex systems in K–12 science education: A review of empirical studies 1995–2015. *Review of Educational Research*, *88*(2), 285–325.

Zhang, L., Bowman, D. A., & Jones, C. N. (2019). Exploring effects of interactivity on learning with interactive storytelling in immersive virtual reality. *Proceedings of the 11th International Conference on Virtual Worlds and Games for Serious Applications (VS-Games)*, 1–8. https://doi.org/10.1109/VS-Games.2019.8864531

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Designing Simulation Module to Diagnose Misconceptions in Learning Natural Selection

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Abstract: This online experiment, involving 28 high school students, investigates frequencies and types of misconceptions while learning natural selection via two types of simulation modules. The experimental group uses an agent-based model which characterizes *P*attern, *A*gents, *I*nteractions, *R*elations, and *C*ausality (PAIR-C) features while the control group employs a commonly used PhET simulation. Although the pre-posttest does not capture significant differences between the two conditions, a set of non-leading prompt questions embedded in both simulation modules successfully captured the differences. Students from the experimental condition revealed fewer frequencies and categories of misconceptions and scored significantly higher in explaining one type of common misconceptions as well as responding to objective prompts than the control condition. Our finding indicates that the PAIR-C simulation module might have a better effect in reducing misconceptions. This study manifests strong potential in using a well-structured online simulation module to diagnose and address students' misconceptions in learning natural selection.

Introduction

In our increasingly interconnected world, issues that emerge from local circumstances can give rise to complex global challenges (Wilensky & Jacobson, 2014). To prepare future generations to become contributing members of society as we move into the post-pandemic era, educators are at the forefront to create order out of the complexities. Helping students understand how a complex phenomenon is formed and why it is happening is critically important for formulating scientific predictions and reasonable decisions.

Many natural and social phenomena can be conceptualized as emergent complex systems. A complex system is a system composed of many elements that interact with each other and their environment. Researchers use the term "emergent process" to describe how macro-level observable patterns emerge from micro-level interactions between numerous independent entities and the resultant patterns are called "emergent phenomena" (Wilensky & Jacobson, 2014). Numerous researchers indicated challenges in introducing the concept of emergent complexity in traditional science curriculum (Yoon et al., 2018; Basu et al., 2015; Hmelo-Silver et al., 2015), and reported that high school students often have difficulty in learning the interactive components of complex systems, holding persistent misconceptions in interpreting emergent processes from a sequential mindset in science classrooms (Chi, 2013; Dickes et al., 2016).

Therefore, the advancement of teaching emergent complexity requires more innovative instructional methods rather than the current traditional approaches. Our objective in this study was two-fold. The first objective is to draw upon the PAIR-C framework (Chi, under review) and agent-based modeling (ABM) literature to develop a simulation module that will constructively engage youth in observing and explaining complex systems. The second objective is to examine the effectiveness of using this simulation module to diagnose and address students' misconceptions in learning the emergent process of natural selection. To this end, the simulation module designed in this study will be used to provide an alternative instructional approach and help transform complex system teaching into flexible and efficient online modules.

Theoretical perspectives

The PAIR-C framework

Despite earlier research that proposed frameworks to characterize complex systems (Jacobson et al., 2011; Hmelo-Silver & Pfeffer, 2004), we employed the PAIR-C framework to create our simulation module because of three unique reasons. First, PAIR-C provides an ontological framework representing two kinds of processes: sequential processes feature linear individualistic causality; emergent processes feature nonlinear collective causality. Second, PAIR-C acknowledges that Patterns, Agents, and Interactions are three dimensions shared by both processes. Third, the Relations and Causality dimensions discriminate between the two kinds of processes from seven aspects. These aspects later become guiding principles for the simulation module design (see Table 1).

Within the PAIR-C framework, *P*attern describes the overall changes by a process that is often visible and meaningful, *A*gents (internal) are elements that participate in the process which produces the pattern (external agents interact with internal agents but do not participate in the pattern), the *I*nteractions of the agents refer to how the agents of the process interact, the *R*elations among the interactions compare agents' interactions, and the *C*ausal relations between the agents-pattern refer to how the interactions between agents produce patterns in emergent processes. The causal relations are also referred to as causal mechanisms with two implications.

Table 1: Seven aspects from the PAIR-C framework to discriminate between two kinds of processes

	Aspects	**Sequential Processes**	**Emergent Processes**
***R*elations among the interactions**	1. The set of interactions available to all agents 2. With whom agents can interact and when for individual interactions 3. Occur in serial order? 4. Conditional dependency: Occurrence of interactions dependent on prior outcomes?	1. Distinct set 2. Restricted other 3. Serial ordering 4. Dependent	1. Same set 2. (Not restricted) Random 3. Simultaneous 4. Independent
***C*ausal relations between the Agents-pattern**	**Causal Mechanism** 5. How the pattern transforms: Qualitative description 6. Agent-pattern causal mechanism for the perceptual pattern: Quantitative computation	Cumulative causal mechanism 5. Additive pattern 6. Cumulative summing of subsequent interactions between units of time	Collective causal mechanism 5. Converging pattern 6. Collective summing of all the agents' interactions within each unit of time
		Two implications	
	7. a. Identifiable causal agents responsible for the pattern b. Alignment between the agents and the pattern	7. a. Single-agent or a group - Centralized control - Special status - Intentional b. Align: congruous	7. a. All agents or a collection - Decentralized control - Equivalent status - Unintentional b. Not align: Incongruous

Common misconceptions in learning natural selection

Researchers (Chi et al., 2012; Gregory, 2009) have recognized that students demonstrated common misconceptions such as teleological perspectives and centralized deterministic mindsets in their reasoning and explanations about natural selection. To address this problem, we aimed to design an agent-based simulation module to help students better observe the mechanisms that drive the emergence of population-level phenomena from smaller scales of agent interactions, understand the random and nonlinear characteristics of the systems, and adopt an unintentional and decentralized perspective in understanding the emergent process of natural selection.

Agent-based models and revisions

In agent-based modeling (ABM), the term "agent" indicates individual computational actors that obey simple rules. It is the *I*nteractions between these *A*gents that give rise to emergent *P*atterns in complex systems. Because the nature of ABM aligns well with the PAIR-C framework, we used the NetLogo agent-based modeling environment (Wilensky, 1999) to construct our simulation models. A recent meta-analysis on simulations for STEM learning found that when the simulation was very structured (i.e. students use the simulation with a prescribed path), it resulted in more cognitive gains than when the simulation allowed for more flexibility in the student interaction with the simulation (D'Angelo et al., 2014). Therefore, we decided to use ABM as a representational tool and design a structured learning trajectory for students to navigate the simulation module.

In searching for ABM simulations, we selected the NetLogo wolf-sheep predation model (Wilensky, 1997) and identified six issues within this model based on the PAIR-C framework. These were: a) The Patterns of current simulations focus on moving entities rather than representing dynamic changes across multiple generations; b) The way to introduce external Agents (e.g. wolves - predators) may induce misconceptions that external agents also participate in the pattern; c) Agents' Interactions (e.g. mating interaction; chasing interaction) are not visible in the simulation. Only the agents' actions (e.g. sheep randomly move) are shown; d) Relations among the Interactions are not visible from watching the random movement of agents; e) The Causal relation characteristics between the agents-pattern (how the pattern converges) are not displayed; f) The collective summing Causal mechanisms (how the pattern is produced) are not explained. We incorporated these identified issues and modified the wolf-sheep predation model in the PAIR-C simulation module. The resulting PAIR-C simulation module will be introduced in the Findings section.

Method

Participants and research design

This online experiment was conducted among 28 participants. These participants were high school students from two science extracurricular programs. Participants were assigned to one of two conditions. Students in the experimental condition (n = 14) were given three modules: 1) an overarching PAIR-C Process Module containing information about the concept of emergent causality by comparing and contrasting every day "emergent" and "sequential" processes; 2) a PAIR-C Natural Selection Lecture; 3) a PAIR-C Simulation Module. Students in the control condition (n = 14) were given three modules as well: 1) a Nature of Science Module, a traditional module introducing the philosophy and methods of scientific exploration; 2) a "Business as Usual (BAU)" Natural Selection Lecture; 3) a BAU Bunny Simulation Module. The BAU bunny simulation is created based on an interactive PhET simulation on Natural Selection. The study involves three tests: pre-test, post-test 1 (after the Natural Selection Module), and post-test 2 (after the Simulation Module).

Data sources

Several different data sources allow researchers to investigate the effectiveness of the PAIR-C simulation module over the BAU simulation module in terms of diagnosing and reducing misconceptions when learning the emergent process of natural selection. A repeated test measure (from pretest to posttest 2, from posttest 1 to posttest 2) was used to examine knowledge gains. Prompt questions embedded in the simulation module also revealed students' formative performance and misconceptions. A feedback survey inserted at the end of the module provided evidence on engagement, module clarity, and learning experience.

Each simulation module consisted of seven parts and three scenarios. Both simulation modules used two types of prompts. The first type of prompts consists of questions that expect students to find clues from observing the simulations. These questions include true or false (T/F) questions, yes or no (Y/N) questions, open-ended (OE) questions, and two-tiered questions (the first-tier is a Y/N question while the second-tier is an OE question asking for explanation). All of these questions were coded and scored based on PAIR-C features shown in Table 1. Overall, students in both groups answered a total of 9 open-ended questions and 21 objective questions which were matched as much as possible to be the same for both conditions. In addition to assessing how students understood the emergent process of natural selection, the second type of prompts was designed not to measure understanding but to better engage students while working through the simulation module.

Procedure and data analyses

The PAIR-C simulation module was operated using Google Form, through which the researcher could conveniently collect students' responses. To examine students' misconceptions about natural selection, we coded student responses to prompt questions within the simulation module. We deliberately designed non-leading prompt questions for the PAIR-C simulation module and the BAU Bunny simulation module to ensure the students' responses to the 9 open-ended prompt questions and the 21 objective questions were comparable across the two conditions. We used a two-step process to score students' responses to the 9 OE questions and later conducted statistical analyses. First, each open-ended prompt was scored for correctness (a score of 2 was given to accurate and complete answers; 1 for accurate but not complete responses; 0 for inaccurate responses). Second, for responses that scored 1 or 0, the responses were coded using the PAIR-C Framework for misconceptions in student responses. In this second step, we also marked undecided responses and other types of errors that led to that score (usually incomplete responses). The responses with scores of 2 were also screened to make sure they were not showing misconceptions. The coding rubric for each OE prompt question was established and checked by two experienced coders (See Table 2 for a sample rubric established by two coders).

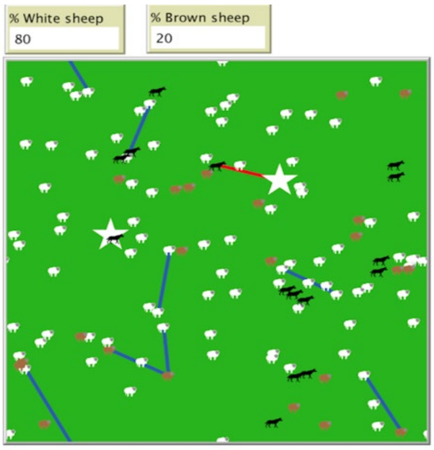
Table 2: The coding rubric and sample responses for prompt Q7b

Score	PAIR-C Simulation Prompt Q7b	Bunny Simulation Prompt Q7b
	Rubric: This question was designed to assess the understanding of the **collective summing** feature. • 2 (correct and complete): collective summing within each unit of time (primary feature) + mentioning one of the secondary features (e.g. misalignment; unrestricted relations) • 1 (correct but not complete): Only mentioning secondary features or implications • 0 (incorrect): showing misconceptions	
2	The number of white sheep is not always increasing, so this is not just about white sheep increasing via mating. Instead, this is a result of white sheep increasing or decreasing via mating, (**collective summing**) and brown sheep increasing or decreasing via mating. So this does not always result in the number of white sheep increasing (not just mating between white sheep; both brown and white sheep can mate **randomly**). OR Considering both the white sheep and the brown sheep, and the mating interactions of all sheep, the white sheep don't have to increase in every generation (**collective summing**), but the percentage of white sheep has an increasing pattern (not **align**).	The number of long-toothed bunnies is not always increasing, so this is not just about long-tooths increasing via mating. Instead, this is a result of long-tooths increasing or decreasing via mating, and short-tooths increasing or decreasing via mating. So this does not always result in the number of long-tooths increasing (not just mating between long-tooths; both long and short-toothed bunnies can mate). OR Considering both the long-tooths and the short-tooths, and the mating interactions of all bunnies, long-toothed bunnies don't have to increase in every generation, but the percentage of long-toothed bunnies has an increasing pattern.
1	only explains misalignment but not collective summing. The percentage of white sheep over brown sheep is always increasing but the number of individuals may not always increase. **(Only mentioning not align implication)**	doesn't say long-toothed bunnies always increase or not; just mentioning long-tooth has an advantage due to environmental factor
0	White sheep are always added to the population between generations to create a pattern of white sheep becoming more common. As white sheep increase, brown sheep will decrease. **(Misconception: align, cumulative summing)**	When time goes on, the long teethed bunny population increases. Therefore, in each generation, long-toothed bunnies are added to the population.

Findings and discussion

Designing PAIR-C simulation

The original wolf-sheep predation model described a set of rules that govern the behaviors (e.g. to move, to reproduce, to eat-sheep, to grow-grass, etc.) of individual computational agents (e.g. sheep, wolves, and grass). As the model runs, all agents concurrently act out their rules without explicitly showing the interactions. To let the audience see what is exactly happening, we made the interactions between agents visible by adding rules to represent interacting agents (e.g. sheep-sheep reproduction, wolves-sheep chasing, See Figure 1 for example).




```
;;; Sheep rules ;;;
to reproduce
  ask sheep [
    let mate other sheep-here
     if count mate >= 1   [
           create-link-with (one-of mate)
      [set link-age 1
      set thickness 0.3
      set color blue]

;;; Wolf rules ;;;
to eat-sheep
let prey one-of sheep-here
  ;; chase a random sheep ;;
  if prey != nobody  [
      create-link-with (prey)
      [set link-age 1
        set thickness 0.3
        set color red]
      if [color] of prey = white
  ;; successfully caught a white sheep ;;
      [ if random-float 100 < 80
        [ask prey [ set size 3
                    set shape "star"
                    set color white]
;;the chased white sheep become bigger for students to see clearly;;
;; the white sheep disappeard to a white star to indicate deadness ;;
```

(a) (b)

Figure 1. The revised wolf-sheep predation scenario (a) with codes (b).

Upon finishing the revision of models, we had addressed the problems of visualizing interactions (problem c) and introducing external agents separately in a later scenario (problem b). To solve the remaining problems, we proceeded with creating the online simulation module. The PAIR-C simulation module contains four basic elements to fix the remaining problems: simulation videos, ABM screenshots, animated pictures, and nonleading prompts. There are 6 simulation videos in the module. Some videos were edited with subtitles that convey clarifying information about the generation periods, the number of sheep, or the percentage of sheep. We also captured static screenshots to show relations among sheep interactions (problem d) as well as generate dynamic patterns across different time periods (problem a) to demonstrate convergence and collective summing mechanism (problem e and f). Meanwhile, animated pictures were used at two different locations to direct students' attention to specific simulation features so that they could intuitively draw implications (i.e. decentralized, equivalent status, unintentional property) to interpret the causal relations between the agents and pattern.

Contrasting PAIR-C simulation with non-PAIR-C simulation

It was found that the PAIR-C simulation is different from the non-PAIR-C (BAU bunny) simulation in three major aspects, considering how students interact with the simulation (interactivity); what is being represented (visibility), and what is being taught in the simulation (learnability).

Interactivity

The PAIR-C simulation was used as a multimedia presentation tool which includes simulation videos, ABS screenshots, and animated pictures. Students interact with it mainly by observation while they could also adjust the speed, replay the simulation videos as well as responding to the embedded prompts at their own pace. The prompts require students to generate new inferences beyond observing or manipulating the simulation videos. Noticeably, the non-PAIR-C simulation is often an embodied simulation tool that allows students to manipulate conditional variables within the simulation. The non-PAIR-C simulation often features an active mode of cognitive engagement when students are only manipulating the simulation (Chi et al., 2018) without generating new inferences from the presented simulation. Besides, in the context of learning natural selection, allowing the unrealistic agency to manipulate simulation tends to reinforce misconceptions about intentionality and special status (see Table 1). In this study, the non-PAIR-C bunny simulation was presented through videos in the same structure as the PAIR-C condition.

Visibility

Students often have difficulties seeing the mechanisms that produce the dynamic changing pattern in simulations (Chi, 2005). The PAIR-C simulation solved this problem by using "links" to visualize interactions among agents and showing collective interactions across multiple generations in multiple ABM screenshots. In contrast, the non-PAIR-C simulation only shows agents' actions or movements at each generation. The bunny simulation directs attention to moving entities rather than how the pattern is produced. For example, in the bunny simulation, students are not able to tell the random nature of the interactions among bunnies through the Pedigree chart (see Figure 2).

(a) (b)

Figure 2. Comparing simulation interface (a) PAIR-C simulation and (b) Bunny simulation.

Learnability
In the PAIR-C simulation module, collective interactions of all agents are counted, nonlinear agents-pattern causal relations that incur misconceptions are explicitly emphasized, and aspects of the Relations among the Interactions are also examined (see Table 1). Conversely, the non-PAIR-C simulation showed individualistic actions of a subgroup, represented linear causal relations between conditions and their consequences on the pattern. Features of the Relations are always not mentioned.

The PAIR-C simulation module

Pre-posttest
A repeated test measure was used in this study, including the pretest, posttest1 (given after the Natural Selection Module), and posttest2 (given after the Simulation Module). This test consists of 20 multiple-choice questions. Among them, 12 questions were hard-level questions, which assessed understandings of different PAIR-C features in the context of natural selection. There were also 5 medium and 3 easy-level factual questions. The majority of these questions were adapted from multiple conceptual inventories (e.g. CINS, CANS, AAAS, and past AP Biology Exams from College Board) with two hard-level questions created by a senior researcher. To determine whether students' scores improve for hard-level questions over time, we conducted a paired samples T-test. The analysis showed that there was no statistically significant improvement from pretest to posttest2 for the control condition, while there was a statistically significant improvement from pretest to posttest2 for the experimental condition, ($t(13) = -2.86, p < 0.05$). Using pre-test hard questions as a covariate, we conducted ANCOVA and compared students' scores on post-test2 hard questions to see if we could find a significant difference between the two groups. There was no statistical significance found between two groups, $F(1, 25) = .388$, $p = .539$, partial $\eta 2 = .015$.

Within module assessment
To examine differences in scores for PAIR-C features between conditions, we combined open-ended questions that shared the same features and ran independent t-tests for each feature. Most of the tests were not significant, except for one type: collective summing (see Figure 3). This shows that the PAIR-C simulation group had significantly higher scores than the BAU bunny simulation group when explaining the collective summing mechanism ($t(26) = 2.82$, $p < 0.01$).

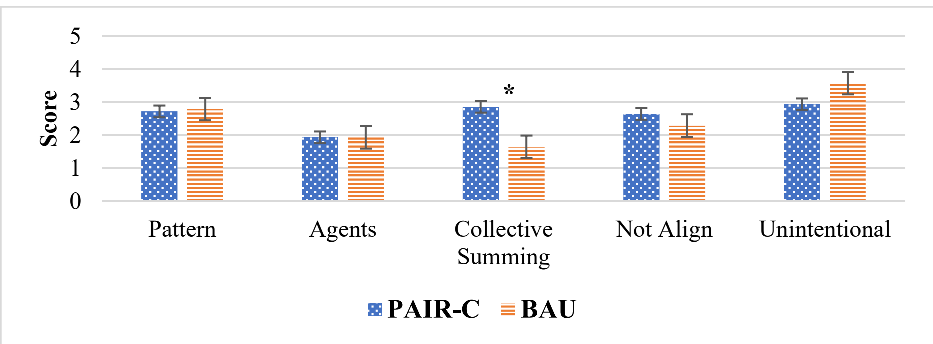


Figure 3. Average scores by condition for open-ended prompt questions.

The number and type of misconceptions that were found in student responses to the open-ended prompt questions were also counted. Overall, there were 21 misconceptions found for the BAU condition while there were 15 misconceptions found for the intervention PAIR-C condition, including the undecided misconceptions. We found that there were 7 instances of restricted relations misconceptions for BAU while there were none for PAIR-C. Because numerous responses demonstrated at least two categories of misconceptions based on the PAIR-C framework, we decided to present the frequency of misconceptions instead of the number of student responses showing misconceptions (See Figure 4).

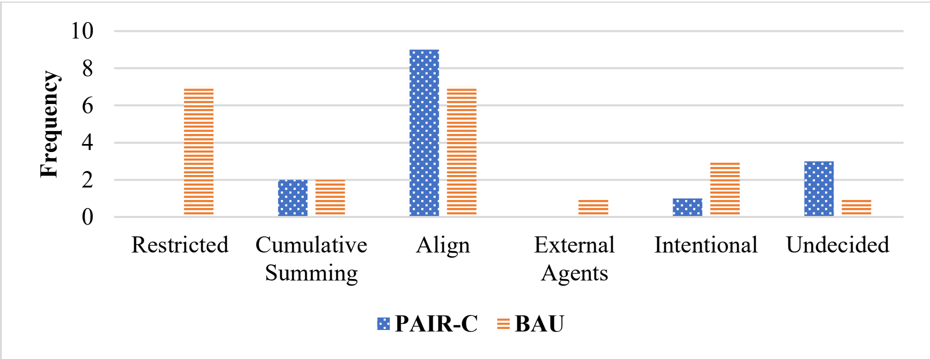


Figure 4. Frequency of misconception types by condition for open-ended prompt questions.

In addition to the open-ended prompt questions, there were 21 objective prompt questions in each of the simulation modules. The 21-question is composed of 2 items on environmental conditions;12 items on Relations (unrestricted, same set, simultaneous, independent); 1 on the external agent; 2 on no causal agent; 1 on non-alignment; 2 on converging pattern; 1 on collective summing. The average scores of these 21 objective prompts were 19.64 for the PAIR-C condition, and 16.50 for the BAU condition (See Figure 5 for the score distribution). A two-sample t-test was conducted which showed a statistically significant difference between the PAIR-C condition and the BAU condition ($t(18) = 3.83$, $p < 0.01$). This result indicates that our PAIR-C simulation module might have a better effect in reducing common misconceptions.

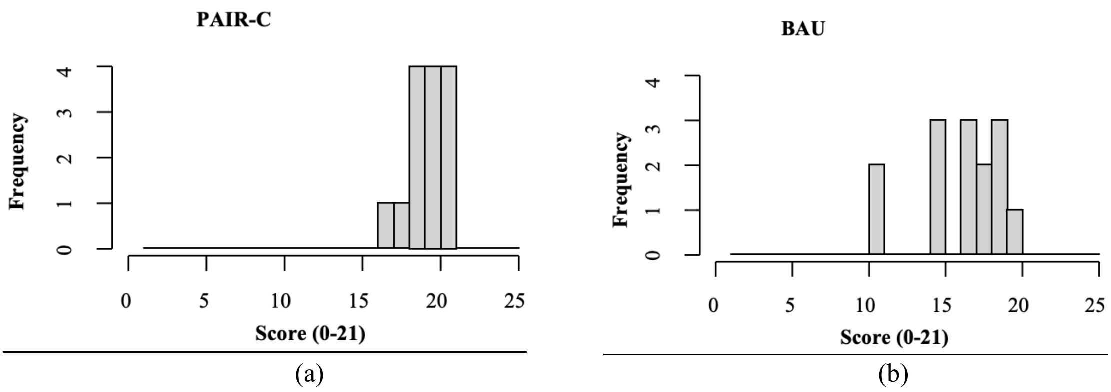


Figure 5. Frequency of score distribution for (a) PAIR-C and (b) BAU conditions on 21 objective prompts.

Feedback survey

The post-simulation survey questions asked students to report engagement, module clarity using a 1-5 Likert Scale. Students in the experimental condition reported an average of 4.14 for engagement and 4.21 for clarity. For the control condition, the average scores for engagement and clarity were 3.86 and 3.36 respectively. We also asked students to describe their experience in using the simulation videos. Nine students from the PAIR-C condition reported that they only played the simulation once. However, only two students from the BAU condition expressed that they played the simulation videos once. Other students from the BAU group stated that they replayed the majority of the videos multiple times. This further manifests the efficiency and clarity of using PAIR-C simulation to represent agent relations among interactions as well as explain the causal mechanism for the emerging pattern. Several students from both conditions suggested that the simulation module could be improved by including more simulation models as examples, and would be more engaging if a narration was provided.

Conclusion

We believe that our PAIR-C simulation module has scholarly implications for simulation-based online teaching practice. Our results highlight the importance of using a simulation module grounded in the agent-based modeling approach and the PAIR-C theoretical framework to scaffold student learning in natural selection as emergent processes. From sorely looking at the simulation prompt data, we found that the PAIR-C simulation with non-leading prompts was able to reveal some important misconception features that other traditional simulations could not capture. However, this study could not validate the effectiveness of the PAIR-C simulation without comparing it with standard agent-based simulation. To address this limitation, future works can focus on conducting a stand-alone study to compare the improved agent-based simulation with PAIR-C features and standard agent-based simulation without PAIR-C features.

References

Chi, M. T. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The journal of the learning sciences*, *14*(2), 161-199. https://doi.org/10.1207/s15327809jls1402_1

Chi, M. T. (2013). Two kinds and four sub-types of misconceived knowledge, ways to change it, and the learning outcomes. In *International handbook of research on conceptual change* (pp. 49-70).

Chi, M. T., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., ... & Yaghmourian, D. L. (2018). Translating the ICAP theory of cognitive engagement into practice. *Cognitive science, 42*(6), 1777-1832. https://doi.org/10.1111/cogs.12626

Chi, M. T., Kristensen, A. K., & Roscoe, R. (2012). Misunderstanding emergent causal mechanism in natural selection. *Evolution challenges: Integrating research and practice in teaching and learning about evolution*, 145-173.

Chi, M. T. (under review). Individualistic versus collective causality: An ontology framework for analyzing processes, explaining misconceptions, and guiding instruction. Educational Psychologist.

Basu, S., Sengupta, P. & Biswas, G. A Scaffolding Framework to Support Learning of Emergent Phenomena Using Multi-Agent-Based Simulation Environments. *Res Sci Educ 45,* 293–324 (2015). https://doi.org/10.1007/s11165-014-9424-z

D'Angelo, C., Rutstein, D., Harris, C., Bernard, R., Borokhovski, E., & Haertel, G. (2014). Simulations for STEM learning: Systematic review and meta-analysis. *Menlo Park: SRI International.*

Dickes, A. C., Sengupta, P., Farris, A. V., & Basu, S. (2016). Development of Mechanistic Reasoning and Multilevel Explanations of Ecology in Third Grade Using Agent-Based Models. *Science Education, 100*(4), 734–776. https://doi.org/10.1002/sce.21217

Gregory, T. R. (2009). Understanding natural selection: essential concepts and common misconceptions. *Evolution: Education and outreach, 2(*2), 156-175.

Hmelo-Silver, C. E., Liu, L., Gray, S., & Jordan, R. (2015). Using representational tools to learn about complex systems: A tale of two classrooms. *Journal of Research in Science Teaching*, *52*(1), 6-35. https://doi.org/10.1002/tea.21187

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive science*, *28*(1), 127-138. https://doi.org/10.1207/s15516709cog2801_7

Jacobson, M. J., Kapur, M., So, H. J., & Lee, J. (2011). The ontologies of complexity and learning about complex systems. *Instructional Science, 39*(5), 763-783. https://doi.org/10.1007/s11251-010-9147-0

Wilensky, U., & Jacobson, M. J. (2014). Complex systems and the learning sciences. In *The Cambridge handbook of the learning sciences*, Second Edition (pp. 319-338). Cambridge University Press. https://doi.org/10.1017/CBO9781139519526.020

Wilensky, U. (1997). NetLogo Wolf Sheep Predation model. http://ccl.northwestern.edu-/netlogo/models/WolfSheepPredation. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Yoon, S. A., Goh, S. E., & Park, M. (2018). Teaching and learning about complex systems in K–12 science education: A review of empirical studies 1995–2015. *Review of Educational Research, 88*(2), 285-325. https://doi.org/10.3102/0034654317746090

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Interlocking Models as Sites of Modeling Practice and Conceptual Innovation

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Abstract: A central goal of both professional and classroom-based scientific communities is building and testing explanatory models of the natural world. The process of modeling a complex phenomenon often requires working across representational systems of differing scales, modalities, and purposes. When put into contact, entities across multiple representational systems can become related or "interlock." This paper describes how students drew from multiple representational systems to construct "interlocking models" and how reasoning with interlocking models supported meaningful practice and conceptual innovation. We present the design and findings from the implementation of a fifth-grade investigation into the conservation of matter. We describe the process of how contradictions between representational systems surfaced and led to interlocking models. Our findings suggest that students can recognize and take up interlocking models that provide a purpose for students to critique and refine their understanding.

Introduction

While model-based reasoning and explanation is a driver of science practice and increasingly of science education, how to design and support learning environments where young students take up modeling as a meaningful practice—one that is purposeful, agentive, and conceptually productive—is an enduring question (Berland et al., 2016; Manz, 2012). In this paper, we explore what can be learned about classroom modeling from a key practice of laboratory science—interlocking models. We share findings related to the challenges and opportunities of designing for interlocking models in a fifth-grade investigation of the conservation of matter. We conclude with insights into how students productively recognized and took up the tensions and pushbacks surfaced by contradictions and interlocking models.

Opportunities and challenges in classroom modeling

Consistent with philosophers and sociologists of science, we conceptualize science as a modeling enterprise (Giere, 1990; Windschitl et al., 2008). Science involves constructing, evaluating, aligning, and refining models in light of their joint bearing on a question or purpose. Models take on many representational forms, including equations, theories, diagrams, and simulations. In classrooms, orienting activity around developing, testing, and revising models can support students to develop science understandings as they engage meaningfully in scientific practice (Gouvea & Passmore, 2017). Yet, how to design and implement learning environments where students make progress on important science ideas as they develop and revise models is not yet fully understood. Teachers can take up models as places to hold ideas or orient so fully to developing canonical models that students have little agency in constructing or critiquing models (Lehrer & Schauble, 2006). Students, who are new to the modeling game and conduct it in communities of practice that differ substantially from those of scientists, may not necessarily take up models as tools for reasoning and communicating (Schwarz et al., 2009). Researchers are still debating how exactly to prioritize students' authorship of science practice as compared to the development of canonical understandings that were developed over periods of time and with tools impossible to instantiate in the classroom (Osborne et al., 2018). To orient our work on these challenges, we draw from situative and socio-cultural accounts of learning that treat practices and ideas as resources participants draw on, re-organize, and over time stabilize as they engage in meaningful activity in communities (Hall & Greeno, 2008). From this perspective, the purposes that students take up for modeling (to demonstrate understanding, to compare ideas, to recognize and orient to contradictions across ideas and evidence) are both of central importance in supporting meaningful science practice and are themselves emergent from activity. Key questions, then, are how (1) those purposes can emerge in activity and (2) how modeling can be productive, from students' point for view, for their conceptual work. Next, we consider how the use of interlocking models can help the field make progress on these questions.

Interlocking models in science laboratories and classrooms

Rather than working with models in isolation, scientists align and integrate multiple models as they work toward building a more complete explanation of a phenomenon (Nersessian, 2010; Rouse, 2015). Nersessian describes how through this process models can "interlock" or come to be taken as bearing on one another. Once interlocked, one model becomes a potential site for new questions, challenges, or refinement of another. For example, neural engineering laboratories construct models consisting of the recreation of phenomenon *in vivo* (e.g., neural networks) as *in vitro* physical models (e.g., dish of neurons) and computational re-descriptions of models (e.g., simulation patterns for the dish). Accounts of interlocking models in science practice offer several potentially useful implications for supporting students to engage in agentive, purposeful, and conceptually productive modeling. First, individual moments of modeling are open-ended and tentative—with no promise that they constitute "progress." Second, interlocking models form a fabric that is not seamless, as information from different representational systems can be inconsistent or contradictory. Contradictions between representational systems can point toward conceptual gaps, discrepancies, and tensions. That is, a key source of conceptual innovation in science is the moments where models "speak" to each other and the differences in what they "say;" these differences can provoke problem-solving processes that drive the refinement of questions, methods, and tentative explanations.

In K-16 science education, designs for model-based learning such as the *bifocal modeling framework* (Blikstein, Fuhrmann, & Salehi, 2016) and *coupled methodological systems* (Gouvea & Wagh, 2018) have used multiple representational systems. These designs have primarily focused on how simulations and physical experimentation can support each other, showing that one representational system can become a source of questions for another and that differences in results can support students' further inquiry. In this paper, we sought to build from this work by pursuing a closer analysis of (1) when and how students come to see representational systems as bearing on each other and (2) how interlocking models can support moments of conceptual innovation, thus allowing us to better understand how educators might design for and support interlocking models in classrooms. To situate our analysis, we first describe the design of a fifth-grade science investigation into the law of conservation of matter in which students worked with multiple representational systems. We then describe how contradictions among emerged as a key mechanism that allowed students to begin to make connections across representational systems, treating them as models that could interlock, or bear on each other. We show how, through questioning and making sense of the contradictions, students developed interlocking models that served as tools for further reasoning.

Research context and design

The work reported here takes place within a larger design-based research study involving a multi-year co-design partnership (Penuel, Roschelle, and Schechtman, 2007) with a public school district in the northeast US. The goal of the project is to redesign the elementary school science investigation to better capitalize on forms of uncertainty that are usually removed from children's experience with empirical activity. In this paper, we report on the second implementation of an investigation co-designed with two teachers. The investigation addresses fifth-grade NGSS standards related to matter and its interactions, specifically that students "measure and graph quantities to provide evidence that regardless of the type of change that occurs when heating, cooling, or mixing substances, the total weight of matter is conserved" and "use a particle model to explain common phenomena involving gases and phase changes" (NGSS Lead States, 2013). Like other standards that we have unpacked with teacher co-design teams, these pose challenges for engaging children in meaningful and agentive modeling practice in which they make progress toward the canonical ideas held in the standards. First, why would students ask about and focus on the weight of substances as a measure of amount, rather than more perceptually available attributes, such as volume? Second, how could we support students to experience weight as not changing, when small fluctuations could be interpreted as confirming prior ideas? Third, how could we set this work in a context where students were making sense of a phenomenon they could experience and wonder about, when water—the only substance to exist in all three phases within earth's temperature ranges – behaves differently (expands as it freezes) and must be explained by a molecular, rather than particle, model? Fourth, how could students come to see the molecular models that they had been developing as useful for understanding changes (or lack thereof) in the size and weight across phase changes? Like many classroom investigations, the questions, measures, evidence, and conceptual entities that children are expected to use are only "obvious" in light of entire set of models that scientists have stabilized in relation to each other.

This context therefore provided a fruitful opportunity to explore using interlocking models. We developed a sequence of activities (Figure 1) in which students engaged with different representational systems: (1) watching a **video** of a glass bottle filled with water and placed outside in cold weather eventually exploding, (2) building **pencil and paper models** to explain why the bottle broke using molecules (drawing on previous work in which they had used a simulation and models to explore why dye diffuses at different rates in different water temperatures), (3) testing questions related to whether water was "getting bigger" using an **empirical investigation**, (4) creating a **data representation** to see what most of the vials did, and (5) returned to their **initial**

models and a **simulation** to develop a class model of water molecules spreading out when frozen—explaining the fact that the same amount, or weight of water, can take up more space when frozen and break a glass bottle. This process set up an introduction to the law of conservation of matter as a sensemaking resource with explanatory power, rather than as either an answer that students could arrive at through developing conceptual models or the "correct explanation" they could be told. Table 1 shows how we considered each of these to be distinct representational systems with specific resources and the potential to interlock.

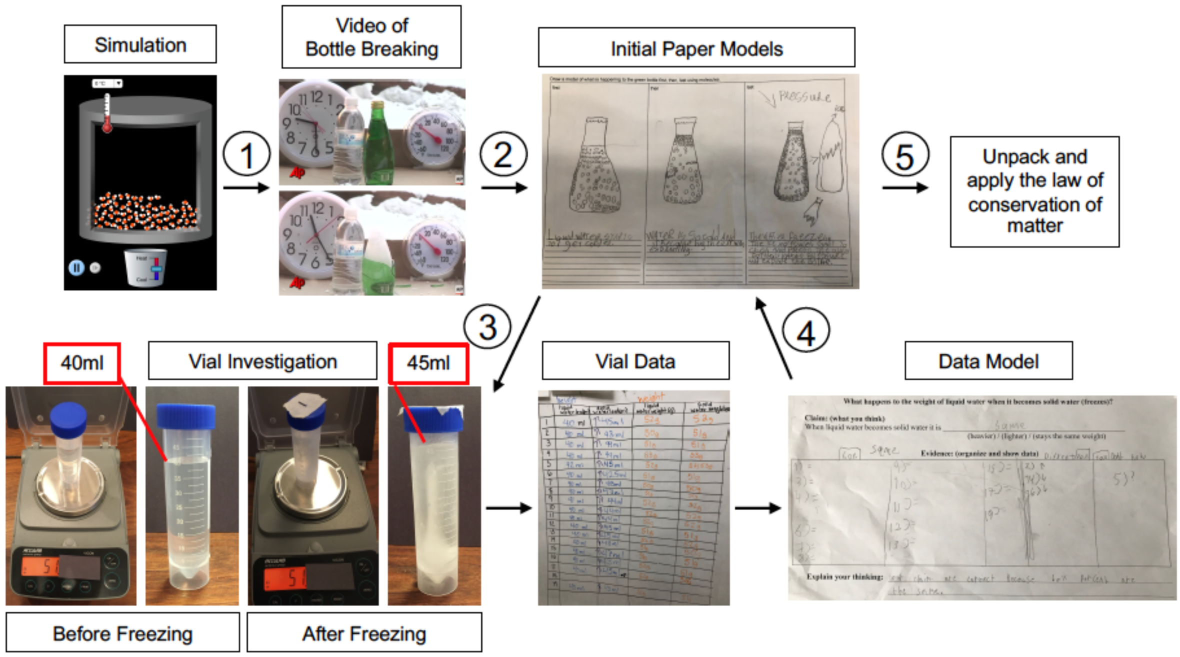


Figure 1. Sequence of Activities

Table 1: Overview of representational systems

Representational System	Conceptual and Representational Features	Opportunities for interlocking models
Simulation	Micro-level molecular representation of phase change in water; highlights how molecules move and arrange with temperature; keeps the number of molecules static; temperature an adjustable parameter.	Introduced in the context of water molecule behaviors under increasing temperatures; exploring the parameters and boundaries of the simulation led to questions about temperature decrease; offered students a canonical model of molecular behavior to apply to the bottle breaking; later, a return to the simulation used refute or support theories of water expansion.
Video of the bottle breaking	Macro-level perceptual representation of phase change; offered access to familiar sensemaking resources (e.g., pressure, air, materiality); static parameters but replayable.	Provided resources to support initial models of the bottle breaking and a context to reason with water getting "bigger" or taking up more space as it freezes.
Pencil and paper models	Student generated micro- and macro-level representation of how and why the bottle breaks using molecules; flexible and open-ended space for students to propose tentative explanations.	Context for students to bring together resources from the multiple representational systems to explain and refine explanations of the bottle breaking at different points in the inquiry.
Empirical model: Vials	Empirical; draws attention to measures of weight and volume (water level) and supports comparison across phase change	Observable and measurable evidence for water level; evidence that weight does not

filled with water and frozen		change, which can connect to number of molecules
Data model: Organized data set	Students organize and compare data to make visible what "most of the vials did."	Supports using data to develop a claim about what most vials did and what water does generally.

Analysis and findings

Across the investigation, we found that students incorporated resources from multiple representational systems to build and revise explanations of water expansion and the conservation of matter. Further, we identified and described moments when systems *interlocked for students,* in that they came to see these representational systems as bearing on each other; for example by using micro-level information from the simulation to explain the macro-level phenomenon of the bottle breaking. In particular, one mechanism that appeared to support students' use of representations as models and their explicit recognition of these systems as bearing on each other was that of *contradictions.* We found that contradictions surfaced when students recognized gaps in conceptual or representational coherence as resources from different representational systems were combined or put side-by-side. When contradictions were made visible and accessible, they became sites of conceptual innovation as new ideas, questions, and even new contradictions emerged. While not all contradictions co-occur with interlocking models, or were contradictions the only evidence of interlocking models, we found that conceptual progress and meaningful practice could often be mapped to key contradictions. In Table 2, we unpack three contradictions that appeared key to modeling and conceptual progress. How each contradiction emerged and pushed back depended on how student perceived the purpose of the interlocking models. We use one contradiction—how solid water can expand if molecules come together as temperature decreases—to illustrate the emergence and work of contradictions and interlocking models.

Table 2: Overview of the role of contradictions across the investigation

Contradiction	How the contradiction emerged	Opportunities for conceptual innovation
1. How can solid water expand outward as it freezes if molecules slow down and come together as temperature decreases?	In the simulation, students saw water molecules slow down and come together as liquid water decreases in temperature. After watching the bottle breaking video, students thought that water expands as it freezes. Students drew on resources from both representational systems as they constructed their initial models.	Students recognized the contradiction between molecules coming together and water expanding, which highlighted a gap between their current understanding of molecules from the simulation and their perceptual understanding of the bottle breaking. Making sense of the gap led to discussions around different dimensions of size and an investigation to measure weight and water level before and after freezing.
2. How can something take up more space (increase in water level or volume) but still have the same weight?	Students conduct the vials investigation and come to the conclusion that as liquid water freezes, water level increases but weight remains the same. This empirical result conflicted with their perceptual experiences that as something "gets bigger" or takes up more space it also weighs more.	The results of the vial investigation—the weight remains the same but the water level increase in most vials—presented a puzzle. Settling the debate over the results required refining a molecular mechanism for water expansion that accounts for size (molecular arrangement) and weight (number of molecules).
3. How can molecules spread out (to generate pressure on the bottle) but stay together (produce a solid)?	In order to explain the bottle breaking, water must be expanding to put pressure on the bottle. This required a molecular	Students located micro-macro level gap between the molecular model of water molecules spreading out but remaining as a

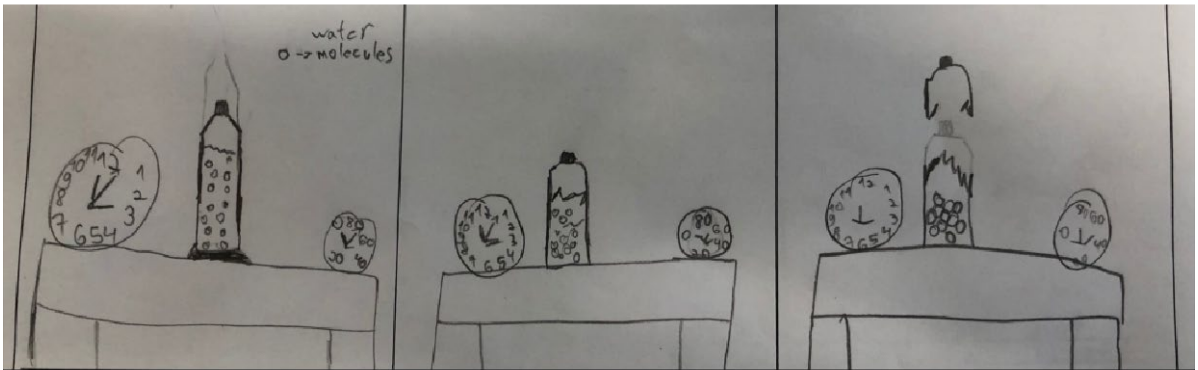
	model of water molecules spreading out as liquid water freezes. This model conflicted with their sensible ideas about solids with molecules tightly packed together.	solid prompted a need to return to the simulation to look closely to what happens to molecules at water's freezing point.

Focal contradiction: How can solid water expand outward as it freezes if molecules slow down and come together as temperature decreases?

One key contradiction that came up over the course of the investigation was between molecular understandings of water and perceptual qualities of water expansion (increases in size, space, or amount). Students who drew on the simulation and earlier class models for how molecules behave as water freezes ran up against a tension in that their molecular understanding—molecules slow down and come together as temperature decreases—aligned with a commonsense understanding of solids (tightly packed, hard, immobile) but could not explain how water expands or creates pressure on the bottle. In the following sections, we illustrate this contradiction as students worked through pencil and paper models before the vial investigation (Figure 1; Points 2 and 3) and as they returned to their initial models to make sense of the results of the vial investigation (Figure 1; Points 4 and 5). We show that this contradiction provided a reoccurring tension at key junctures of the investigation but worked differently based on how and for what purposes models interlocked.

Emergence of the initial contradiction in pencil and paper models

We first consider Roger's (all names pseudonyms) pen and pencil model, developed at the start of the investigation. Students watched the video of the glass bottle breaking, discussed their initial theories, and were asked to draw a model that "showed what happened to the bottle using molecules." Roger's model (Figure 2) indicated a gap between previous models and the bottle breaking that he addressed by including ideas drawn from entities in the video context.



The water is not freezing yet. It is liquid. It is starting to freeze. But the water is warm, and the molecules are spreeding [sic] out. Maybe the energy or the molecules is warm. That is why the molecules are spreeding [sic] out.	The water is more freezed [sic], than the first time. The molecules is getting together, because the water is more colder. And the molecules is slowly and freezing. That happen because the temperature is colder.	The water is totally frozen. And the bottle explode. I think that happened because the lid freezed and there was not space for the cold air to get out. That's why the bottle explode.

Figure 2. Roger's model (handwriting replaced with typeface for legibility).

To develop his model, Roger drew on resources from the video of the bottle breaking, the simulation, and earlier class models. In Frames 1 and 2, we see Roger drawing on ideas from earlier work with the simulation and class models: that molecules come together as water gets colder. His writing is consistent with his drawing, linking water freezing to molecular re-arrangement and a decrease in speed ("getting together" and "slowly"). In Frame 3, Roger continued to show molecules coming together in his drawing, but his written description drew on ideas about cold air and the bottle's lid, from the video.

We see evidence of the simulation and the bottle breaking video interlocking in the Roger's model. In the first two frames, Roger's writing and drawing matched; he drew molecules coming together as the water temperature begins to decrease. In the third frame, he drew molecules packed tightly together as a solid, but then wrote about the bottle breaking because of the lid freezing and "no space" for the air (implicit relation to pressure). The mismatch between his writing and drawing suggest Roger might have understood that molecules coming together cannot fully explain the bottle breaking. Although he was quite sure that this is how molecules behave based on the simulation, in order to complete his model of the bottle breaking he drew on perceptual features of the video—the lid freezing shut, cold air inside the bottle, and lack of space. In short, the contradiction revealed a gap between what he was importing from the simulation and a mechanism for the bottle breaking. Thus, while Roger used molecules as directed and described by the simulation, they were alone not enough to explanation of the bottle breaking.

We see this moment of modeling as a site for conceptual innovation in two ways. For Roger, the search for new resources at the moment of needing an explanation suggested that he might not be satisfied with how his current understandings of molecules can help him construct an explanation. Second, from our point of view as designers and teachers, was that Roger was drawing on molecular arrangements, a resource of the simulation that would be key as we moved into the vial investigation and beyond but was able to sidestep the contradiction we hoped would surface by recruiting an alternative explanation – the air in the bottle needing to get out because the lid exploded. Further, we noted that his molecular arrangement did not correspond with the space that the water took up. Therefore, we chose Roger's model to show the class, wondering if other students would recognize gaps that could lead to further work.

The teacher next projected Roger's model, asked him to explain it, and invited other students to ask clarifying questions and offer critiques. Roger's initially individual model now became a context to collectively reason around the affordances and constraints of one model; with other models (those the students had drawn from themselves) put in contact with this model. While Roger did not yet find his contradiction problematic, other students noticed and probed the contradiction. Casandra asked, "How do the ice gets to the sides [in] the last one?" She noticed the contradiction of molecules coming together and the need of solid water to expand to the sides of the bottle. In addition, her question highlighted the representational need for molecules to represent the edges of water, either as liquid or solid. Her question, and those of other students, implied a need of and mechanism for water expansion not evident in Roger's model. Through her question, Casandra demonstrated how contradictions can elicit questions that surface the need for further explanation. Roger made use of resources from both systems that in turn led to a gap (the arrangement of molecules vs the ice filling the bottle; molecules coming together vs something exploding), community activity around his ideas supported attention to the space that water took up and the fact that the community did not yet have a sufficient model to account for this. This gap subsequently supported a need for the vial investigation (Figure 1; Point 3), in which there was a *reason* to remodel the glass bottle as a simpler system of freezing water measured in height (and weight, which was supported by other model contradictions; Table 1; #2).

<u>Interlocking the contradiction with the vials investigation</u>

After discussing their initial pencil and paper models and turning their attention to the amount or edges of the water, the class tentatively agreed that water "gets bigger" as it freezes and experienced uncertainty about what happened to the weight of the water. We then suggested that they test their ideas, introducing vials that they could fill with water, weigh, and freeze. We further supported them to organize and make claims about the class set of data, developing a consensus claim that "as water freezes, the water level increases but the weight remains the same." At this point, the class had strong empirical evidence that water expands in space but does not increase in weight, but were left with a new puzzle: does it make sense that something could get bigger (water level) but stay the same weight? We revisited three initial models in context with the multiple models we had explore thus far (initial models, the bottle breaking, and vials and consensus claim about water level and weight). We used Roger's model, conjecturing that returning to this model would support conceptual progress, as the representation of molecules coming closer together now contradicted both the bottle breaking video (water expands) and the results of the vial investigation (water level increases). After students considered all three models in small groups, we introduced Roger's model to the whole class with the question: Can this model explain how water expands (gets bigger) when it freezes? In their discussion, students continued to work through the contradiction embedded in Roger's model of the bottle breaking and drew on resources from the vial investigation. During the conversation, one student, Victoria, wondered of Roger's model,

1. Victoria: A lot of people said that they are separating and [expanding], but like we can see in the drawing there they are coming together. So how are they [expanding] and then come together (.) so I am asking=
2. Jackson: =Some people say the water is spread out and (inaudible) but this illustration the water is close together
3. Victoria: That is my question because I don't know if they expanded or came together

While Victoria is not yet directly attending to water level, her question resurfaces the contradiction embedded in Roger's model as a source of tension. As it is taken up by other students, Victoria positioned the contradiction as necessary to resolve before moving forward. The driving question of "Does the model explain how water expands (gets bigger) when it freezes?" was shifted by Victoria, and the students worked to unpack the now further complicated contradiction: How can water molecules come together but water expand? To illustrate, Jackson later responded to Victoria's question, returning to the contradiction and introducing a new mechanism for pressure,

> "the simulation, it was so cold that water molecules and [brings his hands together] and I think it is like this (.) these don't spread out but when the water molecules stay together they make pressure (inaudible) and air molecules don't have the space and the water level up and explode."

We view this moment as a powerful example of interlocking models and the role of contradictions. For Jackson, it is necessary that 1) molecules come together as temperature decreases, as evidenced by the simulation, 2) there must be a mechanism for pressure, as evidenced by the bottle breaking and 3) the water level increases, as evidenced by the vials investigation. All three of these resources are stable enough for Jackson that he introduces them as constraints for an satisfying explanation. In order for these to work together in a plausible explanation, Jackson introduced the idea that pressure on the molecules can explain expansion if you consider air. We consider Jackson's tentative explanation, still in reference to the initial contradiction, evidence that students were moving between the resources of the video, simulation, and the vials. In response, the teacher was able to pivot between representational systems, calling attention to specific aspects or entities to support interlocking models,

1. Teacher: Yes or no (.) does the water level get bigger in this picture (.) so I am going to call on a couple friends to explain their thinking (.) Barry (.) what are you thinking
2. Barry: So that isn't the water level [pointing to the third frame]
3. Teacher: So here yeah the water level what do you see different about the water level in this one
4. Barry: But Roger explained that that was breaking
5. Roger: Something that I need to say is that like the water level of the second one and the third one needed to be bigger than the first one because drew the bottle bigger and the put the water level in the first one higher
6. Teacher: So that's (.) so it seems like that's your thinking now using the information that water level gets bigger that your water level needs to get bigger as well

Through refocusing on a main resource from vials (Line 1), Barry was able to draw on water level and question Roger's model. Barry points out that Roger's "break" was where water level should be located in order to represent water expansion as a mechanism for the bottle breaking. Although Roger's model never intended to show water level increase, he was now held accountable to it in his drawing. Yet, Roger was able to revise his model in the moment, retrofitting water level to his initial drawing as a representational, rather than conceptual, mistake (Line 5). In this episode, the teacher called attention back toward water level, a resource not original to Roger's model, that keyed Barry to press on the contradiction such that Roger could articulate his conceptual understanding and cleverly re-represent the explanation provided by his initial pencil and paper model.

Conclusion and implications

For authentic and epistemically honest modeling to occur in classrooms, designs for practice-based science learning must support students to see models as purposeful contexts for reasoning. This design approach is often discussed in terms of positioning models as tentative or open-ended, in service of scientific practice rather than reaching the canonical answer. Here, we contribute to this literature by explicitly designing in a context where (1) individual representational systems could not fully explain the phenomenon in question and (2) it is the interlocking, or coming together of partial models, that allows students to see models as tentative and incomplete *and* provides a source of conceptual innovation. For example, in our design the representational systems provided resources with different scales and modalities (e.g., the simulation versus the bottle breaking video). Only when these systems interlocked did students find a reason to interrogate the affordances and constraints within and across each representational system in order to develop an explanation of water expansion that made the law of conservation of matter useful.

In our analysis, we sought to understand how models came to interlock for students. We highlighted one mechanism, that of contradictions, that supported students to relate different forms of conceptual and representational information through the development and use of interlocking models. Following Roger's model across the introduction of new representational systems, we showed how contradictions emerged and came to hold interlocking models together. In Roger's initial pencil and paper model, he drew on resources from the simulation and video of the bottle breaking. However, these resources did not come to bear on each other until the contradiction (molecules coming together as water cooled vs moving apart to make the water push on the bottle) surfaced during whole class discussion. With the contradiction now a focus of activity, students questioned the relationships between representations and highlighted gaps in their collective understanding of the phenomenon. We found when these contradictions provided students with pushback, interlocking models emerged *for students* and did work to support conceptual innovation and meaningful practice. In our example, students were able to re-interrogate the contradiction of Roger's model with new assumptions based on the results of the vial investigation. As the contradiction resurfaced for students, it came with new puzzles and problems thus driving a need for iteration and further modeling. This analysis highlights how interlocking models might serve as a productive design tool to support students' meaningful modeling (Berland et al, 2016). It reveals key mechanisms that foreground relationships between representational systems (in this case contradictions). Supporting models to interlock from the students' perspective appears to provide the sort of flexibility and purpose we hope to see in emergent modeling practices as well as in a classroom modeling enterprise.

References

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082-1112.

Blikstein, P., Fuhrmann, T., & Salehi, S. (2016). Using the bifocal modeling framework to resolve "discrepant events" between physical experiments and virtual models in biology. *Journal of Science Education and Technology*, *25*(4), 513-526.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13.

Giere, R. N. (1990). Explaining science: A cognitive approach. Chicago, IL: University of Chicago Press

Gouvea, J., & Passmore, C. (2017). Models of' versus 'Models for. *Science & Education*, *26*(1-2), 49-63.

Gouvea, J. S. & Wagh, A. (2018). Exploring the Unknown: Supporting Students' Navigation of Scientific Uncertainty With Coupled Methodologies. In Kay, J. and Luckin, R. (Eds.) Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 1. London, UK: International Society of the Learning Sciences.

Hall, R., & Greeno, J. G. (2008). Learning and understanding concepts in practice. *21st century education: A reference handbook. Thousand Oaks, CA: Sage*.

Lehrer, R., & Schauble, L. (2006). *Cultivating Model-Based Reasoning in Science Education*. In R. K. Sawyer (Ed.), *The Cambridge handbook of: The learning sciences* (p. 371–387). Cambridge University Press.

Manz, E. (2012). Understanding the codevelopment of modeling practice and ecological knowledge. *Science Education*, *96*(6), 1071-1105.

Nersessian, N. J. (2010). *Creating scientific concepts*. MIT press.

NGSS Lead States. 2013. *Next Generation Science Standards: For States, By State*s. Washington, DC: The National Academies Press.

Osborne, J. F. (2019). Not "hands on" but "minds on": A response to Furtak and Penuel. *Science Education*, *103*(5), 1280-1283.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and practice in technology enhanced learning*, *2*(01), 51-74.

Rouse, J. (2015). *Articulating the world: Conceptual understanding and the scientific image*. University of Chicago Press.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., ... & Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *46*(6), 632-654.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science education*, *92*(5), 941-967.

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Teacher Learning From Implementing an Instructional Design for Literary Argumentation

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Abstract: This paper reports a case study of an 11th grade English teacher's learning through participation in design-based research intended to support students in literary argumentation. Literary argumentation requires that students develop criteria for thematic concepts as common ground for interpretation and discussion of texts. This study examines two components of instruction around the generation of criteria from the first and third years of a design-based research project to understand what the teacher learned from the implementation of a designed 9-week unit and how it informed her iterative design and enactment of a year-long curriculum. Findings showed marked differences in her design across iterations, including in the choice of themes and texts, task and participation structures, and foci of inquiry. The connection between the criteria-building work students did and their subsequent work was also notably different.

Introduction

Research has shown that teacher involvement in design of instructional materials and tasks provides a context for teacher learning and professional development, especially during iterative cycles of design as is the case in design-based research (DBR) (Kyza & Nicolaidou, 2016; Penuel & Gallagher, 2009; Voogt et al., 2015). To date however, there are few analyses of teachers learning through the process of iterative design of instructional units. Our work with teachers during a multi-year design-based research project (Project READI, Goldman et al., 2010) provided a context in which to study what and how teachers learned as they participated in this process. In this paper, we focus on the case of one high school literature teacher, Ms. Edwards, who participated in multiple design cycles over a three-year period. We examine what she learned and the mechanisms supporting that learning.

Designing instruction requires clear explication of the knowledge and practices students are expected to learn and an understanding of how to structure learning experiences to support them in meeting those expectations. Learning experiences encompass the type and structure of tasks, as well as how they are sequenced and coordinated (Kang, et al., 2016). They are critical determiners of the intellectual work and classroom discourse in which students engage (Jackson, et al., 2013; Stein & Lane, 1996). Clear explication of learning goals for students depends on a conceptual analysis of the discipline in which the learning is to occur, in this case literary argumentation. Literary argumentation requires that readers move beyond the literal words and surface meaning of the text to explore deeper meanings (Graves & Frederiksen, 1991; Zeitz, 1994). Interpretations of literary texts are expected to vary as each reader brings their own background knowledge, life experiences, and personal beliefs to the text, but these interpretations still must be based on and bounded by the text (Lee et al., 2016). This variation in interpretation provides fertile ground for argumentation, in which the validity of claims depends on the warrants used to explain the connection between what is in the text and the interpretation. Warrants are drawn from knowledge and experiences readers bring to the literary work, including criteria for various character traits (e.g., heroism, honesty) and overall story themes (e.g., coming of age, identity, gender and power). For example, to argue that Luke Skywalker is heroic depends on understanding the features or characteristics that constitute "hero-hood" and heroic action and using such knowledge to identify parts of the text that provide evidence of those criteria. An important component of instruction that prepares students to engage in literary argumentation, especially the reasoning that warrants claims they make, is establishing criteria for making inferences about characters and themes in literary texts.

What criteria need to be established is dependent on the specific texts and tasks (e.g., character traits, thematic claims) that are the instructional focus. Design work thus begins with close analysis of the texts and the literary problems or interpretive puzzles they pose (Lee et al, 2016; Rainey, 2017). Literary problems are questions about the text that can be answered in various ways, such as "Is this character a hero?" or "Which character has more power?" The interpretive problems identified through such analyses bring to light the criteria students will need to draw on to make interpretive arguments about themes and characters. This information can then guide the design of activities intended to build such knowledge through tasks that tap into the life experiences of the students. One way to do this is to provide students with relatively brief scenarios of everyday life or accessible texts that are culturally familiar (e.g., song lyrics, comics, advertisements). Based on these texts, students are asked to develop criteria for identifying and characterizing a concept, trait, or theme by interrogating familiar contexts that portray aspects of those concepts, traits, or themes (McCann, 2003; Smagorinsky et al., 1987).

Developing criteria around abstract themes with more accessible texts can support students in both identifying and developing thematic interpretations of more complex works (Smith & Hillocks, 1988).

The case study of teacher learning reported in this paper focuses on the design of the criteria building component as related to the themes, texts, and tasks of literary argumentation units designed and implemented over a three-year period by Ms. Edwards. The research questions the case addresses are: *What did the teacher learn from initial implementation that informed the redesign in years 2 and 3, particularly of the criteria building component? How and why did that learning inform revisions to the design?*

Case context

Ms. Edwards taught 11th grade English in a large urban high school serving a diverse student population (47.9% Black, 43.1% Hispanic, 3.8% White, 1.9% Asian, and 3.3% mixed race; 87% free and reduced lunch). As a White teacher in this setting, she was particularly mindful of the importance of drawing on students' experiences outside the classroom and preparing them to pursue their goals beyond high school. She had been teaching for two years when she volunteered to participate in Project READI as part of the literature design team (Goldman et al., 2016).

Ms. Edwards three-year participation in Project READI starting in spring 2013 involved working closely with researchers to iteratively design and implement instruction supporting students in literary analysis and evidence-based argumentation. In Year 1, she implemented a nine-week unit on the theme *coming of age* as reflected in several short stories. This unit was chiefly designed by researchers as an iteration of units implemented in other contexts. In Year 2, she designed a sequence of units focused on the themes of *gender and power* as manifest in two major novels and using shorter texts to build criteria and background knowledge relevant to the context of the novels. This design then underwent minor revisions that were implemented in Year 3. During her time on the project, Ms. Edwards also participated in bi-weekly meetings with the design team, which consisted of researchers and other teachers, and quarterly cross-disciplinary professional development sessions. Three years later, she joined us on a new project focused on teacher learning, providing opportunities for Ms. Edwards and READI researchers to analyze and reflect on her classroom videos and learning experiences from Project READI. (How Teachers learn: Orchestrating Disciplinary Discourse, Goldman, et al., 2018). (See Figure 1.)

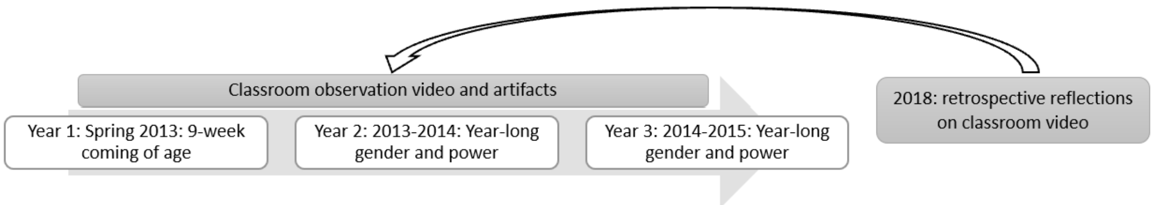

Figure 1. Timeline of Ms. Edwards' participation and data collection.

For the analysis presented here, we focused on criteria building components of literary interpretation as designed and implemented across Years 1, 2, and 3. During the implementation of the first- and third-year units, researchers were in the classrooms almost every day collecting observation data (video and field notes) and debriefing with the teacher after class. During Year 2, the teacher kept a journal documenting implementation and her reflections on it with only occasional classroom observations by researchers.

Data sources for this study are teacher written reflections, researcher analytic memos, and reflective conversations during and after implementations as well as teacher and researcher retrospective reflections on video and field notes from classroom observations (35 from year one, 12 from year two, 111 from year three).

Analytic approach

In the first phase of analysis, we did repeated readings and content analysis of the reflections, analytic memos, and conversations with the teacher. The criteria-building component of the design emerged as a central focus of the teacher's redesign, necessitated by changes to the theme and literary texts that were the backbone of the instructional units. Therefore, we examined additional data sources to identify what changed and evidence for why and how it changed. We segmented each criteria-building component based on changes in the focus of the inquiry or in participation structure (whole class, small group, individual) and characterized each segment according to the nature of activities (reading, discussion, writing, etc.), participation structures, texts and materials, and length of time spent. This gave us a view of the structural similarities and differences in the two years. After that, we used content analysis and repeated readings of transcripts and field notes to identify themes in terms of the instructional design, paying particular attention to how criteria were introduced, the role of students in developing the criteria, the task set-ups (instructions and prompts), how criteria were used in class activities, and the type of support provided by the teacher. We also traced where and how the criteria were invoked in subsequent components of the overall unit. Finally, we returned to the reflections, analytic memos, and conversations with the teacher for evidence of why the teacher revised the design and implementation in the ways she did.

Findings

Based on the implementation of the first, 9-week instructional unit, Ms. Edwards made changes to the theme, literary texts, and tasks that were the focus of the instructional units for the Year 2 implementation. We first consider why the change in focus. We then closely examine what changed in the redesign of the criteria building component. We conclude with examining the how and why of the criteria building redesign and its impact on students' literary interpretation.

Change in choice of themes and texts

One of the more fundamental changes that Ms. Edwards made in designing the year-long curriculum was in the themes. Specifically, she decided to focus on criteria for gender and power instead of coming of age. Although coming of age is a common theme in literary texts, it may not have been as flexible for the variety of texts Ms. Edwards wanted to have students read. She also indicated that during the Year 1 iteration, she felt students lacked interest in the coming of age theme. Indeed, coming of age texts are often recommended for middle school students who are more squarely in the throes of puberty and other changes that generally accompany "coming of age." Her students were 16-17 years old on average and likely looking more towards their adult futures.

The decision to change the theme, specifically to gender and power, was based on the teacher's belief that these themes were both relevant and important for her students to explore, as she indicated:

> "They know the themes of friendship and that kind of thing, but then to scale that out and make literature a way they look at and learn about the world […] This matters more than just this class, but it matters to your world and the way your world looks, in a way that makes them think about some ways the world might not work very well, because I don't think they very often get to do that."

Ms. Edwards' response suggests that she purposefully chose the themes to give students opportunities to learn ways to see and understand the significant roles that gender and power play not only in literature, but also in their own lives and in the world around them. Her reasoning aligns with the epistemic purpose of reading literature as a means of understanding the human condition (Lee et al. 2016).

Choosing to change thematic focus accompanied her choice to use different texts. She chose themes that she could build a year-long curriculum around, using two novels as the focal texts as compared to the short stories used in the nine-week unit. In fact, in designing the year-long curriculum, she chose to use texts that she was familiar with and had taught before. In describing the difference between her teaching one of the novels before and after designing and implementing the first nine-week unit, she said "My practice moved from attention to plot and asking students to make surface connections to characters to attention to language and the way in which it helps the reader to understand characters, theme, etc." Her choice of texts was also ambitious in the later iterations as one of the novels she chose was traditionally used in university level literature classes. In her reflective interviews, she recognized that the complexity of her design was in fact enabled by her experience implementing the first nine-week unit. She explained,

> "How needed it was to have those texts and structures and ways of doing in that 9-week module, how necessary it was to engage in those and have the chance to think about them and reflect on them, and how I might have gotten lost in what I was trying to do had I just tried to superimpose that thinking on what I had already been doing. I think being deep in that work and reflecting on it, and then saying what have I learned and how do I lift that onto a curriculum that is this year-long study of power?"

Having the opportunity to implement the 9-week unit and reflect on it showed her that the work in an English classroom could be fundamentally different from the traditional focus on text comprehension. She realized the need to completely upend the way that she had been teaching, which included generating new designs for the criteria-building piece based on concepts she anticipated students would need to analyze and interpret the novels.

Redesign of the criteria-building component

Ms. Edwards used the same overall three-phase structure that was part of the 9-week unit in the criteria building component for her year-long curriculum: 1) introducing the concepts and generating initial criteria by relating to students' own personal experiences, 2) providing students with everyday situations from which to further develop and apply the criteria, and 3) having students produce a written argument involving use of the criteria. However, there were marked differences in the designs and implementations of each phase of the criteria building component across the three years, including differences in the choice of themes and texts, foci of inquiry, and opportunities to consider various examples of criteria, all of which impacted the use of criteria during the remainder of the units.

Faced with how to prepare students to probe more complex themes in more complex texts, Ms. Edwards had to reflect on what had worked or not during the first implementation and consider that in terms of the new themes. In the first unit, the teacher had introduced the idea of coming of age by asking students in the context of a whole class discussion if they thought that they themselves had come of age and what they thought it meant to come of age. She started a public list of criteria and characteristics that students came up with for coming of age, which was added to during discussion of four scenarios that featured coming of age. Each scenario presented a brief description of a situation that adolescents might find themselves in and the reactions of characters to those situations. For example, the first scenario was about an adolescent girl:

> "Right around the time she turns fourteen, Hillary begins to see her neighbor, who is also fourteen, not just as someone to chase in the streets and make fun of, but someone that she thinks is cute. One day, they are both sitting on her front stoop, watching the cars pass by. Without even really knowing what she is doing, she leans over and kisses him."

Each scenario was followed by three prompts: 1) Has the character come of age? 2) Why or why not? 3) Define coming of age based on your explanation. The first scenario was read and discussed through a teacher-led whole class discussion. That discussion continued the second day and was followed by students working through the rest of the scenarios together with partners or in small groups. These discussions generated a list of criteria that the teacher kept on the wall of the classroom (Figure 2). For the culminating task, students were to decide which criteria was the strongest using the scenarios as evidence. The template provided academic language and sentence structures intended help students express their ideas. The specific instructions were

> "So, you are taking two scenarios and two criteria for coming of age and you're saying: I see that this character and this scenario, you can make some argument about whether they have or haven't come of age based on this criteria [...] I also see that this character and this criteria show a coming of age and I think this is stronger and I am going to use this template to help me make that argument."

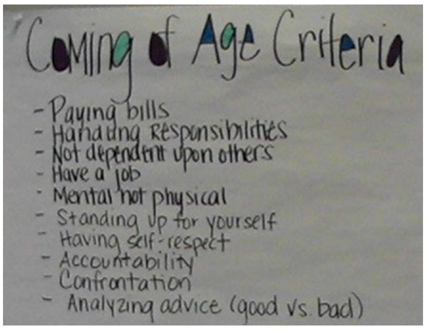

Figure 2. Criteria for coming of age.

These templates were handed in the next day and not discussed further.

Reflections, conversations, and memos around this initial implementation revealed several issues with this design. First was that the scenarios were not ideal for supporting the development of criteria for coming of age. Perhaps evident in the example above, the scenarios were sometimes too literal or obvious to generate much discussion. In addition, students seemed hard-pressed to "define" what it meant to come of age from the scenarios. Coming of age stories typically trace a character across time and emphasize the changes in that character. These scenarios were too brief to be able to see the transformation in a character and so did not lend themselves to developing an understanding of the types of things an author would use to signal coming of age in a character. The difficulties that students had in combination with Ms. Edwards' desire for them to deal with more complex themes prompted her to make several changes to the design in the following years.

Similar to the first iteration, the teacher introduced the thematic concepts for the unit, gender and power, by connecting to students' personal experiences. However, instead of asking what gender and power mean, she had students make a t-chart with one column labeled "men have more power than women" and the other "women have more power than men." She told them to base their ideas on "the world as we know it" and list at least ten criteria on each side of the chart. The teacher modeled phrasing of criteria using an example from a previous class period ("men have the ability to physically intimidate") and then let students work with groups or partners to further fill out their lists. She asked them to "critically think about the ways in our society in which men are more powerful than women and women are more powerful than men." Students continued to work on their lists of criteria independently for homework. The following day these criteria were discussed and as in year 1, a public list was kept (Figure 3).

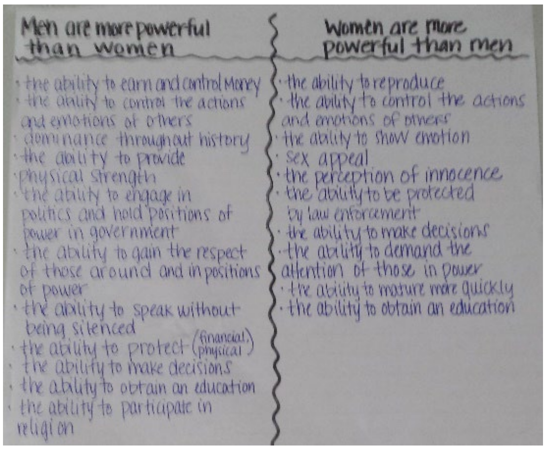

Figure 3. Criteria for gender and power.

These criteria-building tasks generated more and a different type of criteria than in Year 1. This is in part because in Year 1, the primary task was to "define" coming of age, while in Year 3, the teacher set up discussions of gender and power as an argument: "We are going to take each side of this argument and develop criteria for what it looks like when men have more power than women and women have more power than men." By referring to these lists of criteria as sides of an argument, she was emphasizing the idea that the criteria themselves were debatable and negotiable.

Instructional time spent on the criteria-building component was longer than in Year 1 (1.5 lessons in Year 1 versus 2.5 in Year 2) and there were more opportunities for students to practice applying the criteria to different texts after the initial criteria-building exercises. In Year 1, students were not given any opportunity to practice with texts other than during the criteria-building lesson in which a list of criteria were generated. However, in Year 3, Ms. Edwards gave the students more practice in both application and in developing arguments both orally and in writing using a variety of images. That is, after generating the initial list of criteria, Ms. Edwards put four images up on the screen (a crown, a pile of money, a silhouette of a man in a suit, and a stylized image of a muscular body) and asked the students independently to choose one and "in three sentences write why this image connects to or corresponds to power." Students then had time to discuss in small groups the image they chose and what it said about power. This was followed by a whole group discussion of what students thought of the images and how they represented power. The teacher added to the public list of criteria as they discussed. This discussion was interrupted by the bell and picked up at the beginning of class the third day. Then the rest of the lesson on the third day focused on the two images shown in Figure 4.

Figure 4a. Image used to discuss power and gender. Figure 4b. *American Girl in Italy*, 1951, by Ruth Orkin.

The first image, the one of the man with tape over his mouth (Figure 4a), was shown on the screen and used as the basis for discussion. The teacher told students: "I want you to talk about whether the person in this image is powerful or powerless. And when you have that discussion, what I need you to do is refer back to that criteria. So what criteria are you using to say he is either powerful or powerless?" A whole class discussion followed during which the idea that the same evidence could be used to support two different claims surfaced. The second image (Figure 4b, a famous photograph of a woman walking down the street in 1950s Italy) was used to further elaborate how to support interpretive claims with criteria, evidence, and reasoning. The teacher had students discuss the photograph briefly and then independently write a claim as to whether the men or the woman in the photograph had power. Then she had them work together in small groups or with partners to compile evidence from the photograph to support those claims. Lastly, they were to help each other label each piece of evidence with the criteria for power they were using. Toward the end of class, students shared their thinking about the photograph in a whole class discussion. Compared to Year 1, these activities gave students many more opportunities to practice both orally and in writing with varying participation structures and texts.

Another revision from Year 1 was in the culminating writing task. Although in both years the teacher asked the students to produce a written argument as the culminating task for the criteria-building components of instruction, in Year 1, students were simply asked to write an argument about which criteria was strongest, without a particular context to apply it to. In Year 3, the writing task was more involved:

> "For the first paragraph you are going to make a claim, provide evidence and reasoning for the idea that the woman in this picture is in power […] And remember that tape on the mouth, right? Our argument lives or dies in our explanation and our reasoning, so how can you take that piece of evidence and explain to your reader how that evidence proves to you that the woman is in power [...] Your second paragraph is going to take the opposite stance. You are going to make the claim that the men in this image are in power. You are going to provide

> evidence to support that and you are going to provide your reasoning."

The Year 3 written arguments and the possibility of the same evidence being used to argue two different sides were the subject of further discussion in the subsequent class, at the end of which students were given the option to revise their writing. These writing assignments for each year underscore the difference in what students were being asked to do with the thematic criteria. In the later iteration, students were asked to make claims about characters, the woman or men, in the photograph having power and then support those claims with specific evidence, criteria, and reasoning. They also had to argue both sides, drawing attention to the importance in crafting arguments of how criteria, evidence, and reasoning are used to support varying claims. This type of complex reasoning and argumentation was setting the students up for the work Ms. Edwards expected them to do with the longer, more complex texts that were the focus of the units.

Reflecting on implementation: The how and why of teacher learning

Ms. Edwards' revisions to the units implemented were substantial from the initial 9-week unit to the year-long design. These changes can be attributed not only to her decision to change the theme and texts but also to what she noticed in the work that students did during the first implementation. Her written reflections throughout that implementation revealed the extent to which students struggled with using the criteria when they analyzed longer, more complex literary texts. This was the case even though coming of age was a less complex theme. In referring to a Year 1 class discussion about a story in which an adolescent girl in a rage ripped up a neighbor's cherished flowers, Ms. Edwards wrote:

> "Students were successful in determining this moment of the ripping up of the flowers as her coming of age but needed prompting to think through the criteria used to determine this as a coming of age moment"

Ms. Edwards recognized that students did not have a sufficiently robust understanding of coming of age to apply the criteria developed earlier in the unit to a longer story that occurred toward the end of the 9-week unit. She attributed this in part to not having spent enough time on developing and practicing use of the criteria across a range of texts. This led to designing the criteria-building components in subsequent iterations (Years 2 and 3) to include more time and more practice with varying texts, participation structures, and combinations of writing and discussing. In the reflective conversations, the teacher mentioned the importance of giving students an opportunity to write down their thoughts individually before discussing. In one reflection, she noted, "I do think the opportunity for them to write first was important for the discussion that came after." In the Year 2 and 3 iterations, she also saw as beneficial giving students various ways to participate and interact with content, especially for those students who were uncomfortable participating in whole class discussions:

> "I just keep going back to those voices that were quiet. And with the built-in support of writing first and the built-in support of a partner conversation, I think I could have drawn on them because they had those supports. I feel uncomfortable calling on a child without giving them those supports. But because they had the time to write and think and because they had the time to have a partner conversation, it would have been a good move to call out those voices that were silent because they had the support."

These reflections indicate that her movement towards varying participation and task structures was a purposeful choice in the way she implemented the later designs.

Her students' struggle also encouraged her to reflect on what she was learning about her own literary interpretive practices. In reflecting on her experiences, she said, "I realized I wasn't apprenticing them into any of the ways I paid attention to literature." This realization led her to think about how to introduce and support students in those practices rather than on comprehension and character traits, a typical focus of English classes and what her students had gravitated toward in the first iteration. The first 9-week unit provided opportunities to see first-hand what students needed to meaningfully build criteria that were sufficiently robust to support their argumentation in lengthier and more complex texts. One aspect of the design that she knew would help in this support was greater purposefulness and coherence of instruction leading from the criteria-building to the work in the rest of the unit. In Year 1, criteria development focused on whether a character had come of age and on developing a definition of such. Thus, it was not surprising that students ignored the criteria or struggled to use them when interpreting the short stories in the latter part of the unit. For example, the use of coming of age criteria in the following task instructions from the latter part of the unit was unfamiliar:

> "You are going to talk with one person recording: Has the character come of age? Why or why not? Do you view this coming of age as positive or negative? And then you are going to say, 'Ok, I think the character has or hasn't come of age. I think this is positive or negative.' But then you have to go back into the text and say: What does the author think? Does the author think the character has come of age? And how do you know? And then does the author believe this is positive or does the author believe this is negative?"

These questions go beyond simply asking for the theme and applying its definition. This task asks students to analyze the language and structure of the text to make judgments about the author's intentions. This type of task certainly is the work of literary analysis; however, the only prior work specifically with the theme of coming of age was the work during that initial criteria-building. Students were not equipped to go beyond the questions around whether characters had come of age and this likely explains even further why students struggled with these tasks. The teacher wrote the following in her reflections during the implementation:

> "We asked students to think through how the symbol of the marigolds informs our thinking about the main character's coming of age. Students were entirely confused by this."

This led to the teacher having to scaffold students' analyses and arguments to a much greater extent than she had planned, taking two whole lessons to walk through the connection between the language the author used and the theme in the text. Her reflections during the unit repeatedly remarked on how she had spent more time on certain instructional activities than planned. These experiences contributed to redesign decisions about how much time to spend on criteria-building, the necessity of providing various and repeated opportunities to use themes for interpretive purposes, and the need for coherence in the focus of the interpretive problems presented to students.

Unlike in Year 1, the focus of the inquiry throughout the third year followed directly from the way the students had been introduced to the criteria for gender and power, emphasizing the complexity of analyzing texts for these themes and developing strong arguments to support their claims with both textual evidence and criteria. As an ongoing assignment, students kept "critical reading journals," which consisted of quotations from the text followed by three to four sentences analyzing the significance of the quotation in relation to a theme (e.g., What does this passage tell you about gender and power?). The classroom discussions and writing assignments were also often focused on the way gender and power played out among the characters in the various texts. The teacher's struggles with getting students to attend to theme during the first iteration helped her recognize the importance of designing her instruction in a way that allowed the themes to be woven through the texts and tasks throughout the year. The criteria-building set students up to engage deeply and repeatedly with the complexities of gender and power among characters in various texts, hotly debating both their claims and the criteria throughout the year.

Discussion and implications

The case of Ms. Edwards provides a glimpse into the processes involved in teacher learning that can occur in the context of participation in iterative design-based research. The work adds to unpacking *reflection* and *enactment* as two central mechanisms driving teachers' learning and change as proposed by Clarke and Hollingsworth (2002). Ms. Edwards began the project by enacting a designed module that acted as external input to the knowledge, beliefs, and attitudes she brought to the work. The enactment provided feedback on salient outcomes for students: what students were and were not engaging with as well as what they did or did not find problematic. Reflecting on these outcomes on her own and in interaction with researchers supported her restructuring and refining her design decisions in subsequent iterations. The iterations allowed her to practice new ways of engaging students in the intellectual work and thus providing feedback on the design rationale that had driven the changes. The importance of feedback with opportunities to practice is one of the oldest principles of learning in psychology (Thorndike, 1913). This case is a situated manifestation of its relevance to classroom teaching and learning.

The design-based research context provided opportunities not only for external input that set the stage for enactment but opportunities for external perspectives on salient outcomes, joint reflection on their import, and knowledge building about what was needed to support students in the complex work of literary interpretation. These experiences of enactment and reflection inside the process of design-based research helped Ms. Edwards imagine the myriad potentials and possibilities for re-designing instruction in her classroom. In addition, Ms. Edwards' involvement in the larger project's various learning contexts (teacher-researcher relationship, design team meetings, cross-disciplinary professional development meetings) provided multiple opportunities for her to examine and deepen her knowledge of her own literary processes. The increased metacognitive awareness of her own literary interpretation practices reshaped her lens on how she wanted her students to engage with literary works to create warranted literary arguments. Armed with this altered understanding of student learning goals, Ms. Edwards was able to redesign using the underlying principles of the initial module and create activities that supported students in wrestling with complex themes and literary works.

Thus, the redesign of the themes, selection of literary works, and the criteria building sequences could be traced to her own professional learning regarding literary interpretation and argumentation and to feedback from students' engagement and challenges in building criteria for literary argumentation. Researchers engaging collaboratively with teachers in this type of design-based research created opportunities for teaching and learning processes that are unlikely to have occurred had teachers been handed designed curricula to implement, even with high quality professional development intended to prepare them to use the curricula. Thus, this case provides practice-based evidence of the value of iterative cycles of collaborative co-design among teachers and researchers.

References

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and teacher education*, *18*(8), 947-967.

Goldman et al. (2010). *Reading for understanding across grades 6 through 2: Evidence-based argumentation for disciplinary learning.* Grant proposal funded by the Institute of Education Sciences, U.S. Department of Education, through Grant R305F100007 to University of Illinois at Chicago.

Goldman et al. (2018). *How teachers learn: Orchestrating disciplinary discourse in science, literature and mathematics classrooms.* Grant funded by the James S. McDonnel Foundation Teachers as Learners (TAL) program. Grant #: 220020517

Goldman, S. R., Britt, M. A., Brown, W., Cribb, G., George, M., Greenleaf, C., Lee, C. D., Shanahan, C., & READI, P. (2016). Disciplinary Literacies and Learning to Read for Understanding: A Conceptual Framework for Disciplinary Literacy. *Educational Psychologist*, *51*(2), 219–246.

Graves, B., & Frederiksen, C. H. (1996). A cognitive study of literary expertise. In R. J. Kruez & M. S. MacNealy (Eds.), Empirical approaches to literature and aesthetics (pp. 397-418). Norwood, NJ: Ablex.

Jackson, K., Garrison, A., Wilson, J., Gibbons, L., & Shahan, E. (2013). Exploring relationships between setting up complex tasks and opportunities to learn in concluding whole-class discussions in middle-grades mathematics instruction. *Journal for Research in Mathematics Education*, *44*(4), 646-682.

Kang, H., Windschitl, M., Stroupe, D., & Thompson, J. (2016). Designing, launching, and implementing high quality learning opportunities for students that advance scientific thinking. *Journal of Research in Science Teaching*, *53*(9), 1316-1340.

Kyza, E. A., & Nicolaidou, I. (2017). Co-designing reform-based online inquiry learning environments as a situated approach to teachers' professional development. *CoDesign*, *13*(4), 261-286.

Lee, C. D., Goldman, S. R., Levine, S., & Magliano, J. (2016). Epistemic cognition in literary reasoning. *Handbook of epistemic cognition*, 165-183.

McCann, T. M. (2003). Imagine this: Using scenarios to promote authentic discussion. *The English Journal*, *92*, 31–39.

Penuel, W. R., & Gallagher, L. P. (2009). Preparing teachers to design instruction for deep understanding in middle school earth science. *The Journal of the Learning Sciences*, *18*(4), 461-508.

Smagorinsky, P. McCann, T., and Kern, S. (1987). *Explorations: Introductory activities for literature and composition.* Urbana, IL, National Council of Teachers of English

Smith, M. W., & Hillocks, G. (1988). Sensible sequencing: Developing knowledge about literature text by text. *The English Journal*, *77*(6), 44-49.

Stein, M. K., & Lane, S. (1996). Instructional tasks and the development of student capacity to think and reason: An analysis of the relationship between teaching and learning in a reform mathematics project. *Educational Research and Evaluation*, *2*(1), 50-80.

Thorndike, E. L. (1913). *Educational psychology* (Vols 1 and 2). Columbia University Press.

Voogt, J., Laferriere, T., Breuleux, A., Itow, R. C., Hickey, D. T., & McKenney, S. (2015). Collaborative design as a form of professional development. *Instructional science*, *43*(2), 259-282.

Zeitz, C. M. (1994). Expert-novice differences in memory, abstraction, and reasoning in the domain of literature. *Cognition and instruction*, *12*(4), 277-312.

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Noticing, Understanding, and Encouraging Positive Engagement with Collaborative History Learning

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Abstract: This study analyzes the implementation of Net.Create, a collaborative network analysis tool (Craig & Danish, 2018), in the context of a digital humanities classroom. Undergraduate students used network analysis to investigate historical objects gathered from the local community in a History Harvest. This paper focuses on the collaborative engagement of groups as they co-constructed conceptual frameworks in Net.Create to explain the individual, social, and cultural histories attached to these objects. Findings suggest that positive social engagement and metacognitive behaviors can support students' sustained engagement with historical and network analysis ideas. Interwoven personal-oriented and class-oriented social engagement in the data suggest that these forms of engagement can productively sustain engagement with cognitively demanding activities. Having built a supportive environment for collaboration amongst themselves, students were able to smoothly and effectively build on each other's ideas to generate an understanding of historical and network analysis patterns.

Keywords: student engagement, history, network analysis, CSCL

Introduction

Promoting student engagement with history has been an important goal for history learning research (Brush & Saye, 2008; Sakr, Jewitt, & Price, 2016). However, studies of student engagement in history often focus on a single variable, such as excitement (e.g., Squire & Barab, 2004) or empathy (e.g., Endacott & Brooks, 2013; Savenije & de Brujin, 2017). This contrasts with research in other disciplines, which often investigate the impact of multiple, interrelated dimensions of engagement on learning (Sinatra et al., 2015; Fredricks, 2011; Sinha et al., 2015). This paper explores a multidimensional framework of student engagement to understand mechanisms by which collaborative activity and network analysis can support deeper engagement with history learning. We analyze Net.Create, a collaborative network analysis tool (Craig & Danish, 2018; Craig et al., 2020), in the context of an undergraduate digital humanities classroom, where students were tasked with representing complex historical data for public consumption. Students used digital humanities tools (network analysis, mapping, and text analysis) to represent data gathered from a History Harvest. The History Harvest model brings students, academic researchers, and communities into partnership to preserve objects that tell personal and familial histories while keeping those objects with their owners. To accomplish this, history students photograph objects and conduct interviews about their importance for the community's history. Students then use digital tools to create interactive representations to display connections between personal, familial, cultural, and local histories.

This paper focuses on the collaborative engagement of groups that chose Net.Create to represent their objects. Net.Create engages students in detailed investigations of historical sources by providing a framework to support the contextualization of individual historical details in a complex web of people, places, concepts, and events. A persistent problem with history engagement is moving students beyond surface-level interest in a historical problem and towards the analysis and interpretation of historical sources (Brush & Saye, 2008). To understand how Net.Create supports this deeper engagement with historical analysis, we explore the following research question: *How did students engage behaviorally, cognitively, socially, and emotionally with and around Net.Create as they created networks of historical objects, and how did this influence their learning?*

Literature review

The History Harvest as a component of authentic historical thinking

Representing historical objects and their stories for the public offers unique opportunities for undergraduate engagement with history. Traditional large-lecture classes typically present history as a collection of facts to be memorized, thus obscuring how history is built up through multiple narratives and perspectives (Wineburg, 1991; Nokes, 2013; Wineburg, 2018). Engaging students in the authentic practices of historians—collecting artifacts, analyzing multiple narratives, and drawing connections—helps students refine historical thinking and argumentation skills that are key to the discipline (Shopkow, 2017; Martin & Monte-Sano, 2008; Lévesque, 2008).

In this study, some artifacts collected by students were passed down through generations, while others were found, purchased, or received as a gift. For instance, one contributor shared a Japanese kimono that her grandfather brought back from Japan after serving in World War II. Situating class activities in community history increases the likelihood of deep cognitive engagement, because students must generate a workable solution to a real-world question of historical practice without a predetermined "correct" answer (Hmelo-Silver, 2004). Such ill-structured problems ground learning in disciplinary knowledge and practices (Bae et al., 2019). Authentic problems can also engage learners' prior knowledge and experiences and motivate extended engagement (Hmelo-Silver, 2004; Blumenfeld et al., 1991). In this study, students were asked to represent historical objects in a way that reveals the social and cultural connections between them while also highlighting their unique features. This approach offers students authority over how they build historical arguments from a complex dataset and problematizes the notion of history as having one "true" perspective, both of which can influence learners' engagement with history learning (Freedman, 2020). To support students in navigating this open-ended problem, the Net.Create tool (see Design section) was offered to students as one option to explore, analyze, and represent this complexity.

Using the structure of network analysis to frame an ill-structured problem

Digital historians balance between different methodological approaches to the study of change and continuity as they negotiate structured network analysis and individual close-reading of primary sources (Gould, 2003; Padgett and Ansell, 1993; Graham, Milligan, Weingart 2016). The open-ended nature of that negotiation provides an ill-structured, authentic historical-thinking problem that encourages deep collaborative discussion. Making history palatable for the public is also an ill-structured problem because historical complexity can be represented in many forms. Students were tasked with using digital tools to answer team-generated research questions, such as "How do the cultural differences of each object affect how they serve as a mode of individual self-expression?" After entering data about their objects to explore possible answers, students created public web pages to communicate their discoveries. Groups then used Net.Create and network analysis methods to investigate the multiple historical narratives attached to their objects and generate a representation to help the public interpret these histories.

For network analysts, decisions about transforming the open prose of historical primary sources into structured data shape which elements of the dataset are highlighted or obscured (Durland & Fredricks, 2005). Networks are composed of nodes (circles which represent people, places, objects, and concepts) and edges (lines connecting the circles which represent relationships between nodes). Students make decisions about types of nodes to add to the network as well as types of relationships between nodes that are worth highlighting. These decisions affect how viewers interpret the final network, because well-connected nodes will appear larger, signifying the importance of that object or concept for the overall network. The types and numbers of edges created will also influence which nodes have high measures of betweenness, or in other words which nodes link parts of the network that would be otherwise unrelated (Carrington, 2005).

Student engagement in building a collaborative network of history

Students are more likely to engage deeply with learning in a task that is authentic for both disciplinary practice and complexity (Calabrese Barton & Tan, 2010). To capture this engagement, it is useful to conceptualize engagement as containing multiple, overlapping dimensions (Fredricks, Blumenfeld, & Paris, 2004; Fredricks, 2011). Behavioral, cognitive, and emotional dimensions are commonly agreed upon as key aspects of engagement (Fredricks et al., 2004). Social engagement has also been recognized as a fourth significant dimension, given the importance of mutually respectful interactions for collaborative learning (Sinha et al., 2015; Isohätälä et al., 2018). This multidimensional conceptualization highlights that engagement is not a static attribute, but rather a dynamic state that unfolds over time and is transformed by context (Fredricks, 2011; Sakr et al., 2016). It is important to note that studying a single facet of engagement is not only theoretically problematic, but it does not reveal the complex mechanisms by which behavior, cognition, emotion, and social relationships interact to open or foreclose opportunities for learning more broadly (Sinatra et al., 2015). The present study takes a multifaceted approach to understand how emotional connections shape and are shaped by social engagement and in turn deepen students' cognitive engagement with historical and network analysis concepts. Drawing on frameworks that have been applied in other disciplinary contexts (Fredricks et al., 2004; Sinha et al., 2015), we conceptualize engagement along behavioral, cognitive, social, and emotional dimensions to capture the complex ways that engagement unfolds over time as learners interact with each other and their environments (Sinatra et al., 2015).

An analysis of engagement in context requires the application of a sociocultural theoretical lens, which views engagement as a dialectic give-and-take process between learners and their social, cultural, and political environments (Sinatra et al., 2015). Engagement cannot be separated from the contexts in which it is produced—in other words, it cannot be captured in a single decontextualized snapshot but must instead be understood as "unfolding in place and time" (Sakr et al., 2016, p. 84). From this situated perspective, surveys of individual engagement variables are not enough, and analyses should instead take up a frame of learners-in-context that highlights social positioning, available forms of participation, and the collective meaning assigned to these interactions (Nolen, Horn, & Ward, 2015). Behavioral, cognitive, social, and emotional dimensions are interwoven together in interactions between learners, so it is not always easy to operationalize where one dimension ends and another begins (Fredricks et al., 2004). To clarify dimensional boundaries, we consider behavioral engagement as the overarching visible "evidence" of learners' engagement (e.g., entering network data into the computer), and cognitive, social, and emotional engagement as different goals that engaged behaviors may fulfill. Behavioral engagement encompasses ways in which students participate in the activity that surrounds them (e.g., asking questions, taking notes; Fredricks et al., 2004). The other three dimensions can then be defined through subsets of behaviors that make conceptual ideas, social relationships, and emotional reactions visible to other participants. Engaging along one dimension is good (e.g., taking notes), while engaging along multiple dimensions is better (e.g., taking notes while expressing excitement and soliciting contributions from peers).

Cognitive engagement is defined both as learners' reflections on conceptual ideas, questions, and problems (Sinha et al., 2015) and as their use of metacognitive strategies to control and improve their learning (Greene, 2015). This dimension can be analyzed through the public negotiations and discussions that students engage in as they work to represent their historical data together. Collaborative activities are a powerful way to foster cognitive engagement because students must explain and justify their ideas to their peers (Gresalfi, 2009). In the context of Net.Create activities, students must determine what conceptual links to create between objects, such as geographic origins, cultural traditions, and personal experiences. They also negotiate network structures (e.g., what counts as a node or an edge) so that conceptual links are visible and interpretable to network viewers.

Collaboration can also socially engage students when groups thoughtfully consider and respect the contributions of all members (Sinha et al., 2015). Positive social engagement reflects "learners' abilities and efforts to sustain cohesive, mutually respectful social interaction...including developing trust and fostering safety for collaboration and building a sense of community with a shared goal" (Isohätälä et al., 2018, p. 2). This might look like a balanced discussion in which each student can share and safely debate ideas without risking rejection. Negative social engagement would be seen through exclusion, ignoring the perspectives of group members, or social loafing (e.g., letting one person do all the data entry while others text on their phones) (Isohätälä et al., 2018). The instructor encouraged positive social engagement in this study by having each student take responsibility for a different set of historical objects, which they then had to add to their group's network.

The network tasks supported by Net.Create offer students a way to engage emotionally as well, which can be defined as the positive and negative reactions that learners have to activities (Fredricks et al., 2004). Students' emotional engagement with history can influence the extent to which they identify with people from the past, as well as their creation of links between past and present experiences (Sakr et al., 2016). Thus, supporting students in experiencing emotional reactions such as curiosity and empathy is central to the design of engaging history learning activities. When creating connections in Net.Create, students were encouraged to consider the perspectives of the people, families, and cultures who the objects belong to, which could help them identify and empathize with the emotional links that these people had to their donated objects (Endacott & Brooks, 2013).

Design

The Net.Create software (Craig & Danish, 2018) is designed to support collaborative, simultaneous data entry into a live network visualization, so that groups can enter and revise data to represent relationships between individual people, objects, and ideas in a complex dataset. To generate a visualization, students added nodes (objects, places, people, events, and concepts) into the network and then linked these nodes using edges (categories of relationships that describe how two nodes are connected) (Figure 1). Each node and edge entry had text boxes for students to explain historical significance and how the entry relates to the overall network. Nodes with many connections grew larger and pulled smaller nodes towards them to represent their growing importance.

Analyzing relationships between central nodes and outlier nodes helped students identify connections between gathered objects and was one of three digital methods students could choose after they completed the history-harvest portion of the course (see "authentic historical thinking" above in lit review). To support students as they transitioned from the community-interaction unit to the analysis unit, several mid-semester class sessions were set aside for in-person data entry and analysis. The sessions are labeled Days 1-4 to denote their chronological sequence but were not consecutive—the research team gathered data from a sampling of class periods across the semester to capture group engagement as it shifted over time. On Day 1, students drafted research questions to guide their analysis of objects collected from the History Harvest. On Day 2, groups entered data about their objects into Net.Create and analyzed connections between their objects' histories. On Day 3, they used evidence from their networks to draft paragraphs for web pages, to explain to the public their discovered patterns. Finally, on Day 4, they gave final class presentations summarizing their group's historical research.

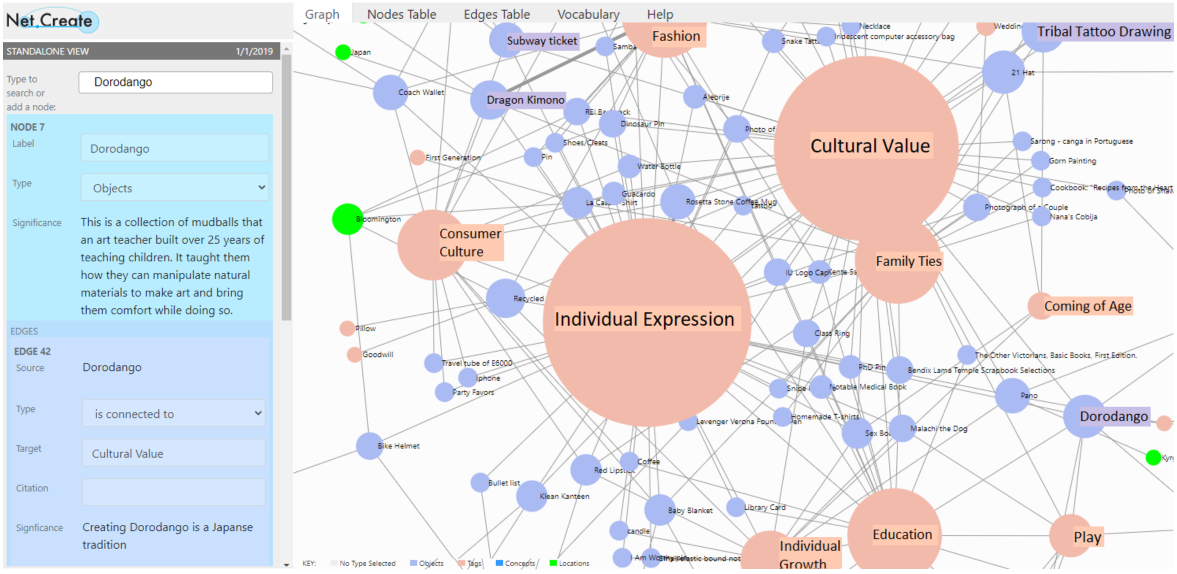

Figure 1. A node and edge entered by students (left) in their network of historical objects and concepts (right)

Methods

This paper focuses on the collaborative engagement of one focus group (n = 3 students) in a 25-student undergraduate digital history course at a large university in the Midwestern United States. A qualitative analysis of this group's interactions allowed us to explore how cognitive, social, emotional, and behavioral engagement intertwine to support students' learning during group work. The dataset, which consists of 4.5 hours of group audio data drawn from four different class sessions, was segmented into 30-second segments to give coders a standard unit of analysis for tracking engagement patterns (Isohätälä et al., 2018). We established seven general codes from the literature: 1) Metacognitive behaviors; 2) Positive emotional reactions; 3) Negative emotional reactions; 4) Positive social interaction; 5) Negative social interaction; two cognitive-conceptual codes capturing discussions of 6) Historical argumentation and 7) Network analysis concepts. The codes were used to tag engagement patterns and identify key episodes rather than evaluate discussion quality. Coders applied each code only once per 30-second segment and applied as many codes as were applicable for that segment. A second coder analyzed 1 hour of data to provide interrater reliability measures (1 / 4.5 hours of data, or 22% of the dataset).

Because behavioral engagement takes a variety of forms (e.g., active listening, independent work) and provides evidence of the other three dimensions, we did not code for behavioral engagement but instead analyzed it qualitatively in selected episodes. We identified episodes in which multiple coded dimensions of engagement overlapped to explore the complex interactions between dimensions, which are not yet well understood (Sinatra et al., 2015). For example, episodes of extended social engagement mixed with metacognitive and conceptual engagement were pulled to explore how these dimensions might be building on one another to support learning. These episodes of complex engagement were then qualitatively analyzed using interaction analysis (Jordan & Henderson, 1995), which involved multiple rounds of listening to audio clips, transcription of key episodes, and analysis of screen capture and video data when available to contextualize student conversations.

Findings

Coding of group interactions revealed that positive social engagement and metacognitive behaviors were most common. For example, Figure 2 shows group engagement across Day 1, with minutes 0-24 of class on the first line, 25-49 on the second line, and 50-72 on line three. Each column represents one 30-second segment of activity. Group members were periodically monitoring their collective progress, voicing confusion, asking for help, and clarifying goals and plans (i.e., cognitive engagement via metacognitive behaviors). They also consistently solicited ideas, responded to contributions, affirmed the value of peers' ideas, and engaged in friendly teasing and humor (i.e., social engagement via positive group interactions). The other five general codes also appeared across the dataset, though less consistently. Negative emotional and negative social engagement were relatively rare (e.g., negative social engagement did not appear on Day 1), while positive emotional engagement was moderately common but not as consistently present as positive social engagement. Most positive-emotion moments appeared as laughter around teasing or humor. Finally, historical argumentation and network analysis discussions were also moderately present, often towards the end of class during group review of network entries and webpage writings.

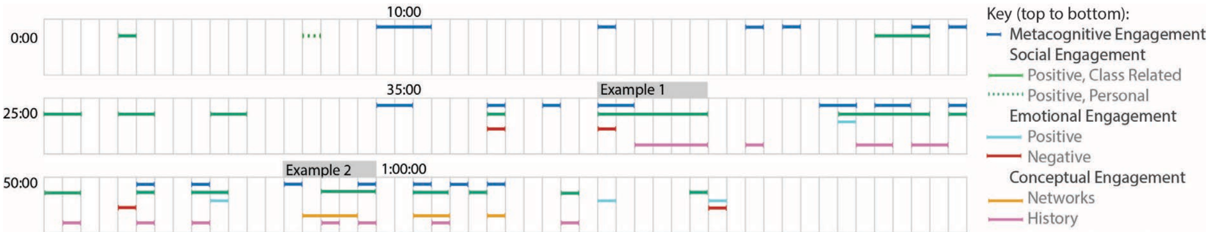

Figure 2. A timeline of the focus group's engagement along the seven coded dimensions during Day 1

Given the consistent presence of positive social engagement and metacognitive behaviors, we focused our qualitative analysis on the possible functions of these forms of engagement in supporting students' conceptual understanding. We present two episodes below demonstrating how these dimensions overlapped in discussions. In the first example (Table 1; Example 1 in Figure 2), our focus group (Patrick, Aubrey, and Jordan) have joined with another group (Students 1-3) to brainstorm research questions. The segment begins with several metacognitive behaviors: Patrick agrees to take notes, and Aubrey reminds him that the goal is to record their brainstorming. Aubrey and Jordan then organize the discussion by proposing that everyone share what object they have been studying. When Student 3 says his object too quietly, the group responds with positive social engagement in the form of polite questioning, re-voicing, and a bit of humor that carries on for ten lines of talk (one student misheard and thought Student 3's object, a subway ticket, was a Subway cookie from the sandwich shop). The discussion preceding the transcribed segment intertwines cognitive and social engagement as students use metacognitive behaviors to steer the conversation towards a collective goal. Students are consistently socially engaged, using laughter and humor to keep the conversation moving when a student is briefly misheard. This social engagement then transitions seamlessly into a discussion of potential concepts to organize their analysis:

Table 1: Positive social engagement in the form of respectful disagreement

Line	Speaker	
1	Aubrey	I feel like individual expression is probably
2	Patrick	Individual expression is definitely—like I think everyone can hit on that
3	Aubrey	Mhmm
4	Jordan	That's uh
5	Patrick	Cause they're all individual items
6	Jordan	Individual expression um…like it could get even deeper into cultural expression too
7	Patrick	I was gonna say even sediment—sen-i-ment—like, how sentimental it is
8	Aubrey	Mine's not very sentimental
9	Patrick	Oh, no?
10	Student 2	Same here
11	Patrick	Oh really?
12	Aubrey	Mine are just—
13	Student 2	Just tattoos
14	Jordan	Mine's pretty sentimental
15	Student 2	It's not sentimental, it's just more of a—like the self-expression angle
16	Jordan	See mine's more of like a sentimental tattoo
17	Student 2	What?
18	Jordan	It's like a more of like a tribal tattoo from like a ((inaudible))
19	Aubrey	Mine is—mine is used in education. To play as development...so
20		((inaudible side conversation))
21	Aubrey	I don't know if that technically- if that would fit with sentimentality. I feel like that's more of like- Like, how I- how I'm relating it to individual expression is through individual growth rather than sentimentality

In this discussion, students shift fluidly between multiple forms of engagement as they share ideas and negotiate what aspects of their historical objects should shape group analysis. Positive social engagement transitions seamlessly into a historical analysis of potential categories to address similarities between the group's objects (lines 1-7). When Aubrey and Student 2 respectfully disagree with a suggested category, Patrick pauses to question and listen to their reasoning for not wanting to use sentimentality as a conceptual frame (lines 8-11). These respectful interactions influence how the group's final network (Figure 1) unfolds—the group leaves out sentimentality and instead uses family ties, cultural value, coming of age, individual expression, and individual growth to better represent the similarities and differences between their objects' histories. This positive group functioning, with its blend of supportive, light-hearted discussion and guiding metacognitive behaviors, appears frequently in our focus group's interactions. While some might assume social engagement would distract from disciplinary engagement, it appeared in many cases to advance engagement with conceptual ideas. In a later episode (Table 2; Example 2 in Figure 2), our group again engages in metacognitive behaviors by reflecting on their research questions and assessing how their collaborative network sheds light on their data.

Table 2: Positive social engagement in the form of building on one another's conceptual ideas

Line	Speaker	
1	Aubrey	I feel like our question actually—I feel like our question actually like works well
2	Patrick	Mhmm
3	Aubrey	With (.) um network analysis, because like the middle of the structure is like, individual self-expression then, our branches are like—you know how I was saying earlier like individual growth as ((inaudible)) education, individual growth as a mode for self-expression. So then my like, thing related to it is like, individual growth. And then through that I would have like all the things relating to mine. And then you guys would have the same
4	Both J&P	Yeah
5	Aubrey	And there are probably crossovers between
6	Jordan	Yeah, and like with individual growth on yours, mine's about coming of age
7	Aubrey	Yeah
8		[…] ((group briefly clarifies which research question they're talking about))
9	Patrick	Cause each of us has a different object, and like not saying that tattoos are similar, but they're not—they have totally different meanings
10	Aubrey	Right. Right right. Right.
11	Patrick	So yeah you're totally right, as long as we have a center-
12	Aubrey	Like and I think the center-
13	Patrick	-we each branch out and we'll find like smaller parts that each go together
14	Aubrey	And like I feel like our center can literally just be individual self-expression, like as simple as that
15	Patrick	Yeah, that's what I was thinking
16	Aubrey	And then I feel like our network analysis, you know how she ((instructor)) was saying like, there's something that always ends up, like in the- it gets like super centralized
17	Patrick	Yeah. They'll be different parts that come together, and we'll find that out soon as they come out

This episode demonstrates a solid collaborative foundation that supports conceptual richness. Students negotiate their collective understanding and affirm the value of peers' ideas. Throughout the segment, all three group members offer small verbal acknowledgements (e.g., "mhmm", "yeah", "totally") to encourage one another's continued sharing of ideas. Aubrey makes important observations about how branching nodes and centralized nodes highlight relevant conceptual tags, and Jordan responds to Aubrey's mention of "crossovers" by noting a commonality between his object and Aubrey's (line 6). Patrick also builds on Aubrey's ideas with multiple explicit affirmations ("you're totally right", line 11) while adding his own idea that building the network will reveal emergent patterns (line 17). The group's final network (Figure 1) reveals how these early negotiations supported later engagement with the Net.Create tool. Jordan and Aubrey's objects do indeed end up in "branches", with Aubrey's dorodango linked to education, play, and individual growth, and Jordan's tribal drawing tattoo linked to coming of age and cultural value. Patrick's comment about ideas coming together (line 17) also played out in the group's network. The group predicted individual expression would be an important concept (line 14), but cultural value also became a central node. This engagement with network analysis structures helped this group engage with the history as well. Linking their objects to distinct conceptual tags helped make visible Patrick's understanding that a tattoo isn't just a tattoo (line 9)—each object has its own history and sources of meaning.

After the transcribed segment, the discussion wraps up with another blend of social support and humor. Patrick's "Good job, Aubrey" was met with thanks and Aubrey's joke that "there's a brain in here sometimes." These small moments of positive social engagement, which may seem insignificant in isolation, appear to build up across the activities, providing a consistent supportive context in which to negotiate evolving ideas. Based on the glimpse this focus group provides into the benefits of social engagement and metacognitive behaviors, positive social engagement has the potential to form a foundation for future engagement, with teasing and humor not only creating a positive context for discussion but also sustaining engagement through moments of confusion or frustration. For example, in other focus episodes students joked about having no idea what's going on as a light-hearted bid to solicit support from group members without directly asking for help. Productive behavioral and conceptual engagement (e.g., entering data into the network) also often coincided with personal-oriented positive social engagement (e.g., discussing plans for the weekend), which typically lasted for only a minute or two before the group returned to discussing the task. This suggests that class-oriented and personal-oriented engagement could sustain one another productively and provide temporary breaks during a cognitively demanding activity. It is likely that such complex relationships between forms of engagement could perform a variety of functions depending on context, and so future research should investigate additional patterns in how these dimensions interact with one another.

Discussion and conclusions

The complex potential interactions between social engagement, metacognitive behaviors, and other aspects of engagement suggest that engaging students deeply with history learning requires a consideration of how activities are structured to support positive group interactions. The extent to which collaborative group members support one another's ideas and encourage sustained participation in the face of obstacles may have a significant influence on their synthesis of historical ideas. Additionally, a classroom environment that encourages voicing confusion and seeking help can support students in monitoring their own understanding and the collective understanding of peers. Much of the conceptual work that students were engaging with was not visible in discussions with their group members; instead, it was more apparent in their writing. Net.Create offered students an alternate pathway for making their cognitive engagement with history visible to each other through prompts to write about the significance of each object. Students could move from entering individual historical details into the network to making higher-level summaries of patterns in their group discussions, constructing both individual understandings of their objects and collective understandings of how these objects are conceptually related. The combination of positive social and cognitive engagement appeared to help groups sustain their engagement across long periods of independent group work, with group members periodically checking in with one another and bolstering group cohesion with light-hearted jokes. While such aspects of positive social engagement may appear tangential to learning at first glance, qualitative analysis of this focus group suggests that small moments of humor, supportiveness, and mutual respect can set the stage for later moments of deep conceptual engagement. This highlights that cohesive group functioning, which plays a central role in collaborative science learning contexts (Sinha et al., 2015; Isohätälä et al., 2018), may be of central importance for history learning, as well. Having built a supportive environment for collaboration, these students effectively constructed a collective understanding of historical and network analysis patterns and made those patterns visible for their community.

References

Bae, H., Craig, K., Danish, J., Hmelo-Silver, C. E., Uttamchandani, S., & Szostalo, M. (2019). Mediating collaboration in history with network analysis. In Lund, K., Niccolai, G. P., Lavoué, E., Gweon, C. H., & Baker, M. (Eds.), *A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 2*, International Society of the Learning Sciences, 949-950.

Blumenfeld, P. C., Soloway, E., Marx, R. W., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating project-based learning: Sustaining the doing, supporting the learning. *Educational Psychologist, 26*(3-4), 369-398.

Brush, T. & Saye, J. (2008). The effects of multimedia-supported problem-based inquiry on student engagement, empathy, and assumptions about history. *Interdisciplinary Journal of Problem-based Learning, 2*(1).

Calabrese Barton, A. & Tan, E. (2010). We Be Burnin'! Agency, Identity, and Science Learning. *Journal of the Learning Sciences, 19*(2), 187-229.

Carrington, P. J., Scott, J., and Wasserman, S. (Eds.). (2005). *Models and Methods in Social Network Analysis.* Cambridge University Press.

Craig, K. and Danish, J. (2018). Net.Create [Computer software]. Available from Netcreate.org [2018].

Craig, K., Humburg, M., Danish, J., Szostalo, M., Hmelo-Silver, C., & McCranie, A. (2020). Increasing Students' Social Engagement During COVID-19 with Net.Create: Collaborative Social Network Analysis to Map Historical Pandemics During a Pandemic. *Information and Learning Sciences, 121*(7/8), 533-547.

Durland, M. M., and Fredericks, K. A. (2005). An introduction to social network analysis. *New Directions for Evaluation, 105*, 5-13.
Endacott, J. & Brooks, S. (2013). An updated theoretical and practical model for promoting historical empathy. Social Studies Research and Practice, 8, 41-58.
Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School Engagement: Potential of the Concept, State of the Evidence. *Review of Educational Research, 74*(1), 59-109.
Fredricks, J. A. (2011). Engagement in school and out-of-school contexts: A multidimensional view of engagement. *Theory Into Practice, 50*, 327-335.
Freedman, E. B. (2020). When discussions sputter or take flight: Comparing productive disciplinary engagement in two history classes. Journal of the Learning Sciences, 29(3), 385-429.
Gould, R. V. (2003). Use of network tools in comparative historical research. In Amenta, E., Mahoney, J., & Rueschemeyer, D. (Eds.) *Comparative Historical Analysis in the Social Sciences.* Cambridge University Press.
Graham, S., Milligan, I., Weingart, S. (2016). *The Historian's Macroscope: Big Digital History.* Imperial College Press.
Greene, B. A. (2015). Measuring cognitive engagement with self-report scales: Reflections from over 20 years of research. *Educational Psychologist 50*(1), 14-30.
Gresalfi, M. (2009). Taking up opportunities to learn: Constructing dispositions in mathematics classrooms. *Journal of the Learning Sciences, 18*(3), 327-369.
Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn? *Educational Psychology Review, 16*, 235-266.
Isohätälä, J., Näykki, P., Järvelä, S. and Baker, M. J. (2018). Striking a balance: Socio-emotional processes during argumentation in collaborative learning interaction. *Learning, Culture and Social Interaction, 16*, 1-19.
Jordan, B. & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39-103.
Lévesque, S. (2008). *Thinking Historically: Educating Students for the Twenty-First Century.* Toronto, Canada: University of Toronto Press.
Martin, D., & Monte-Sano, C. (2008). Inquiry, Controversy and Ambiguous Texts. In Warren, W., & D. A. Cantù (Eds.), *History Education 101: The Past, Present, and Future of Teacher Preparation* (pp. 167-186). Charlotte, NC: Information Age Publishing.
Nokes, J. D. (2013). *Building Students' Historical Literacies: Learning to Read and Reason with Historical Texts and Evidence*. Routledge.
Nolen, S. B., Horn, I. S., & Ward, C. J. (2015). Situating motivation. *Educational Psychologist, 50*(3), 234-237.
Padgett, J. F. & Ansell, C. K. (1993). Robust Action and the Rise of the Medici, 1400-1434. *American Journal of Sociology, 98*(6), 1259-1319.
Sakr, M., Jewitt, C., & Price, S. (2016). Mobile Experiences of Historical Place: A Multimodal Analysis of Emotional Engagement. *Journal of the Learning Sciences, 25*(1), 51-92.
Savenije, G. M. & de Brujin, P. (2017). Historical empathy in a museum: Uniting contextualisation and emotional engagement, *International Journal of Heritage Studies, 23*(9), 832-845.
Shopkow, L. (2017). How Many Sources Do I Need? *The History Teacher, 50*(2), 169-200.
Sinatra, G. M., Heddy, B. C., & Lombardi, D. (2015). The Challenges of Defining and Measuring Student Engagement in Science. *Educational Psychologist, 50*(1), 1-13.
Sinha, S., Rogat, T. K., Adams-Wiggins, K. R., Hmelo-Silver, C. E. (2015). Collaborative group engagement in a computer-supported inquiry learning environment. *International Journal of Computer-Supported Collaborative Learning, 10*, 273-307.
Squire, K. & Barab, S. (2004). Replaying History: Engaging Urban Underserved Students in Learning World History Through Computer Simulation Games. In Kafai, Y. B., Sandoval, W. A., Enyedy, N., Nixon, A. S., & Herrera, F. (Eds.), International Conference of the Learning Sciences 2004: Embracing Diversity in the Learning Sciences (pp. 505-512). Santa Monica, CA: Lawrence Erlbaum Associates.
Wineburg, S. S. (1991). On the reading of historical texts: Notes on the breach between school and academy. American Educational Research Journal, 28(3), 495-519.
Wineburg, S. S., Smith, M., Breakstone, J. (2018). What is Learned in College History Classes? *Journal of American History, 104*(4), 983-93.

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"Making it Culturally Relevant": A Visual Learning Analytics System Supporting Teachers to Reflect on Classroom Equity

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Abstract: Experience is an important dimension of learning (Roth & Jornet, 2014). Research has drawn attention to the importance of equitable learning environments where all students experience opportunities to contribute to knowledge-building activities. Working in partnership with five middle school science teachers and two instructional coaches, we have developed a visual learning analytics system that aims to support teachers in reflecting on variability in students' classroom experiences linked to race and gender. This system, the Student Electronic Exit Ticket (SEET), captures and visualizes student experience data related to three constructs that prior research indicates are reflective of equitable classroom experiences: coherence, relevance, and contribution. We share findings from a qualitative study of how the SEET system visualizations supported teachers and coaches to recognize and respond to classroom inequities. Further, we discuss our design process with teachers and how this partnership influenced the visual feedback display.

Introduction

It is critical to make science meaningful to students from a wide variety of backgrounds, identities, languages, and cultures. Equitable practices in science classrooms are supported when we are able to make science culturally relevant to all students. Students can have inequitable learning experiences when teaching and subsequent actions are idealized in potential harmful ways based on learner attributes, such as geography, zip code, language, religion, gender, race, ethnicity, or socio-economic status (Brown, 2019). For instance, a student's way of speaking or their choice of clothes can deem them as not intelligent to the teacher, and these perspectives on ability can be rooted in biases around culture and race. This has been called the "Black Tax" in science classrooms, which refers to the "additional hurdle or cost faced by many students of color" (Brown). This black tax narrative is not only restricted to Black communities, instead it frames the narrative of many non-white populations who experience challenges (Brown, p.13).

In order to disrupt this narrative and create equitable learning environments, teachers need ways to more deeply recognize, understand, and engage with their students' experiences of the classroom. Attending to students' experiences involves integrating the practical, intellectual, and affective dimensions of classroom life (Roth & Jornet, 2014). Understanding students' experience in the classroom can help science teachers alter their instruction in ways that make it more culturally sustainable for a diverse student body, across gender and race (Paris & Alim, 2017). Penuel and Shepard (2016) note that helping teachers to understand the socio-cognitive dimensions of classroom experience (attending to the social nature of cognition) and the socio-cultural dimensions (attending to the value of participation in disciplinary ways of knowing and doing) of their students' experiences can support efforts to promote equity in classrooms.

Taking a student-centered approach and gathering reliable information about students' experiences in the classroom sheds light on the learning community and processes from students' perspective (Penuel & Watkins, 2019). Drawing on recent efforts to produce 'Equity Analytics' as a quantitative approach to view patterns of equity and inequity in classroom participation across gender and race (Reinholz & Shah, 2018), we have developed an innovative system of surveys and visualizations that captures and visualizes student experience data revolving around three constructs: coherence, relevance, and contribution. The Student Electronic Exit Ticket (SEET) system includes three major components: multiple versions of a student survey that can be administered anonymously in classrooms, a data management component, and a corresponding analytical system for teachers that visualizes these survey responses and disaggregates them by gender and race. In this study, we examine how different visualizations of student experience data during design process of the tool can support teachers to understand and reflect on the experiences of diverse students in their classrooms. We also report on how adopting a user-centered design process helped in selecting and adapting the user interface of the SEET system.

In our research, we worked closely with five middle school science teachers and two instructional coaches to design the visualizations and understand affordances offered by different representations for identifying patterns of equity and inequity of experience in science classrooms. Our ultimate goal is to develop analytic and instructional routines that help teachers to interpret these data and use them to reflect on their classroom instruction. The following research questions guided this paper: 1. How do different data visualizations create different opportunities for teacher's sense-making? 2. In what ways does visualizing students' experience data promote teachers' reflections on equitably supporting students' needs?

Conceptual framework

We argue that supporting equity involves understanding learners' experiences based on three constructs: coherence, relevance, and contribution (Reiser et al., 2017, NASEM, 2018, Miller et al., 2018). To this end, we have created an experience based formative assessment premised on these constructs called the Student Electronic Exit (SEET). SEET data provide targeted information about learners' experiences within a particular academic unit and classroom. Each construct comprises a unique set of questions. SEET questions related to coherence ask students whether they understand how current classroom activities contribute to the purpose of the larger investigations in which they are engaged. Coherent learning experiences appear connected from the students' perspective, where the progression of learning experiences is driven by student questions, ideas, and investigations (Reiser et al., 2017). Questions related to relevance ask students to consider the degree to which lessons matter to the students themselves, to the class, and to the larger community (Penuel et al., 2018; NASEM, 2018). For contribution, SEET questions ask students whether they shared their ideas in a group discussion, heard ideas shared by others, and whether others' ideas impacted their thinking. The aim of using the SEET assessment in the classroom is not to judge teachers or identify students' understanding of disciplinary content. Rather, the SEET assessment is intended to help create an environment for improving teacher instruction and diminishing classroom inequity.

Overview of the SEET system

The SEET system uses experience sampling to gather information about students' classroom experiences. Experience sampling is a technique for gathering data about how people feel and think during random intervals in their lives (Larson & Csikszentmihalyi, 2014). In our context, the teacher decides when to sample students' classroom experiences. The SEET system uses a thirteen-item survey to gather information from students on their perceptions of coherence, relevance, and contribution for that day's classroom experiences. This survey is designed to take only a few minutes for students to complete at the end of a class session. It is important to note that the SEET system does not collect names of students, provide individual-level feedback to teachers, nor does it display disaggregated data across gender and race if there are fewer than three students belonging to a particular gender or race to protect the anonymity of the students. Key steps in the workflow for teachers and students are: (1) The teacher administers a survey that asks students to reflect on today's classroom experiences, (2) Each student in the class receives the survey and reports on their experience, (3) Student responses from the entire class are combined and displayed to the teacher through a visual analytics dashboard based on the three focal constructs, (4) Teachers reflect on the student experiences' with visualizations

Data and study methods

We recruited five middle school science educators (two identified as female and three as male) and two science instructional coaches (one female and one male) from a large, urban school district in the Midwest to participate. The materials for this study included 30 different visualizations across three constructs. Round one included visualizations from a made-up dataset created by the first author that had significant differences in student experience across gender and race. For round two, we drafted visualizations using actual classroom data collected from a middle school science teacher's classroom in the same school district. This teacher was not a study participant.

In Round One, three science teachers (one female and two male) and two science instructional coaches (male and female) were asked individually and in pairs to reflect on selected visualizations from a pool of 14 different visualizations. Each session took 30-35 minutes. Teachers were shown a visualization and asked to think aloud as they tried to interpret its meaning and its implications for teaching. Think aloud protocols are a technique for understanding the cognitive processes of the participant when a stimulus is introduced during decision making (Ericcson & Simon, 1993). After each think-aloud, teachers completed a short interview about each visualization. During the interviews, we probed teachers about their thinking, asking them "What are you wondering about, assuming this is a real classroom? What is the need in your classroom that this visualization points to, if this were your classroom's data?". After seeing all the visualizations, we asked teachers to tell us which ones they believed to be most useful for helping them monitor their students' classroom experiences.

For Round Two, the same investigative process was followed with two science teachers (one female, one male) and the number of visualizations was increased to 30 (the 14 from Round One and 16 additional visualizations). New visualizations were created to address teacher feedback from Round One.

To gain deeper insights into how specific visualizations supported teachers' reflection processes, we analyzed our qualitative data with an inductive lens using a grounded theory approach to identify themes (Charmaz, 2014). The first author went through all the transcripts line by line to develop a preliminary code book. This preliminary codebook was developed into a mutually exhaustive and exclusive code book as shown in Table 1, after two authors met multiple times to reach consensus. The high-level codes included "Data reflection", "Interpretability and Recommendations". Within each high-level code there are multiple sub-codes. The two coders established high levels of interrater agreement calculated using Cohen's Kappa; κ= 0.88 for Data Reflections and κ= 0.89 for Interpretability and Recommendations.

Table 1: Coding teachers' responses to the data visualizations

High level Codes	Sub-codes	Examples
Data Reflection	• None: Teacher finds nothing • Find: teacher finds a particular data pattern. • Inquire: Teachers reflect on student experience data possible relationships between constructs and findings. • Instructional need or aim: Teacher thinks on what can be the next steps. • Pointing towards equity: Teacher talks about students from non-dominant groups and BIPOC, and/or when teacher talks about "equity" or "inequity" across gender or race.	• Find: "If you answered questions last, did you share any ideas out loud today. That is really striking to me." • Inquire: "I am curious about these don't know categories, what commonalities are there between those statements?" • Instructional need or aim: "So, I would think that's like something on me to make sure I'm tying it back to like our bigger picture." • Pointing towards equity: "Did anyone else share? 85% say others shared? To me, this kind of points to a sense of inequity."
Interpret-ability and recomme-ndations	• None: Teacher doesn't interpret and provide recommendations • Hard Identification: Hard to interpret the visualization • Easy Identification: Easy to interpret the visualization • Attraction or compelling point: Teacher reasoning about the compelling and attractiveness in visualization • Anytime Principle: Teacher has some anytime principle in mind on how to read visualization. Sense-making process tied up with the anytime principle. (Russel, Stefik, Pirolli, &, Card, 1993) • Design Suggestion: Teacher provide design suggestion for interpretation of the visualization • Construct Suggestion: Teacher provide suggestion related to constructs of the survey item SEET	• Hard Identification: I'm wondering about if I think the volume bubbles are kind of a neat idea for an easy glance piece. But I'm also maybe struggling to find how helpful they are. • Easy Identification: "One of the things just like overall style, I like looking at the colors, color gradation a lot better." • Attraction or compelling point: "It's a lot better, a lot easier to figure out what's being visualized. Than the size" or "I like this, I think the most because it gives me data per population" • Anytime Principle: "But it took like, my eyes kept fluttering back and forth, and back and forth, and back and forth. And then I was just jotting. We've got tables, bar graphs, what do I need to look at first? So finally, I just started looking at this table." • Design Suggestion: "I would like them portioned out per population. so, you could quickly see the smallest population or the largest percentage" • Construct Suggestion: "Knowing my students, that's the comfort area. If I don't understand that question, or I don't know it, I'm gonna choose."

Results and discussion

During round I, the first three teachers selected visualizations: Horizontal Stacked Bar Chart, Line Chart, as these supported them in the sense-making of data. Both coaches selected: Choropleth Heat map, Bubble chart, and Line chart, provided the most appropriate sense-making to them. From round II with two science teachers they selected visualizations: Horizontal Bar Chart, Choropleth Heat map, Line Chart. We finalized the 'Horizontal bar chart with '%yes' only', 'Choropleth Heat map with disaggregation of gender and race' and 'line chart' into the visual feedback displays of SEET shown below created from a made-up dataset.

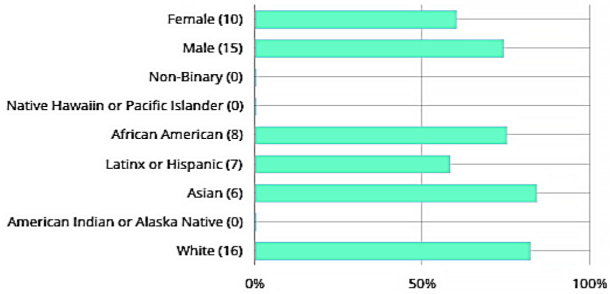

Figure 1: Bar Chart by Gender and Race

Figure 2: Choropleth Heatmap by Gender and Race

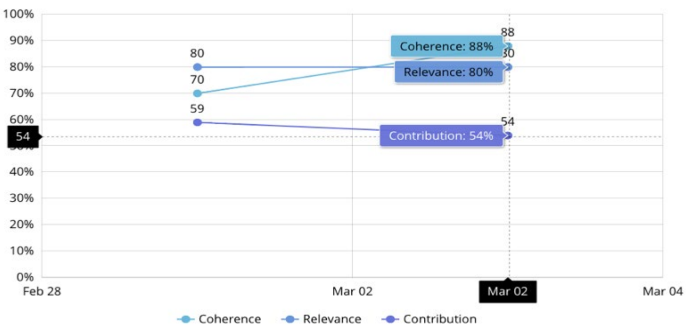

Figure 3: Over time by Coherence, Relevance, and Contribution

We found that the side-by-side bar charts facilitate easy comparisons, when they show a simple percentage of "yeses". We implemented small multiples of bar charts (figure 1), adjacent to each other as suggested in prior work by Heer, Bostock & Ogievetsky (2010). The choropleth heat map in figure 2 displays data disaggregated by gender and race, the first three rows at the top display different genders, and then there is intentional space to start with different race categories. These categories are based on the U.S. census. Each column at the top belongs to lesson or measures (coherence, relevance, and contribution) related questions. Color facilitates thinking about the dimensions of experience that are being measured. Although the color is less precise as compared to position based visual representations such as scatterplots, bar graphs, and line graphs, they provide a significant 'big picture' information to the users (Albers et al., 2014). The line chart in figure 3 is one type of implementation of its three variants: i) line chart visualized by correct average of SEET measures over time (see Figure 3) ii) line chart visualized by gender and race data over time for a single classroom period iii) line chart visualized by each question over time for a single classroom period. All these visualizations and variants are implemented in the SEET system.

Now we present data from teachers and instructional coaches for both rounds on how their interaction with different visualizations supported several reflections on equity and instruction prompted different reflections on student experience and how it helped in shaping the design of the user interface of the SEET system.

Data reflection

Analysis of our qualitative data suggests that these selected visualizations in figure 1, 2, 3 can be effective in supporting teachers to reflect on their students' classroom experiences. We now present a few cases where teachers expressed their perceptions related to student experience.

Mr. Alan (Science Teacher), all names are pseudonyms, when asked on what they see looking at data patterns in the horizontal disaggregated bar chart visualization (Figure 3), he responded:

> So, within the kind of the first boxes up here, there is a group of students who seem to be making more sense of the driving question and how it ties into less, and then other students. And it's looking like it's just the white students better following along better with the driving question board and how it ties into what they did in class and the unit, things like that. But then when we transition down to the other questions, matters to the people in the community and things like that. I'm not really seeing much there in terms of some overall takeaways, except for maybe the Black students. I don't know how many are in there, though. Like, is that 18%? That one kid or total of five? Okay, there? Yes, I see it now. Total five kids. Okay. So, one of those five kids found that it tied back to their community and things like that, but the four of the five basically didn't notice that. (Mr. Alan, round II)

Mr. Alan in his reflection on what is the instructional need based on this classroom, responded:

> The instructional need would probably be making this culturally relevant to all students in the classroom, making sure that all students do find a connection to it, whatever they're learning, because it's clear that all students aren't finding that connection from the lesson to what's important to them or their community, only some students are, and it's solely dependent on cultural background or ethnicity. (Mr. Alan, round II)

Mr. Alan showed concern about the Black students who didn't have the same percentage of "yeses" as the other students in the classroom. He tied the classroom experience to the classroom environment: saying it was not conducive to all the students from different backgrounds and cultures. In most parts of the interview Mr. Alan was concerned about the instructional connection to minoritized students such as Asian students and how to make it a more positive environment by making lessons coherent and equitable.

Similarly, when Mr. Meer and Mr. Tim (Science Teachers) are asked what they notice from the data visualization showing change over time, how they might use this data formatively for thinking or reflecting on things in classrooms, Meer responded:

> It's interesting that overall, we see it trending upwards. Like, obviously, I feel like that's each piece of the lesson building on itself, but super big drop off for lesson 3D for males and yeah, a big spike there for females so again, there had to be some kind of a gender disconnect when we get to lesson 3D. Yeah, lesson 3D obviously was off. So, it'd be a good starting point to look there. How can we make lesson 3D more equitable? I think it would definitely give me some empathy; especially like you said for here in coherence for females. (Meer, Round I)

While Mr. Meer pointing towards disaggregated bar chart question on coherence, he reflected:

> I would definitely drive my instruction to help to target this group, clearly. This was my classes with my data, I did not do my job enriching these female students. So, that would really cause me to go back and reflect and hopefully make some changes. This piece of data allows me to just directly ask them, what did you need that I didn't give you? (Mr. Meer, Round I)

Tim and Meer, both noticed the experience of the female students as not to the level of male students in the classroom. Meer was concerned about what he didn't do to make the classroom experience better for the female students and how he would inquire with students to make a better classroom connection across the parts of the unit to make an equitable environment for them. Mr. Tim and Mr. Meer both agreed that over time data can be helpful for them in identifying connections across the units and also disaggregated bar charts would help them target more specifically each classroom for coherence, relevance and contribution.

Mr. John and Ms. Becky (Instructional coaches), when asked about what's the instructional need based on the bubble chart representation, Mr. John pointed to inequity of experience related to the relevance for the students.

> Deeper piece and harder the relevance question six, there's an imbalance for who this seems to apply to. There's definitely a certain level of students who aren't feeling like this, this describes

> them. So that's like a larger piece. Like, which curriculum are we using? How do we want to make adaptations larger across our district. And then thinking about the training for those pieces. If we had the time to do professional learning. What implementations will we do? (Mr. John, Round I)

Mr. John's explanation pointed to the need for more relevant instruction for improving student experience on this construct. He indicated that few groups of students are not finding relevance with the lesson and how he can scaffold their experience with more relevant curricula that connects with their classroom experiences. He also wondered how professional learning and their implementations might help teachers for enhancing experience related to relevance. Listening to Mr. John's conversation, Ms. Becky, talked about the result of those interventions and how it can impact the classroom.

> Absolutely. And I think just techniques to incorporate some of these other pieces to help teachers make sure that all students are participating in, are able to connect to whatever it is that's going on. And also making it relevant too like, are we talking about an issue that the students can connect to that has a part of their normal life? (Ms. Becky, Round I)

Ms. Becky stressed on the importance of making sure that students contribute and make lessons relevant to their lives, and how instructional coaches can help teachers in facilitating these roles. Ms. Becky also narrated how student experience can be an opportunity for teachers to learn more and improve classroom environment while interacting with the Choropleth Heat map visualization.

> I think this is a really cool opportunity for teachers to gauge their classroom and their students. Like you can see there's a relatively high participation going on in the class verbally, but then there might be some understanding issues that are happening in kid's heads. So, the teachers. But I think this is a really informative opportunity for teachers to say, okay, we might need to work on this a bit more. Or how do I encourage my kids to speak up. I think it's informative for the teachers themselves. (Ms. Becky, Round I)

Ms. Becky pointed out how this representation is providing an opportunity for teachers to hear and know students' inner voices that can totally be different from their behavior in the classroom and be useful to teachers. As interviewer asked Ms. Becky and Mr. John on what instructional need this points to as your role as district leaders and instructional coaches, Becky responded:

> A lot of teaching strategies, you know, you could do a professional learning experience based on each one of these questions. And focus just on pulling that out for the teachers. Have you really included this method of instruction? Or this piece of instruction. (Ms. Beck, Round I)

Ms. Becky and Mr. John both directed on understanding student experience data with different representations as opportunities for teachers to connect with their students. And how they can use targeted strategies with the teachers to meet the instructional needs of diverse and multicultural students. They noted that the engagement level of students tied with the success of students.

In summary, teachers we worked with cared about student experience related to coherence, relevance and contribution as much as they do about the content knowledge. Teachers know experience to be an integral part of academic success for students. Visualizations that disaggregated data by gender and race help them identify issues of equity in all instances, at least this was the case in our study. We found that these visualizations supported teachers to inquire about the experience of students and consider implications for instruction. They showed care for the experience of racially minoritized students and the experience of girls, and they valued student experience data that made this visible. However, how teachers can make use of this experience data related to coherence, relevance and contribution to enrich classrooms and student lives remains an underexplored and rich phenomenon. Visual learning analytic tools can be leveraged for the sake of supporting teachers' engagement with students' experience in the service of creating equitable and just learning environments.

Interpretability and recommendations

Teachers' reflection on the interpretability of visualizations showed us where their interests lie and informs user-centered design of the SEET system. Below we discuss two examples of teacher noticing and suggestions that helped in developing the user interface of the system.

Example No 1: Horizontally categorizing bar chart by gender and Race

When the interviewer posted a data display containing disaggregated vertical and horizontal stacked bar charts to Ms. Yarosh (Science Teacher) to elicit her thinking and understanding would she prefer a horizontal or vertical bar chart, she responded:

> And I'm wondering if they're bars stacked on top of each other. So that takes quite a bit of thinking to unpack what's happening there? Um in question three. Well, I would say that these could all be bars but proportioned out between lesson three A. So, a bar that is proportionally representative of 20%, and then one that would show stacks on stacks on top of each other, not on top of each other like this but next to each other. So, you get that quick visual like, woah 63%. A quick visual for each lesson, right? So, I think either way, I would like them portioned out per population. So, you could quickly see the smallest population or the largest percentage. (Ms. Yarosh, Round I)

Ms. Yarosh initially expressed her thoughts that vertically stacked bars categorized by each lesson are hard for her to interpret the differences across race levels. She suggested that rather than stacking race categories on top of each other vertically on a bar, she would place them next to each other for a quick comparison across student populations to quickly compare. This conversation and suggestion of the teacher led to the design of a horizontal disaggregated bar chart based on categories for gender and race, see figure 1.

Example No 2: Showing only "yeses" or correct responses facilitates comparisons.

A constructive suggestion by Ms. Yarosh shaped the design of visualization, as students were answering multiple choice questions that had three response options ('Yes', 'I don't know', and 'No'). During the first round, we displayed all three responses, conjecturing that it would help teachers identify patterns across the response types (Figure 4(A)). The yellow color represents the percentage of the class who said 'Yeses', Cyan represents 'I don't know', and Blue represents 'No', to a survey question based on a particular construct. Contrary to our expectations, teachers preferred visualizing only the 'yes' responses.

> So, I guess for me, this neutral choice doesn't necessarily give me the information I'm seeking. I would prefer it matters or it doesn't. (Ms. Yarosh, Round I)

Analyses of additional qualitative data suggested that displaying only the "yes" responses helped teachers to compare patterns across the three constructs; many instances teachers also showed that approach helped spark discussions about the low percentage of "yeses" answers from the students, as they perceived it a simpler solution for cross comparison across questions. This also facilitated cross comparison between constructs; coherence, relevance and contribution by pointing teachers' attention only to one value. The resulting visualization based on teacher feedback was a horizontal bar chart displaying only the 'yes' percentage only (Figure 4(B)).

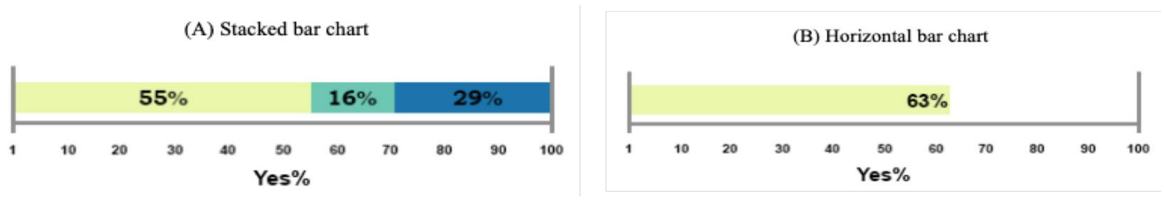

Figure 4: (A) Visualizing the student experience based on 'Yeses', 'I don't Know', 'No' (B) Visualizing 'Yeses' of the student experience

Discussion and conclusion

The main objective of this study was to provide insights from the design process of the Student Electronic Exit Ticket (SEET) system and teachers' thought process. We presented key teacher and instructional coaches' experiences that played a pivotal role in finalizing the visual feedback displays. A rich understanding of student experience should support teachers to modify their instructional or curricular agenda to better promote equity in the classroom. Along with the help of teacher partners, our team has designed and developed an exemplar application supporting 'Equity Analytics'. Shah and Reinholtz (2018) called for researchers to build tools and extend 'Equity Analytics' work with its applications to support equity across different disciplines. With the wide adoption of such tools, teachers can understand student experiences at scale to make classrooms equitable.

Our focus in this paper has been on analyzing how teachers perceive equity in the classroom when aided with visual learning analytics. We learned that it is imperative for researchers and system designers to have an open perspective when designing feedback dashboards and to deeply attend to teachers' perspectives and guidance in order to ultimately bring equity to the classroom in meaningful and relevant ways. The teachers' part of the study were from same school district and subject area (middle school science), a broader and more diverse group of teachers would be needed to further validate our findings.

Understanding student experiences can help teachers to shape classrooms to be more equitable by making them culturally relevant and sustainable (Paris & Alim, 2017; Brown, 2019), enabling all students to contribute and build on each other's knowledge. It is critical to quantify differences in students' classroom experiences in order to remove inequities based on characteristics such as gender and ethnicity. Ahn and colleagues (2019) discussed the value of using human-centered-design methods with teachers when designing instructor dashboards providing data on student learning. The aim of our design process was to apply such methods to explore how learning analytics tools can be adapted rather than adopted by teachers and to understand how the design process itself can foster new innovations in designing dashboards. Adapting these design methods influenced the design of the tool and helped with improvement efforts of supporting mathematics teachers. The dashboard helped to visualize patterns easily in data on experience for groups of individuals, such as individuals who are in the same classrooms in the context of their teacher-researcher partnership. Co-designing visual analytics with teachers can play an important role, providing help with interpretable data that enables them to make informed judgments about students' experiences and to modify their instructional practices accordingly. At the same time, preparing teachers to make sense of these data is not sufficient to promote equity, without consideration for systemic factors such as segregation, racism, and gender inequality in society--that help explain patterns of inequity in student experience data.

References

Albers, D., Correll, M., Gleicher, M., & Franconeri, S. (2014). Ensemble processing of color and shape: Beyond mean judgments. *Journal of Vision, 14*(10), 1056-1056.

Ahn, J., Campos, F., Hays, M., & DiGiacomo, D. (2019). Designing in context: reaching beyond usability in learning Analytics Dashboard Design. *Journal of Learning Analytics, 6*(2), 70-85.

Brown, B. A. (2019). *Science in the city: Culturally relevant STEM education.* Harvard Education Press.

Heer, J., Bostock, M., & Ogievetsky, V. (2010). A tour through the visualization zoo. *Communications of the ACM,* 53(6), 59-67.

Ericcson, K. A., & Simon, H. A. (1993). *Protocol analysis: Verbal reports as data* (revised ed.). MIT Press.

Larson, R., & Csikszentmihalyi, M. (2014). The experience sampling method. In M. Csikszentmihalyi (Ed.), *Flow and the foundations of positive psychology* (pp. 21-34). Springer, Dordrecht.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053-1075.

National Academies of Sciences, Engineering, and Medicine. (2018). *How people learn II: Learners, contexts, and cultures.* National Academies Press.

Paris, D., & Alim, H. S. (Eds.). (2017). *Culturally sustaining pedagogies: Teaching and learning for justice in a changing world.* Teachers College Press.

Penuel, W. R., & Shepard, L. A. (2016). Assessment and teaching. In D. H. Gitomer & C. A. Bell (Eds.), *Handbook of Research on Teaching* (pp. 787-851). AERA.

Penuel, W. R., & Watkins, D. A. (2019). Assessment to promote equity and epistemic justice: A use-case of a research-practice partnership in science education. *The ANNALS of the American Academy of Political and Social Science, 683*(1), 201-216.

Reinholz, D. L., & Shah, N. (2018). Equity analytics: A methodological approach for quantifying participation patterns in mathematics classroom discourse. *Journal for Research in Mathematics Education, 49*(2), 140-177.

Roth, W. M., & Jornet, A. (2014). Toward a theory of experience. *Science Education, 98* (1), 106-126.

Reiser, B. J., Novak, M., & McGill, T. A. (2017). Coherence from the students' perspective: Why the vision of the framework for K-12 science requires more than simply "combining" three dimensions of science learning. In Board on Science Education (Ed.), Instructional Materials for the Next Generation Science Standards. National Academies Press.

Russell, D. M., Stefik, M. J., Pirolli, P., & Card, S. K. (1993, May). The cost structure of sensemaking. In Proceedings of the *INTERACT'93 and CHI'93 conference on Human factors in computing systems* (pp. 269-276).

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Creative Transfer and Domain-Specific Knowledge: The Effect of Prior Exposure

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Abstract: The payoff of meaningful instruction is not just in the immediate retention of learned information, but also in transfer to novel situations in the future. This project focuses on what Haskell (2001) calls "creative transfer", the highest form of transfer of learning. 298 grade-five students from three elementary schools in Singapore took part in the study. This paper examines the extent to which the participants' *domain-specific knowledge* of the already-learned topics of *fraction multiplication* and *whole-number division* can predict their creative transfer to the untaught topic of *fraction division*. The data suggests that prior knowledge of whole-number division and fraction multiplication contributed significantly to creative transfer performance. Further analysis indicated that for participants who had less exposure to fraction division, their creative transfer was predicted by procedural flexibility for whole-number division, conceptual knowledge, and marginally by procedural knowledge for fraction multiplication. Implications for teaching and learning is discussed.

Keywords: creative transfer, domain-specific knowledge, whole-number division, fraction multiplication, fraction division

Introduction

Efficient learning involves the ability to acquire knowledge quickly while also being able to transfer the newly acquired knowledge beyond specific contexts and instances (Chang, Rosenberg-Lee, Qin, & Menon, 2019). Transfer occurs when prior knowledge is used to support new learning and problem solving (Sidney & Alibali, 2015). Creative transfer is regarded as the highest level of transfer in Haskell's (2001) taxonomy. It differs from other types of transfer as students need to expand, combine and adapt their knowledge in transfer to create novel concepts and procedures, rather than merely gaining the insight that something is similar to something else and applying knowledge across the two seemingly different contexts (Calais,2006).

In this paper, we study transfer by specifically looking at students creating new concepts or procedures from what they already know. As stated by Schoenfeld (1999), "we couldn't survive if we weren't able to adapt what we know to circumstances that differ, at least in some degree, from the circumstances in which we learned it" (p. 7). Calais (2006) provides an example, assuming a student has the prerequisite knowledge on the earth's uniform gravitational field. To explain what they feel when they stand in an elevator accelerating upwards, they need to create new concepts and procedures to explain the phenomena, for example, the concept and procedure related to the Principle of Equivalence for Einstein's Theory of General Relativity. The new concepts and procedures being created are built upon the student's existing knowledge, for example by expanding, integrating, and adapting existing knowledge in novel ways.

Transfer is important. The payoff of meaningful instruction is not just in immediate retention of the learned information, but also in transfer to novel situations in the future (Mayer, 1983). These situations may not be known to the present teachers and learners, so students need to be capable of dealing with creative transfer tasks that teachers do not (and could not) *directly* prepare them for.

Past studies (Carraher & Schliemann, 2002; Dunbar, 2001) suggest that even far transfer to isomorphic problems is hard to achieve (Duncker, 1945). Isomorphic problems (e.g., a pair of two-variable mathematics problems) embody similar relational structures and hence can be solved by transferring across a procedure or solution strategy. However, students often have difficulty recognizing the relational similarities between isomorphic problems. Bailin (1988) argues that even the most radically creative products, must be tied to the past (e.g., problems, representations, procedures, strategies, and concepts encountered before). Creative transfer is challenging because even if students can recognize the similarities and linkages between two problems, they still must combine and adapt their knowledge for transfer to take place. From a situated transfer (Engle,2006) perspective, transfer is promoted when a learner expansively frames the learning and transfer contexts.

Despite the challenges, transfer can take place spontaneously and effortlessly. In Forsyth's (2012) study, a physics undergraduate claimed that physics helped them understand many other subjects, such as the connection between basic principles in quantum mechanics and a pre-Socratic philosopher's concept of flow. Yet, Schoenfeld

(1999) notices that while we always adapt what we know to circumstances that differ, transfer is still "mysteriously absent from the psychological laboratory; it seems to vanish when experimenters try to pin it down" (p. 7).

A successful transfer requires identifying similarities between the source and target problems and an extension of knowledge to the target problem from a previously learned source problem (Gentner, Rattermann, & Forbus, 1993). Research indicates that both surface and structural similarities can influence transfer. Surface similarity is a similarity of features that do not influence goal attainment i.e. features that are not relevant to conceptual structure (Holyoak & Koh, 1987; Sidney & Alibali, 2017). Structural similarities are casual and conceptual relationships between the source and target problems (Holyoak & Koh, 1987; Sidney & Alibali, 2017). An example to represent this would be if we compare two scenes, one where a truck is towing a car and one where a car is towing a boat (Huang & Kapur, 2015). The structural similarity between the two scenes would be the towing of an object while the surface similarity would be the car (because both scenes used the same vehicle) (Huang & Kapur, 2015). Source and target problems that share a common structure will have a higher probability of transfer (Gentner et al., 1993). When the source and target problems have different surface features, it can be difficult for spontaneous transfer to occur (Day & Goldstone, 2012). Additionally, when source and target problems share surface similarities without structural similarities, negative transfer may occur (Chen & Daehler, 1989). One reason for these transfer challenges attributes to students' knowledge of the source problem, particularly when the structural features between the source and target problems have some variations (Dinsmore, Baggetta, Doyle, & Loughlin, 2013), as in the case of creative transfer.

This paper seeks to explore the relationship between domain-specific knowledge and creative transfer. Transfer literature states adaptive expertise provides the basis for transfer (Baroody, Feil, & Johnson, 2007; Schwartz, Bransford, & Sears, 2005). Adaptive expertise, often studied as procedural flexibility, is influenced by both conceptual and procedural knowledge (Baroody et al., 2007; Schneider, Rittle-Johnson, & Star, 2011).

Adaptive expertise is often studied in terms of procedural flexibility (Rittle-Johnson, Star, & Durkin, 2012) which refers to learners knowing multiple methods to solve a problem and being able to choose the best method for each problem (Rittle-Johnson et al. 2012, Schneider et al., 2011). Greater procedural flexibility is often associated with other forms of domain-specific knowledge such as conceptual and procedural knowledge. Conceptual knowledge increases the ability for flexibility and adaptability and provides a criterion to select for alternative possibilities for each step of a solution method (Hatano, 2003). Procedural knowledge provides a basis for procedural flexibility as it is the ability to solve problems (Schneider et al., 2011). Schneider and colleagues (2011) in their study related to the domain of equation solving noted that both conceptual knowledge and procedural knowledge contribute independently to procedural flexibility. While there is an understanding of the effect of these forms of domain-knowledge on procedural flexibility, creative transfer is more than just procedural flexibility. It involves not just flexibility in choosing methods but the creation of novel methods.

In the creativity literature, spontaneous transfer requires the creative generation of novel methods by expanding, combining, and adapting existing knowledge (Mumford, 2001). Domain expertise is found to influence these creative processes (Weisberg,1999). Typically, domain expertise refers to years of immersion in the field (Weisberg, 1999) or students' most recent grades in exams (Jeon, Moon, & French, 2011), like a mathematics exam result. The different types of domain-specific knowledge are not sufficiently differentiated nor measured in the existing creativity literature.

Considering these gaps in the literature, we work in the context of mathematics education to explore the effects of domain-specific knowledge on creative transfer. We operationalized domain-specific knowledge using measures of conceptual knowledge, procedural knowledge, and procedural flexibility. This study aims to understand the extent to which different types of domain-specific knowledge (i.e., conceptual knowledge, procedural knowledge, and procedural flexibility) on prerequisite curriculum topics, (i.e., whole-number division and fraction multiplication) predict students' performance in creative transfer (to fraction division).

Method

Research design and participants

A cross-sectional study was conducted with 298 fifth-grade students from three elementary schools in Singapore. The participants were previously taught the topics of whole-number division (in grade 3) and fraction multiplication (in grade 4). According to the participating schools' curriculum schedule, fraction division had not been introduced at the point of data collection.

Procedure, instruments, and reliabilities.

The participants' domain-specific knowledge on the topics of whole-number division and fraction multiplication and their creative transfer on the topic of fraction division were measured in the form of four pen-and-paper quizzes over three consecutive mornings (about 45 minutes each) in the participants' usual classroom setting.

The 9-item quiz for procedural knowledge was designed to measure the use of appropriate solution procedures for fraction multiplication and whole-number division questions. The overall reliability for this quiz is .92. The reliability of the subscales of whole-number division and fraction multiplication are .81 and .93, respectively.

Procedural flexibility was measured using a 5-item quiz administered on day 1. Marks were awarded for presenting multiple solution methods and the identification of the most efficient solution method, for fraction multiplication and whole-number division questions. The overall reliability for this quiz is .89. The reliability of the subscales of whole-number division and fraction multiplication are .84 and .87, respectively.

The measure for conceptual knowledge consisted of 6-item 'word problem' type questions. Answers had to be given through diagrams or written explanations, it was administered on day 2. The overall reliability is .65 and the reliability of the subscales on whole-number division and fraction multiplication are .39 and .64, respectively. Given the low reliability of the whole-number division subscale, only the overall measurement of conceptual knowledge was included in data analysis.

The creative transfer quiz was administered on day 3 and included 8-items, which focus on solving questions for fraction divide by a whole-number and fraction divide by a fraction. The reliability of the measurement is .77. A dichotomous question was included at the end of each item asking the participants how they came up with the answers. They could choose between the options of 'I have learned it before' and 'I invented it myself'.

The four quizzes were marked by two raters independently after some training. The inter-rater reliability of the four quizzes, in terms of Intra-class Correlation Coefficient (ICC), are 0.99, 0.99, 0.97, and 0.98, respectively.

Data analysis and findings

Pre-analysis

Initial descriptive analysis of the data was conducted to check the normality of the distribution of each measurement. The knowledge of whole-number division and fraction multiplication variables were created by summating all the items related to whole-number division and fraction multiplication across the first three quizzes. The descriptive statistics for the measurements and reliability (Cronbach's alpha) are presented in Tables 1 and 2.

Table 1: Descriptives for measurements and reliabilities of domain-specific knowledge and creative transfer

Quiz (Reliability)	*M*	*SD*	Maximum	Minimum	Full score
Procedural Knowledge (PK) (.92)	12.42	3.86	15	0	15
PK – whole-number division (.81)	1.49	0.80	2	0	2
PK - fraction multiplication (.93)	10.93	3.51	13	0	13
Procedural Flexibility (PF) (.89)	12.60	6.79	33	0	No upper bound
PF – whole-number division (.84)	2.93	2.69	11	0	No upper bound
PF - fraction multiplication (.87)	9.68	5.03	24	0	No upper bound
Conceptual Knowledge (CK) (.65)	3.19	2.54	13	0	26
Creative Transfer (CT) (.77)	4.80	4.65	21	0	22

Table 2. Descriptives for measurements and reliabilities of different prior-knowledge domains

Knowledge domain (Reliability)	*M*	*SD*	Maximum	Minimum
Knowledge of whole-number division (.92)	6.59	4.20	22	0
Knowledge of fraction multiplication (.89)	20.65	7.69	37	0

The scores for the procedural knowledge measure were positively skewed. This may be because Singapore students are generally strong at procedural knowledge. Furthermore, our concern was on whether the participants could use the procedures accurately, so the marking of procedural knowledge was based on method marking (i.e., whether appropriate procedures were used). Errors in arithmetic calculations were not penalized. The scores for the conceptual knowledge measure had a negative skew. Since the participants had not been formally taught fraction division at the point of data collection, students generally did not do very well in the creative transfer tasks. Given the violation of normality in the data, robust variants of statistical tests were used for analysis.

Students' prior exposure to fraction division

For the creative transfer task (i.e., fraction division), we noticed that the participants used a variety of solution methods, including the invert-and-multiply method which is the most common method taught to solve fraction division. This informed us to consider the participant's level of prior exposure to fraction division, despite the topic not having been introduced in the students' school curriculum at the time of data collection.

Participants were asked to answer the dichotomous question 'How did you come with this explanation?' at the end of all 8-items of the creative transfer instrument. Based on participants' responses to the dichotomous question: (i.e., 'I have learned it before' or 'I invented it myself'), we were able to divide the participants into three different groups based on their level of prior exposure to fraction division. For the *more-exposure* group (N = 70, M = 6.41), the participants responded in all the dichotomous questions that they had learnt the solutions before. For the *no-exposure* group (N = 14, M = 2.57), the participants responded in all the dichotomous questions that they invented the solutions by themselves. For the *less-exposure* group (N = 209, M = 4.53), the participants' responses were mixed (i.e., some solutions were learnt, and some solutions were invented).

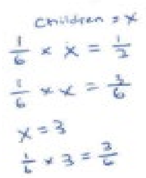
We analysed the difference between the groups using a robust variant of one-way independent ANOVA and a bootstrap post-hoc test (using the WRS2 library on R; Mair & Wilcox, 2020). The results indicated that there is an overall significant difference between groups (F_t = 7.94, p < .01, ξ =.45) The post-hoc test states that there was a significant difference between the *more-exposure* group and the *no-exposure* group (Mean difference = 5.45, 95% CI [0.92, 7.51], p < .01). There was also a significant difference between the *more-exposure* group and the *less-exposure* group (Mean difference = 2.78, 95% CI [0.54,4.51], p < .01). There was no significant difference between the *no-exposure* and *less-exposure* groups.

Methods used for creative transfer

We categorized the solution methods used by participants for creative transfer. Overall, we identified five categories of solution methods: invert-and-multiply, working backwards (see Figure 1), equivalent fractions (see Figure 2), study smaller and miscellaneous methods.

For the 'working backwards' method participants solve the fraction division problem by treating it as a reverse of fraction multiplication. For the 'equivalent fraction' and 'study smaller' methods the fraction (in the question) is converted to an equivalent fraction so that the numerator of the dividend is divisible by the given divisor. The 'study smaller units' method uses diagrams to solve the equation while the 'equivalent fraction' method uses mathematical notation. The 'invert-and-multiply' method is the standard method that is typically taught in schools and miscellaneous methods were methods that could not be classified into any of the given categories.

Examples of the 'equivalent fraction' and 'working backwards' methods are given below:



Original

$$\text{ch}\,ildren = x$$
$$\frac{1}{6} \times x$$
$$\frac{1}{6} \times x = \frac{3}{6}$$
$$x = 3$$
$$\frac{1}{6} \times 3 = \frac{3}{6}$$

Reproduced

Figure 1. 'Working backwards' original and reproduced response

Original

$$\frac{1}{3} \div 4$$
$$= \frac{1 \times 4}{3 \times 4} \div \frac{4}{1}$$
$$= \frac{1}{12}$$

Reproduced

Figure 2. 'Equivalent fractions' original and reproduced response

Since the invert-and-multiply method dominates formally taught procedure of fraction division (Slattery & Fitzmaurice, 2014), it is a good indicator of students' prior exposure to fraction division. Analysis indicates that the percentage of individuals who used the invert-and-multiply method *correctly at least once* was 60% for the *more-exposure* group and 37% for the *less-exposure* group. It should be noted that despite prior exposure, the participants' performance in creative transfer is rather low (i.e., out of a full score of 22, the means for the *more-exposure*, *less-exposure,* and *no-exposure* groups were 6.41, 4.53, and 2.57 respectively). It suggests that the participants' exposure to fraction division and the formal method of invert-and-multiply was very limited.

The extent to which prior knowledge influences creative transfer

Boostrap regression analysis (Using SPSS) was conducted to investigate the effect of prior knowledge on creative transfer. Overall, prior knowledge in whole-number division and fraction multiplication were significant for creative transfer. The prior knowledge accounted for 29% (R^2 = .29, adjusted R^2 = .28) of the overall variability. Whole number-division (β = 0.39, p < .01) and fraction multiplication (β = 0.22, p < .01) were significant in predicting creative transfer, the unique attribution (sr^2) for these variables was 11.3% and 3.5% respectively.

Analysis was conducted to understand the extent to which prerequisite knowledge predicts creative transfer for the *more-exposure* and *low-exposure* groups. We decided to omit the *no-exposure* group from further analysis due to low sample size (N = 14).

The overall regression model for both the *more-exposure* and *less-exposure* group was significant in predicting creative transfer, they accounted for a significant 22% (R^2 = .22, adjusted R^2 = .19) and 31% (R^2 = .31, adjusted R^2 = .31) of the variability respectively. The *more-exposure* group had an effect size of medium to large (f^2=.28) and the *less-exposure* group had a large effect size (f^2=.46).

For the *more-exposure* group knowledge of whole-number division (β = 0.30, p = .02) significantly predicted creative transfer, the unique attribution of (sr^2) of this variable is 6%. For the *less-exposure* group the knowledge of both fraction multiplication (β = 0.21, p < .01) and whole-number division (β = 0.43 p < .01) significant predicted creative transfer scores, the unique attribution of (sr^2) of these variables is 3.3% and 14% respectively. The results are summarised in the table below:

Table 3: Summary of multiple regression analysis for prerequisite knowledge predicting creative transfer

Level of exposure		*B*	*β*	*Sig.*	95% Confidence Interval	
					Lower	Upper
More-exposure	Knowledge of whole-number division	0.32	0.30	.01	0.06	0.59
	Knowledge of fraction multiplication	0.17	0.24	.09	-0.03	0.37
Less-exposure	Knowledge of whole-number division	0.46	0.43	.00	0.29	0.61
	Knowledge of fraction multiplication	0.12	0.21	.00	0.05	0.19

The extent to which types of domain-specific knowledge predicts creative transfer

Bootstrap regression analysis (Using SPSS) was conducted to understand how different types of domain-specific knowledge predict the participants' performance in creative transfer. The results are summarised in Table 4.

For the *more-exposure* group, all the specific types of the domain-knowledge (procedural knowledge, procedural flexibility, and conceptual knowledge) were non-significant predictors.

For the *less-exposure* group the overall model accounted for a significant 32% (R^2 = .32, adjusted R^2 = .30) of the variability in creative transfer performance (F(3,92) = 14.60, p < .01), with an effect size of f^2 = .47 which is considered a large effect size. Procedural flexibility for whole-number division (β = 0.19, p < .04) and conceptual knowledge (β = 0.31, p < .01) significantly predicted creative transfer. The unique attribution (sr^2) of these variables is 2% and 8% respectively. Procedural knowledge for fraction multiplication was marginally significant (β = 0.12, p = .05).

Table 4: Summary of regression analysis for different types of domain knowledge predicting creative transfer

Level of Exposure		*B*	*β*	*Sig.*	95% Confidence Interval	
					Lower	Upper
More-exposure	Procedural Knowledge (whole-number division)	0.08	0.01	.93	-1.67	1.88
	Procedural Knowledge (fraction multiplication)	0.17	0.10	.46	-0.40	0.59
	Procedural Flexibility (fraction multiplication)	0.14	0.14	.37	-0.24	0.52
	Procedural Flexibility (whole-number division)	0.38	0.22	.12	-0.09	0.88
	Conceptual Knowledge	0.35	0.19	.10	-0.04	0.92
Less-exposure	Procedural Knowledge (whole-number division)	0.49	0.09	.22	-0.27	1.29
	Procedural Knowledge (fraction multiplication)	0.15	0.12	.05	-0.01	0.29

	Procedural Flexibility (fraction multiplication)	0.08	0.09	.32	-0.07	0.25
	Procedural Flexibility (whole-number division)	0.33	0.19	.04	0.04	0.63
	Conceptual Knowledge	0.55	0.31	.00	0.31	0.78

Discussion

The main aim of this study was to understand the effect of domain-specific knowledge on creative transfer. This aim was operationalized by measuring domain-specific knowledge – specifically procedural knowledge, procedural flexibility, and conceptual knowledge- on the prior knowledge of whole-number division and fraction multiplication and creative transfer to fraction division. While fraction division had not been introduced by schools, the participants might have gained some prior exposure through external and informal sources such as tuition. Based on prior exposure to fraction division, the participants were divided into *more-exposure*, *less-exposure,* and *no-exposure* groups.

While the *more-exposure* group's performance in fraction division might largely be due to their prior exposure, we propose that the *less-exposure* group's performance was mainly due to their creative transfer effort. Firstly, on average, the *less-exposure* group only scored 4.53 (out of 22), suggesting that their knowledge of fraction division is far from satisfactory. Furthermore, about two-thirds of the participants in this group could not correctly use the invert-and-multiply procedure, even once.

Secondly, we know that the formal teaching of fraction division often focuses on rote memorization of the invert-and-multiply procedure without developing a clear understanding of the concepts (Sharp & Adams, 2002). If the *less-exposure* group worked on the fraction division questions mainly based on what they learnt about fraction division, they would not need to draw on their prior knowledge (e.g., procedural flexibility for whole-number division). However, this was not the case in the regression model of the *less-exposure* group, which shows that procedural flexibility for whole-number division and conceptual knowledge significantly predicted their performance in fraction division, while procedural knowledge for fraction multiplication was marginally significant. In contrast, the regression model for the *more-exposure* group reveals that none of the specific types of prior domain-specific knowledge predicted the *more-exposure* group's performance in fraction division. This implies that when students have a better mastery of fraction division through formal teaching with rote memorization, they could rely on their memorized invert-and-multiply procedure rather than draw on specific prior domain-specific knowledge (such as conceptual knowledge on whole-number division and fraction multiplication).

Our findings affirm the literature for the transfer from whole-number division to fraction division. A study by Sidney & Alibali (2015) finds that being exposed to whole-number division right before learning the invert-and-multiply procedure for fraction division, leads to higher conceptual understanding of fraction division. Our findings reveal that for the *more-exposure* group, their knowledge on whole-number division predicted their performance in fraction division, even though no specific type of knowledge (e.g., procedural flexibility) on whole-number division was significant. The findings highlight that students who had better knowledge of whole-number division would learn fraction division better (in their prior exposure to fraction division). Our findings on the *less-exposure* group further highlight that when students do not have strong prior exposure to fraction division, their procedural flexibility of whole-number division is particularly useful for transfer in inventing novel solutions to fraction division problems. From a situated perspective of transfer, it is integral to frame specific knowledge concepts as part of larger concepts (Engle, 2006). This encourages students to apply what they have learned to intuitively create new concepts (Engle, 2006). Students may have been exposed to the idea that mathematical concepts are linked and used that knowledge to apply their existing knowledge to fraction division.

We also underscore the importance of procedural knowledge on fraction multiplication in the transfer to fraction division. The literature regards the transfer from whole-number division to fraction division as an analogical one and argues that the similarity between fraction multiplication and fraction division is merely at the surface level (Sidney & Alibali, 2017). In our study, the procedures created by the participants (see Figures 1 and 2) reveal the integration of fraction multiplication operations into the novel methods. In Figure 1, students used fraction multiplication for equivalent fraction (i.e., $\frac{a}{b} = \frac{a\times c}{b\times c}$), and in Figure 2, students transferred the fraction multiplication operation (i.e., $\frac{a}{b} \times \frac{c}{d} = \frac{a\times c}{b\times d}$) to fraction division ($\frac{a}{b} \div \frac{c}{d} = \frac{a\div c}{b\div d}$). We argue that in both figures, particularly in Figure 2, the procedure of fraction multiplication is not merely a surface feature, but an important structural feature (in addition to whole-number division) to be mapped and transferred with adaptation (e.g., adapting from multiplication to division) to solve fraction division problems. Inferring from the regression model for the *low-exposure* group, successful adaptation requires good conceptual knowledge on whole-number division and fraction multiplication.

While the literature tends to conceive the transfer from whole-number division to fraction division as analogical transfer (Sidney & Alibali, 2017), we recognize the structural relevance of fraction multiplication for transfer to fraction division. Transferring of whole-number division knowledge is necessary but not sufficient for creating novel procedures to solve fraction division problems. The transfer, integration, and adaptation of fraction multiplication operations (as opposed to other fraction operations, such as fraction subtraction) is also critical. Hence, we propose that using creative procedures to solve fraction division problems involves creative transfer, which requires creatively integrating whole-number division procedures with fraction multiplication procedures and adapting them to create novel methods (as shown in Figures 1 and 2).

A major limitation for this study is the lower reliability of the measurement of conceptual knowledge compared to other instruments (Cronbach's α =.65). In the literature, the measurement reliability of conceptual knowledge always suffers from the absence of a proven reliable instrument (Rittle-Johnson & Schneider, 2014). Future studies may need to consider refining the instrument. Additionally, there was a low sample size for the *no-exposure* group, which led to its exclusion from analysis. For future studies, a pre-assessment of prior exposure to the transfer domain may be beneficial to ensure balanced group size.

This study has implications for the teaching of domain-specific knowledge in preparing for creative transfer. First, it is noted that fraction division is not in the Grade-5 curriculum and most likely, the participants gained their exposure through tuition, which primarily favors rote memorization of the invert-and-multiply procedure (Sharp & Adams, 2002). As shown in the regression model for the *more-exposure* group, rote memorization would discourage making use of prior knowledge and tends to create knowledge in silos. In comparison, when students with less exposure to fraction division are given a chance to create their own novel procedures, better connections of knowledge would be developed in the process of creative transfer. Hence, in practice, whether in schools or tuition, giving students a chance for creative transfer would allow them to benefit from their inherent creativity, and would improve their ability to cohere their knowledge. Second, there is increasing advocacy for the development of students' conceptual knowledge and procedural flexibility (Heinze, Star, & Verschaffel, 2009) in the literature; our findings support this sentiment. We advocate for more focus on developing students' conceptual knowledge and procedural flexibility, which would not only benefit their learning of the current curriculum topic but will also prepare them better for creative transfer in the future.

References

Bailin, S. (1988). *Achieving extraordinary ends: An essay on creativity*. Springer Netherlands.

Baroody, A. J., Feil, Y., & Johnson, A. R. (2007). An alternative reconceptualization of procedural and conceptual knowledge. *Journal for Research in Mathematics* Education, *38*(2), 115-131. https://www.jstor.org/stable/30034952

Calais, G. J. (2006). Haskell's taxonomies of transfer of learning: Implications for classroom instruction. *National Forum of Applied Educational Research Journal*, *20*, 1-8.

Carraher, D., & Schliemann, A. D. (2002). The transfer dilemma. *Journal of the Learning Sciences*, *11*(1), 1-24. https://doi.org/10.1207/S15327809JLS1101_1

Chang, H., Rosenberg-Lee, M., Qin, S., & Menon, V. (2019). Faster learners transfer their knowledge better: Behavioral, mnemonic, and neural mechanisms of individual differences in children's learning. *Developmental Cognitive Neuroscience*, *40*, 100719. https://doi.org/10.1016/j.dcn.2019.100719

Chen, Z., & Daehler, M. W. (1989). Positive and negative transfer in analogical problem solving by 6-year-old children. *Cognitive Development*, *4*(4), 327-344. https://doi.org/10.1016/s0885-2014(89)90031-2

Day, S. B., & Goldstone, R. L. (2012). The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist*, *47*(3), 153-176. https://doi.org/10.1080/00461520.2012.-696438

Dinsmore, D. L., Baggetta, P., Doyle, S., & Loughlin, S. M. (2013). The role of initial learning, problem features, prior knowledge, and pattern recognition on transfer success. *The Journal of Experimental Education*, *82*(1), 121-141. https://doi.org/10.1080/00220973.2013.835299

Dunbar, K. (2001). The analogical paradox: Why analogy is so easy in naturalistic settings yet so difficult in the psychological laboratory. In D. Gentner, K. J. Holyoak, & B. Kokinov (Eds.), *The analogical mind: Perspectives from cognitive science*(pp.313-334). MIT Press. https://doi.org/10.7551/mitpress/1251.001.0001

Duncker, K. (1945). On problem solving. *Psychological Monographs*, *58*(5), i-113. https://doi.org/10.1037/-h0093599

Engle, R. A. (2006). Framing interactions to foster generative learning: A Situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences*, *15*(4), 451-498. https://doi.org/-10.1207/s15327809jls1504_2

Forsyth, B. R. (2012). Beyond physics: a case for far transfer. *Instructional Science*, 40, 515-535. https://doi.org/10.1007/s11251-011-9188-z
Gentner, D., Rattermann, M. J., & Forbus, K. D. (1993). The roles of similarity in transfer: Separating retrievability from inferential sources. *Cognitive Psychology*, *25*,524-575. https://doi.org/10.1006/cogp.1993.1013
Haskell, R. E. (2001). *Transfer of learning: Cognition, instruction, and reasoning*. Academic Press. https://doi.org/10.1016/B978-0-12-330595-4.X5000-8
Hatano, G. (2003). Forward. In A. J. Baroody & A. Dowker (Eds.), *The development of arithmetic concepts and skills: Constructing adaptive expertise* (1st ed., pp. xi - xiii). Lawrence Erlbaum Associates Publishers.
Heinze, A., Star, J. R., & Verschaffel, L. (2009). Flexible and adaptive use of strategies and representations in mathematics education. *ZDM Mathematics Education*, *41*(5), 535-540. https://doi.org/10.1007/s11858-009-0214-4
Holyoak, K. J., & Koh, K. (1987). Surface and structural similarity in analogical transfer. *Memory & Cognition*, *15*(4), 332-340. https://doi.org/10.3758/BF03197035
Huang, J. S., & Kapur, M. (2015). Can "less" create "more" in analogical reasoning? *Learning: Research and Practice*, *1*(2), 133-151. https://doi.org/10.1080/23735082.2015.1071232
Jeon, K.-N., Moon, S. M., & French, B. (2011). Differential effects of divergent thinking, domain knowledge, and interest on creative performance in art and math. *Creativity Research Journal*, *23*(1), 60-71. https://doi.org/10.1080/10400419.2011.545750
Mair, P., & Wilcox, R. (2020). Robust statistical methods in R using the WRS2 package. *Behavior Research Methods*, *52*(2), 464-488. https://doi.org/10.3758/s13428-019-01246-w
Mayer, R. E. (1983). What have we learned about increasing the meaningfulness of science prose?. *Science Education*, *67*(2), 223-237. https://doi.org/10.1002/sce.3730670210
Mumford, M. D. (2001). Something old, something new: Revisiting Guilford's conception of creative problem solving. *Creativity Research Journal*, *13*(3-4), 267-276. https://doi.org/10.1207/S15326934CRJ1334_04
Novick, L. R. (1988). Analogical transfer, problem similarity, and expertise. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *14*(3), 510-520. https://doi.org/10.1037//0278-7393.14.3.510
Rittle-Johnson, B., Star, J. R., & Durkin, K. (2012). Developing procedural flexibility: Are novices prepared to learn from comparing procedures?. *British Journal of Educational Psychology*, *82*(3), 436-455.https://doi.org/10.1111/j.2044-8279.2011.02037.x
Schneider, M., Rittle-Johnson, B., & Star, J. R. (2011). Relations among conceptual knowledge, procedural knowledge, and procedural flexibility in two samples differing in prior knowledge. *Developmental Psychology*, *47*(6), 1525-1538. https://doi.org/10.1037/a0024997
Schoenfeld, A. H. (1999). Looking toward the 21st century: Challenges of educational theory and practice. *Educational Researcher*, *28*(7), 4-14. https://doi.org/10.3102/0013189X028007004
Schwartz, D. L., Bransford, J. D., & Sears, D. (2005). Efficiency and innovation in transfer. In J. P. Mestre (Ed.), *Transfer of learning from a modern multidisciplinary perspective* (pp. 1-51). Information Age Publishing.
Sharp, J., & Adams, B. (2002). Children's constructions of knowledge for fraction division after solving realistic problems. *The Journal of Educational Research*, *95*(6), 333-347. https://www.jstor.org/stable/27542399
Sidney, P. G., & Alibali, M. W. (2015). Making connections in math: Activating a prior knowledge analogue matters for learning. *Journal of Cognition and Development*, *16*(1), 160-185. https://doi.org/10.1080/15248372.2013.792091
Sidney, P. G., & Alibali, M. W. (2017). Creating a context for learning: Activating children's whole number knowledge prepares them to understand fraction division. *Journal of Numerical Cognition*, *3*(1), 31-57. https://doi.org/10.5964/jnc.v3i1.71
Slattery, J., & Fitzmaurice, O. (2014). 'Ours is not to reason why, just invert and multiply': An insight into Irish prospective secondary teachers' conceptual understanding of the division of fractions. *Irish Educational Studies*, *33*(4), 467-488. https://doi.org/10.1080/03323315.2014.982346
Weisberg, R. W. (1999). Creativity and knowledge: A challenge to theories. In R. J. Sternberg (Ed.), *Handbook of creativity* (pp. 226-250). Cambridge University Press. https://doi.org/10.017/CBO9780511807916.014

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Empowering Students to be Data Literate: The Design and Implementation of a Learning Environment to Foster Critical Data Literacy

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Abstract: Business giants collect and analyze personal data on a massive scale, including those of children's, to predict behavior and inform algorithmic decision-making. Such efforts reflect a form of "biopower", allowing control over other people, whose data are exploited. To safeguard children's data rights, scholars call for the need to empower children through critical data education. In our work we seek to understand how children can be empowered to reflect on the use of their own self-tracking devices and gain a deeper understanding of the political economy. This paper describes the design-based research process of designing an educational intervention that employed the use of activity trackers by elementary school students. This effort helped us peel back the layers of children's understanding of their own digital traces and supported their engagement in critical discussions. The paper concludes with lessons learned from the implementations on developing learning materials to foster critical data literacy.

Keywords: critical data literacy, personal digital data, design-based research, data privacy, self-tracking

Introduction

In an age when almost all dimensions of our lives are constantly digitized and datafied, concerns have been raised about the detailed personal information that is continuously generated through ubiquitous technologies. The term "datafication" is often used in the literature to describe how people's daily activities, practices and sensitive personal data are turned into digital information (Van Dijck, 2014). "Dataveillance" as a result of constant datafication, is the tracking and use of data for the purposes of monitoring people's activity (Van Dijck, 2014), and often happens through opaque algorithmic techniques. Such techniques collect and store people's personal information in large datasets, giving rise to Big Data accessed and exploited by third parties. Lupton (2020) explains two uses of personal data by third parties: (a) Collection and use of personal data to improve or market products or sell them to other companies for other types of exploitation, and (b) User profiling to inform the process of algorithmic decision-making with the support of artificial intelligence and deep learning models.

Scholars argue that this algorithmic decision-making has started to "unbalance" civil society, since it is used to sort and categorize individuals based on their data profiles (Pangrazio & Selwyn, 2020). Such categorization may have negative impact on individuals, including children, and may be unjustly used to exclude citizens from future opportunities. This data profiling and algorithmic decision-making is characterized in the literature as a form of soft "biopower" which affects individuals through a series of dividing practices manifested within relations of power by governments, business giants and other authorities (Lupton 2020; Pangrazio & Selwyn, 2020). Foucault discussed the issue of biopower long before the digital age as a means to control people through their personal information. Nowadays, these control practices can lead to the stratification and categorization of citizens based on data profiling (Pangrazio & Selwyn, 2020) because individuals lack the necessary knowledge and skills to identify where, how and why their personal data are being collected, stored, monetized and manipulated by others (Livingstone, Stoilova & Nandagiri, 2019; Pangrazio & Selwyn, 2020). This form of biopower affects children in a significant manner. As children and youth are constantly connected to digital devices, they become producers of a vast amount of personal data. Collecting, processing and assessing information on appearance, growth, development, health, social interactions, moods, behaviors, educational achievements and other features, without the consent of the children and, on several occasions, of their guardians, undermines their rights (Lupton & Williamson, 2017) and jeopardizes their future.

Scholars suggest that researchers and educational designers should focus on how to empower students and youth through critical data education and the development of critical data literacies (Pangrazio & Selwyn, 2020; Stornaiuolo, 2020). Children and youth's education about critical data literacy is necessary for developing the data skills to navigate in a datafied culture and see themselves as people with data rights (Stornaiuolo, 2020). Nonetheless, the kind of pedagogical support needed to empower students for recognizing, understanding and acting on their data practices should be further explored (Stornaiuolo, 2020). This study continues work reported by Agesilaou and Kyza (2021) on upper elementary school students' awareness of digital personal data, feelings of ownership of digital data and their understanding of privacy risks; informed by this work, this paper reports on how these findings informed the iterative design of a scaffolded inquiry environment designed to engage students in critically discussing about personal digital data in a formal educational setting.

Literature review

Empowerment through critical data literacy

Philip, Schuler-Brown and Way (2013) highlight the importance of "empowering students with knowledge" (p.106), to help students understand the role of their personal data contributions to the big data industry and exert control over the commercial exploitation of their data by third parties. Livingstone, Stoilova and Nandagiri (2020) discuss the difficulty of empowering children via personal data literacy because of the complexities involved in data protection and privacy regulations. They argue that learning how to navigate the contemporary digital landscape in terms of privacy is necessary but not sufficient to protect and empower children (Livingstone, Stoilova & Nandagiri, 2020). What is needed for children to ensure their data rights in a datafied society is a deeper critical understanding of the digital environment behind the digital interface, including the social relations and interactions that are embedded within it and which drive the emergence of the current business models (Livingstone, Stoilova & Nandagiri, 2020).

The idea of helping students acquire informed understanding of the massive dataveillance of everyday activities and be able to act based on this understanding has its roots in Paulo Freire, who talked about deliberate education in which teachers are not the authority, and students have the opportunity to question their reality and assume an active role in changing their society (Freire, 1970). This pedagogy supports students' opportunity to make decisions and act as agents of change in a datafied society, through the adoption of protective and resilient behavior towards the exploitation of their digital traces. It is of paramount importance to explore the extent to which students understand their personal data practices and the implications these have in the big data era. Such understanding will inform current efforts on how to better guide children through education for consciously being involved in practices that lead to the generation of personal and sensitive digital data. Such approaches have been reported as missing from contemporary education (Pangrazio & Sefton-Green, 2020).

Pangrazio and Sefton-Green (2020) discuss how data literacy approaches reported in the literature have been implemented in educational settings. They first note that research on data literacy pedagogy is limited. A conclusion derived from their study is that current data literacy efforts are unable to capture the range of skills and dispositions needed to tackle datafication and that the term needs more theorization to address a more critical and practical approach (Pangrazio & Sefton-Green, 2020). Pangrazio and Selwyn (2020) suggest that a critical data education should reflect the following objectives: (1) "Developing understanding of datafication processes, especially around what becomes a 'data object', how it is processed and used; (2) Critically reflecting on the importance of metrics in social media use, and the significance of numerisation in society; (3) Developing awareness and understanding of the political economy of digital platforms, including the capacity to track, profile and predict; (4) Identifying how digital platforms (including the interface and design) position users and shape their participation; (5) Identifying and using a range of strategies and tactics to protect their personal data; and (6) Gaining a sense of the longer-term implications of personal data practices" (Pangrazio & Selwyn, 2020, p.6).

Children's awareness of data privacy and third-party exploitation

Children are immersed in a variety of social networking activities that entail the disclosure of personal information. According to Livingstone, Stoilova and Nandagiri (2019) the full complexity of children's privacy online can be captured by three main types of relationships: between an individual and (i) other individuals or groups ('interpersonal privacy'); (ii) a public or third sector (not-for-profit) organization ('institutional privacy'); or (iii) a commercial (for- profit) organization ('commercial privacy'). In addition, Livingstone et al. distinguished between the types of data being shared online: (a) *Data given* by the individuals knowingly during their online media consumption, (b) *Data traces*, which are data left online, most of the times unknowingly, and are captured from data-tracking devices or plug-ins such as geolocation, cookies, etc., and (c) *Inferred data* which are created from the combination of the two former categories, using algorithms leading to the profiling of the data subjects. The inferred data fall into the category of commercial privacy. According to Livingstone, Stoilova and Nandagiri (2019) much less research has been focused on inferred data.

Research on children's online practices shows that their online media consumption has dramatically increased, even though children are reported to lack the necessary understanding and skills to securely navigate the digital environment. According to a survey conducted with 5,436 Canadian students in grades 4-11(Steeves, 2014), 32% of students in grades 4-6 have a Facebook account and 16% have a Twitter account. Steeves also examined students' privacy attitudes towards strangers and marketers. A large percentage of students (39%) stated that companies are not interested in what they do online, and 68% believed that if a website has a privacy policy, it means they will not share students' personal information with others. Livingstone, Stoilova and Nandagiri (2019) reviewed 105 empirical research studies from countries around the world, to assess students' skills in regulating their online privacy and the level of their understanding of the commercial use of their personal data. Children, ages 11-16, are reported to have difficulties in understanding the concept of personal data, have gaps in their knowledge and awareness of issues surrounding their online privacy and display a general inability to see how their data might be valuable to anyone (Livingstone et al., 2019).

Chi, Jeng, Acker and Bowler (2018) argue that in order to understand teens and their interactions with data, a holistic approach should be followed concentrating not just on behaviors, but also on the interplay of behavior with cognition and affect. They investigated how youth (aged 11-18) feel, think and behave in regard to their personal data online employing the Affective-Behavioral-Cognitive (ABC) model of attitudes. They found that young people were confident about their digital skills when using technology and were favorable towards having total control over their personal data. At the same time, they showed fear or anger when talking about who could access their online data, and the loss of empowerment and control over their digital data. These results, though, refer to students' perceptions, not their actual skills. The study participants showed a lack of awareness of what data were released to other entities, and how this might affect them.

Ey and Glenn Cupit (2011) interviewed children five to eight years old to examine their understanding of online risks, as well as their management strategies. In general, children identified several internet risks, but were unable to connect these risks with potentially dangerous situations. Specifically, when children were asked about placing their personal information on the internet, 54 out of the 57 children reported that it is not safe to give your name, address or photo on the internet. Similarly, Selwyn and Pangrazio (2018) ran a series of workshops with young people, ages 13-17, to explore their current understandings of personal data and data mining from third parties, and also to help them develop resistance practices. The findings of the study showed that the workshop activities were successful in making young people more conscious about their data trails, but less successful in cultivating the participants' need to act differently and employ resistance practices, such as using software to identify who might be tracking their personal data.

Such studies highlight the lack of young people's awareness of their personal digital data and the implications of their data actions online, but also expose the inability of young users to adopt protective and resilient practices towards the exploitation of their digital traces.

Research aim
This study is part of a design-based research project investigating upper elementary students' awareness of data privacy issues and psychological ownership of digital data. We are interested in understanding how students can be empowered through scaffolded inquiry experiences to reflect on their own personal digital data and gain a deeper understanding of the digital infrastructure and the political economy. Specifically, we focus on how the objectives of critical data education can be approached pedagogically, especially since the theory in this area is still evolving and research-based curricula are limited. Therefore, the main goal of this study was to analyze our design efforts to explore which pedagogical features have potential to scaffold students' critical discussions about personal digital data in formal educational settings. In this paper, we report on the design iterations and findings, and conclude with a set of empirically driven design guidelines for developing learning environments that can engage students in critical reflections on the uses of their personal digital data.

Methods

Theoretical foundations of the learning environment
The design of the learning environment was informed by Freire's critical pedagogy ideas and critical data education, as discussed in Pangrazio and Selwyn (2020): the goal of the designed materials was to scaffold students in understanding their personal digital data contributions and empowering them in making decisions based on their own values. The learning environment is also informed by critical theories of data literacy. The pedagogical approach for developing the curriculum is inquiry-based learning in an effort to engage students in authentic learning inquiries about their own personal digital data. Inquiry-based learning usually consists of five

phases: Orientation, Conceptualization, Investigation, Conclusion and Discussion (Pedaste et al., 2015). The inquiry-based learning approach has been chosen because it encourages Freire's view of education, since the learner in inquiry-based learning is expected to assume responsibility of their own knowledge-building process, and students' active participation is highly emphasized.

Design process

Learning materials aiming to foster critical data literacy are limited in formal educational settings (Pangrazio & Sefton-Green, 2020). The learning environment, developed for upper elementary students, was designed following a design-based research approach (Barab & Squire, 2004; Design-Based Research Collective, 2003), and implemented in two suburban schools. It was revised through two design cycles, which we report next. One of the main objectives of this learning environment was to develop activities that scaffold students in engaging in critical discussions and reflections of their own personal data. Towards this goal we developed a learning environment that employed the use of activity trackers by students. Activity trackers were chosen because they are popular smart devices with these ages and allowed students in our studies to unobtrusively generate their own personal digital data through physical activity. At the same time access to activity trackers is not usually prohibited in schools, as social media often are, thus making the alignment with the elementary school curriculum easier. Each student was provided with an activity tracker adjusted to his/her personal information (such as pseudonym, sex, year of birth, height and weight) after receiving signed informed consent by their legal guardians. Figure 1 presents an overview of the design cycle of the learning environment.

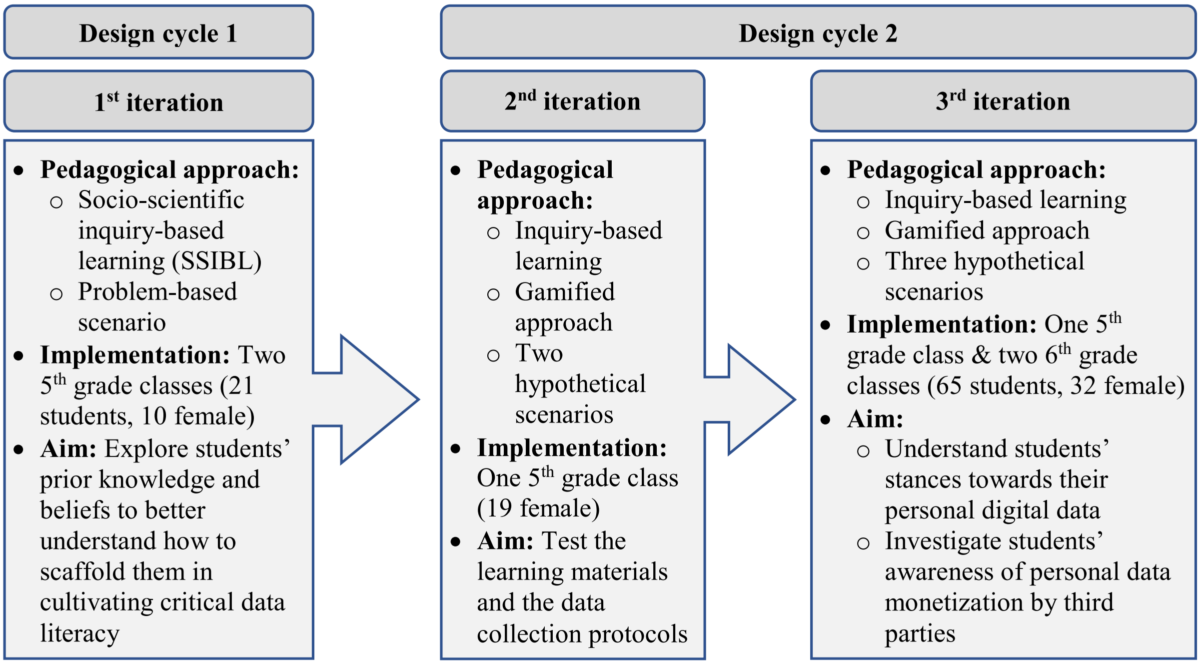

Figure 1: Design-based process of the learning environment.

Design cycle 1

Aim: Gain insights into students' initial understanding of the ethical dimensions and privacy issues related to using activity trackers and generating a vast amount of self-tracking data. We wanted to identify students' prior knowledge and beliefs to better understand how to scaffold them in cultivating a critical stance about personal digital data.

Implementation: The learning environment was implemented in two fifth grade classes with a total of 21 students (10 female). During the enactment students worked both individually and collaboratively, divided in four groups.

Approach: Socio-scientific inquiry-based learning, SSIBL (Levinson, 2018). The learning environment was structured around a driving question with students assuming roles of different stakeholders.

Learning sequence: An educational intervention that employed activity trackers and offered students the opportunity to collect and critically consider data from their own physical activity, was designed by a co-design team, with input from collaborating teachers. The module was designed for four 80-minute lessons. The first

lesson begins with a short, animated story ending with the driving question "Would you use an activity tracker to monitor your physical condition?" Each student was provided with an activity tracker, adjusted to his/her personal information, and performed a sequence of physical activities in the school yard. Students kept the activity trackers for three days to be used during school hours. The second lesson was about physical education and nutrition. During the third lesson, students discussed the graphical representations of their own physical activity data and assumed roles to investigate the pros and cons of using activity trackers as presented by the following stakeholders: companies who develop activity trackers; scientists and doctors; users of activity trackers; and insurance companies. The lesson ended with a debate between representatives of each stakeholder. During the fourth lesson, students discussed how the personal data from activity trackers are provided to third parties and what ethical aspects this might involve. Examples of the privacy policy and terms and conditions of various websites, including of the activity trackers' platform, were discussed.
Data collection and analysis: Data were obtained from video-recordings of three student groups during the third and fourth lessons which featured their own personal digital data discussions. Videos were carefully reviewed based on the critical incident technique (Flanagan, 1954) to identify incidents in which students had been engaged in critical discussions about the ethical dimensions and the privacy issues related to using activity trackers.
Findings: Students engaged in critical discussions about their self-tracking data. They believed that their data can be used by others, but most of them could not explain who these people might be. Students also believed that access to their self-tracking data by others is less important or serious as compared to someone having access to their conversations on social media. Even though we observed incidents of critical discussions in all groups, those reflected the opinions of some students. Not all group members participated in the discussions and this raised the question of how to scaffold each student in voicing their opinions on the matter. Similarly, during the debate activity, students identified arguments supporting their assigned stakeholder role, but these arguments did not reflect students' personal opinions and stances towards the use of their self-tracking data. We also noticed that students had difficulties in interpretating the graphical representations and in understanding their own data visualizations and needed further scaffolding to engage in such discussions.

Implications for design

The SSIBL pedagogical approach used in the first iteration was successful in helping students recognize the plurality of stakeholders involved in the issue in real life, and in helping us understand how students engage in collaborative discussions about the uses of personal digital data. In our next iterations, though, the aim was to develop learning activities that would be more personally meaningful to students and to give the opportunity to each student to shape the collaborative discussion. To address this goal, the SSIBL ethical dimension remained as the core of the learning environment, but we proceeded with the following revisions:

1. We decided that it would be better to have students at this age reflecting on their personal data rather than assuming roles of different stakeholders. In combination with their experience of using the activity trackers during the implementation, this would provide students with the opportunity to express their own personal opinions about the use of their self-tracking data.
2. Students were less engaged in some activities, so we decided to embed gamification elements in the learning environment to increase their motivation to participate. Using the ABC model of attitudes, activities were re-designed to attend to affective, behavioral and cognitive components of the task.
3. Based on findings indicating that students were not aware of who might use their personal data, we decided to design activities that would allow students to contextualize these ideas using multiple scenarios that resembled situations they may encounter in their personal lives. For this reason, we developed three hypothetical scenarios of specific companies asking for access to students' self-tracking data. We used these activities to help us gain additional insights about how students perceived the privacy of their personal data in actions (vs. based only on self-reported interview data).
4. We decided to keep the collaborative aspect of the learning environment and have students discuss in groups as the debate was important for externalizing ideas and highlighting the complexity of the situation; however, it was also important to encourage the participation of all students in the discussion. We, therefore, decided to scaffold the group decision making process in each scenario, by introducing an activity during which all students would first reflect on and articulate their personal opinion to the question raised in each hypothetical scenario.
5. We simplified the complex data visualizations and embedded them in the hypothetical scenarios to provide a meaningful context for interpretation.

Design cycle 2

Aim: With the second design attempt we aimed at gaining a deeper understanding of students' stances towards their own personal data in relation to online privacy and data monetization by third parties by increasing student engagement with the ideas both at an individual and at the group level.

Implementation: The learning environment was pilot tested in one fifth grade class of 19 students (8 female). After making necessary improvements, a revised version (third iteration) was implemented in one fifth and two sixth grade classes with 63 students in total (32 female) from the same school. During the enactments, students were divided in four groups per class.

Approach: Inquiry-based learning enhanced by gamification elements. Hypothetical scenarios were embedded in the learning environment to personalize the experience and invite students' reflections and critical discussion.

Learning sequence: The learning environment *"Who's looking at my data? Learning using activity trackers",* consists of three 80-minute lessons; the activity sequence progresses from familiarizing students with activity trackers through experiential activities (Lesson 1) to the exploration of three hypothetical scenarios presented and explored through a gamified approach (Lessons 2 & 3). In Lessons 2 and 3, students were presented with their mission: the director of a company that develops and sells activity trackers is asking for their help to reply to three requests, presented in three scenarios, about the release of students' personal tracking data. All three scenarios included information on: (a) the type of data being collected, (b) the requesting stakeholder, (c) the purpose of usage, and (d) the perceived benefits for kids. Our aim was to scaffold students in taking a position on each hypothetical scenario; we framed each scenario so as to highlight both the positive and the negative outcomes of conceding data ownership to empower students' impartial decision. The three scenarios were: (A) a sports company is requesting access to students' personal tracking data so that they can send them discount coupons and promotions based on their physical activities; (B) a health insurance company is asking for a girl's heart rate data to decide whether to cover medical expenses related to treating her heart disease, and (C) a children's gym owner gave each gym member a free activity tracker and is now asking for their permission to post their activity data on a members-only website for a monthly competition, with a free, one-month subscription to the gym as the prize.

Students in each class worked in four groups of six students each (12 groups in total). A progress map, showing start, middle and end points which the students should reach, was used to scaffold students' inquiry in each scenario activity. Each group had a unique logo chosen at the first lesson, and the progress map was updated with each group's achievements at several points during the investigation, by moving each group's logo to the current point. At the start line, students were asked to read the letter sent to the director. At the first station of the progress map, each student had to make an individual decision on what to advise the director. The individual decisions were followed by group discussion leading to an initial written group decision, as follows: *"We the (name of the team), advise the director of the company to respond (positively/negatively) to the sports company/insurance company/gym owner, because…"*. At the second station, students were provided with different data visualizations of the self-tracking data, according to each scenario, to scaffold their initial group decision. At the third and final station students had to declare their final decision, after examining the data visualizations they accumulated from the second station. After each scenario, all groups had to announce their decisions and provide evidence-based arguments. Plenary discussion followed to explore each group's arguments and explain the unanimity or the diversity of their decision.

Data collection and analysis: Data obtained from video-recordings from three student groups in each class (nine groups in total) during the second and third lesson, and semi-structured interviews obtained by all students before and after the learning interventions. Videos were carefully reviewed following the critical incident technique (Flanagan, 1954) to identify incidents in which students had been engaged in critical discussions about allowing or denying the companies in each of the scenarios to access and use their self-tracking data. During these episodes, we focused on how the learning materials and the resources made available to students had scaffolded or hindered their critical discussion. The interviews were analyzed using two coding schemes, reported in Agesilaou and Kyza (2021). The first coding scheme, which was based on the ABC model (Chi, Jeng, Acker & Bowler, 2018) and on Pangrazio and Selwyn's (2019) work, was used to identify students' Affective, Behavioral, and Cognitive states towards personal data privacy practices and to help us understand students' awareness of the commercial use of their personal digital data. The second coding scheme was used to identify students' conceptualization of ownership of their personal digital data.

Findings: The analysis of the video-recordings indicated that students were more engaged and motivated to participate in the collaborative discussions during the second design cycle which employed a gamified approach using a series of hypothetical scenarios. The hypothetical scenarios provided the opportunity to approach the matter from multiple angles; since they were neutrally framed they allowed students to express different points of view leading to interesting discussions. In contrast to the implementation of the first design iteration, students were more confident to collaboratively discuss the three scenarios and to provide their experience as users.

During the second design attempt, we guided students to examine the three hypothetical scenarios following the same steps, which were visible in the progress map placed on the blackboard. By the second and third scenario, students already knew how to proceed. This enabled each student team to continue on its own pace and allowed the teacher the opportunity to provide differentiated scaffolding to each team. Allowing students to track their progress, through the progress map, restructured the classroom organization between the teams and the teacher, but also between the members of each team. Even though students knew that there was no prize if they finished their inquiry steps first, they were monitoring the other teams' progress, and on many occasions asked their teammates to avoid off-task discussions and to contribute to the collaborative work.

The analysis of the interviews indicated that students would feel anger, fear, stress and be offended if someone gained access to their data without their permission. Our analysis revealed that students employ privacy and security mechanisms to their personal digital data to avoid data violations from hackers, hazardous communication with strangers and disclosure of geolocation information. While students' answers before the learning intervention, as to who might be interested in their personal digital data, were more general (e.g. hackers, strangers, for bullying purposes), after the learning intervention more (but still not all) students became more specific and reported that their data can be used by companies, highlighting the potential of our intervention to positively affect students' awareness of personal data mining. We also examined students' conceptualization of ownership of their personal digital data. The majority of students believed that they are the only owners of their data; only few students were aware that when giving permission to a commercial entity to access your data, one also agrees to shared ownership and shared rights about those data.

Implications for design

These results indicate that future efforts should focus on helping students acquire a better understanding of the transfer of data ownership to third parties, along with what happens with the data analysis and profiling of their personal data, in order to develop the necessary competencies to decide which privacy and security practices towards their personal digital data they wish to employ. The analysis of students' interviews and in-class group discussions indicated that students' willingness to concede data ownership to third parties is dependent on *the nature of the personal data being shared*, *how they will be used*, *by whom* and *for what purposes*. These criteria shaped students' decisions in the three hypothetical scenarios. Students were positive in conceding data ownership to the sports company (9/12 groups) and the insurance company (12/12 groups), but negative to conceding data ownership to the gym owner (9/12 groups). These results highlight that context is important on how students evaluate data privacy and how they perceive the commercial utilization of their personal digital data.

Discussion and conclusions

Design-based research serves twin and complementary goals: While it seeks to validate learning theories in real-world practice, it also contributes to the development of these theories (Hoadley, 2004). The goal of this design-based research effort was to design a learning environment for upper elementary students to support their understanding of the data economy and the commercial exploitation of their personal digital data. Informed by critical theories of data literacy, we designed and implemented a learning environment in order to understand how children and youth can be empowered through scaffolded inquiry experiences to reflect on the use of their own smart, self-tracking devices. Lessons learned from the two design cycles described in this study, show that the following design principles are important in shaping students' development of critical data literacy: (1) Contextualization is an important factor which can shape students' understanding of the exploitation of their personal digital data and foster engagement in critical discussions. There are four determinants of students' willingness to concede data ownership to third parties: the nature of the personal data being shared, how they will be used, by whom and for what purposes. The results of this study suggest that students evaluate shared ownership of personal digital data based on different criteria and this impacts their willingness to disclose or protect personal information, and their willingness to share data ownership with third parties. Future efforts should consider these criteria when designing learning materials aiming to foster critical data literacy. (2) Setting up a scaffolded, personally-motivating, critical inquiry context increases students' willingness and ability to engage with the ideas. In our study, it was important to support students' engagement with the, otherwise, abstract ideas of data privacy by connecting experiential activities with individual and group-level reflection. The gamified approach and task-driven activities fueled engagement, transforming the activity-trackers and the scenaria that were linked to them to evocative objects (Turkle, 2007).

Our ongoing work, of which this study is a part, also contributes to theory building about students' conceptualization of the psychological ownership of digital data, which has been less explored in the literature, and critical data literacy education efforts. Attending to the affective-behavioral-cognitive (ABC) components of the task increased students' critical discussions. Yet still, students in our study believed they were the only owners of their self-tracking data, even in the cases when they agreed to give access to their data to third parties, such as the companies presented in the three hypothetical scenarios. In order for students to develop critical data literacy, they have to gain a deeper critical understanding of the digital infrastructure, and how data flows from the individual devices and applications, to second and third parties managing those data. Such an understanding is necessary for students to realize the subsequent data transfers and data rights to others.

Efforts to design learning materials aiming to foster critical data literacy in formal education have been reported as limited in the literature (Pangrazio & Sefton-Green, 2020; Pangrazio & Selwyn, 2019). Our study is among the first efforts to understand how students can be scaffolded in developing the conceptual and practical competencies needed to gain a deeper understanding of the digital environment and the political economy. Such initiatives are important in contributing to the discussion of how critical data literacy can be theorized in formal educational settings and supported through empirically validated research-based curricula.

References

Agesilaou, A. & Kyza,E.A. (2021). Title of manuscript. [Manuscript submitted for publication]. Department of Communication and Internet Studies. Cyprus University of Technology.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences, 13*(1), 1-14. https://doi.org/10.1207/s15327809jls1301_1.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. *Educational Researcher*, *32*(1), 5-8. https://doi.org/10.3102/0013189X032001005.

Chi, Y., Jeng, W., Acker, A., & Bowler, L. (2018, March). Affective, behavioral, and cognitive aspects of teen perspectives on personal data in social media: A model of youth data literacy. In *International Conference on Information* (pp. 442-452). Springer.

Ey, L. A., & Glenn Cupit, C. (2011). Exploring young children's understanding of risks associated with Internet usage and their concepts of management strategies. *Journal of Early Childhood Research*, *9*(1), 53-65.

Flanagan, J. C. (1954). The critical incident technique. *Psychological bulletin*, *51*(4), 327.

Freire, P. (1970). Pedagogy of the oppressed (MB Ramos, Trans.). New York: Continuum, 2007.

Hoadley, C. M. (2004). Methodological alignment in design-based research. *Educational Psychologist*, *39*(4), 203-212.

Levinson, R. (2018). Introducing socio-scientific inquiry-based learning (SSIBL). School Science Review, 100(371), 31-35.

Livingstone, S., Stoilova, M. & Nandagiri, R. (2019). Children's data and privacy online: Growing up in a digital age. An evidence review. London: London School of Economics and Political Science.

Lupton, D. (2020). *Data selves: More-than-human perspectives*. John Wiley & Sons.

Lupton, D., & Williamson, B. (2017). The datafied child: The dataveillance of children and implications for their rights. *New Media & Society*, *19*(5), 780-794.

Pangrazio, L., & Sefton-Green, J. (2020). The social utility of 'data literacy'. *Learning, Media and Technology*, *45*(2), 208-220.

Pangrazio, L., & Selwyn, N. (2020). Towards a school-based 'critical data education'. *Pedagogy, Culture & Society*, 1-18.

Pangrazio, L., & Selwyn, N. (2019). 'Personal data literacies': A critical literacies approach to enhancing understandings of personal digital data. *New Media and Society*, 21(2), 419–437.

Pedaste, M., Mäeots, M., Siiman, L. A., De Jong, T., Van Riesen, S. A., Kamp, E. T., ... & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational research review*, 14, 47-61.

Philip, T. M., Schuler-Brown, S., & Way, W. (2013). A framework for learning about big data with mobile technologies for democratic participation: Possibilities, limitations, and unanticipated obstacles. *Technology, Knowledge and Learning*, *18*(3), 103-120.

Selwyn, N., & Pangrazio, L. (2018). Doing data differently? Developing personal data tactics and strategies amongst young mobile media users. *Big Data & Society*, *5*(1), 205395171876502.

Steeves, V. (2014). *Young Canadians in a Wired World, Phase III-Online Privacy, Online Publicity*. Ottawa: Media Smarts.

Stornaiuolo, A. (2020). Authoring data stories in a media makerspace: Adolescents developing critical data literacies. *Journal of the Learning Sciences*, *29*(1), 81-103.

Turkle, S. (Ed.). (2007). *Evocative objects: Things we think with*. Cambridge, MA: MIT press.

Van Dijck, J. (2014). Datafication, dataism and dataveillance: Big Data between scientific paradigm and ideology. *Surveillance & society*, *12*(2), 197-208.

Curricular Reorganization in the Third Space: A Case of Consequential Reasoning around Data

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Abstract: Writing Data Stories is a social design-based research project to co-design and study data literacy units. The project encourages nondominant students to integrate everyday practices and scientific datasets by using storytelling and computational transformation to highlight personally and socially relevant issues. We present an analysis of one cycle of instruction where students pursued an unanticipated path of investigation—locating themselves on a map within a data analysis tool though the dataset lacked geographic information. A researcher initially considered this path to be unproductive, but changed focus as the teacher followed students' lead and encouraged exploration of the map in subsequent classes. Using conceptions of third space, we examine the sequence through which teachers and students co-produced a reorganization of the activity, power relations, and curriculum toward expansive data reasoning. We contrast this productive reorganization with marginalization of other student practices, identifying implications for curricular design and classroom research.

Keywords: data reasoning, third space, consequential learning, social design-based experiments

Introduction

Work exploring the importance, emergence and design of *Third Space* (Gutierrez, 2008; Gutierrez & Jurow, 2016) has centered primarily on supporting nondominant youth in informal learning contexts. In these informal contexts, educators have more flexibility than classroom teachers, and power relations between those involved—students, informal educators, researchers, and classroom teachers—tend to be more fluid. In contrast, in the vast majority of formal schooling contexts, students and classroom teachers must contend with institutional constraints of content standards and testing, without adequate support for more expansive approaches. Despite these challenges, the concept of Third Space has been used in school settings. For example, Gutiérrez et al. (1999), examined how teacher and student talk and knowledge in a science classroom were reorganized to create opportunities for authentic interaction and a shift in the social organization of learning. Like Gutiérrez et al.(1999), our work is also focused on Third Spaces in science classroom contexts. Using a design-based approach,we examine how student interests and exploration can drive curricular design and mediate a reorganization of student, teacher, researcher relations.

It is well recognized that STEM classrooms are often not supportive or encouraging spaces for nondominant youth (Martin, 2013; Bang, Warren, Rosebury, Medin, 2012). Prior research has used a Third Space lens on STEM in formal contexts, including work that has explored the merging of students' cultural repertoires of practice and social worlds with conventional STEM disciplines/practices (Barton & Tan, 2009), and that has focused on the development of relevant or relatable content (Barton, Tan, & Rivet, 2008; Moje, et al, 2004; Vick 2018). In our conceptualization, Third Space functions as a collective zone of proximal development (Gutiérrez, 2008; Vygotsky, 1978) or ZoPED (Griffin & Cole, 1984) wherein students and teachers co-construct knowledge in ways that reorganize the relation of everyday concepts and practices with scientific ones (Gutierrez & Jurow, 2016). In the context of design, the aim of supporting the emergence of a Third Space is to leverage resonances between scientific and everyday knowledge and practices that elevate nondominant students as sensemakers.

The Writing Data Stories project ("WDS"; IIS-1900606) seeks to develop and study curricular units that reposition the everyday knowledge and practices of youth of nondominant communities by placing that knowledge in direct conversation with scientific datasets and analytic practices such as data visualization, data transformation, and storytelling. A distinguishing principle in our work is understanding Third Space as a significant disruption to and reorganization of intellectual space, including a reorganization of what ideas and practices are valued, how they are linked, and whose linguistic and epistemic practices are privileged. Specifically, the project seeks to reconfigure students' relationships to data, which is often presented as an objective representation of reality that is granted higher epistemic status than other ways of knowing, including students' own experience (Bang and Medin, 2010). The project aims to elevate and weave the experiences of students from non-dominant communities *alongside and integrated into* scientific datasets, through students' use of computational "data moves" (Erickson, Wilkerson, Finzer, & Reischmann, 2019) to inscribe their own knowledge, experiences, and values into the datasets (for example, by adding foods or variables such as cost, taste, or accessibility to a nutrition dataset). Our project goal is to make a significant contribution to the research on Third Space by studying and identifying consequential data literacy approaches for nondominant youth. A Third-Space-designed data literacy project must contest deficit discourses and disrupt rigid authoritative practices and ideas, highlighting social and cultural dimensions to "objective" pre-existing datasets. In this way, the project enables a reorganization of classroom roles and the relationships between everyday practices and disciplinary reasoning about data.

The case we share here offers specific insight into how learning in a Third Space de-centers authoritative views of STEM as data experiences are co-constructed by students, teachers, and researchers. Third spaces emerge in contexts with histories of practice, as well as in moment-to-moment activity. Our overall analysis focused on multiple moments in which the tools and goals of a particular lesson were reorganized in response to students' unexpected interests. Importantly, this became a sight of significant learning for the research team and informed subsequent curricular design. In the analysis of the unfolding of this example, we highlight four phases of the reorganization and coproduction of this particular Third Space. The first phase entails a researcher-designed exploration activity that privileged everyday practices of students in collective knowledge production about the Common Online Data Analysis Platform (CODAP) and a nutrition dataset. The second emerged when students—afforded the open-endedness of exploration—reoriented toward map exploration and away from the nutrition dataset. The third phase occurred when the teacher, rejecting the researcher's initial advice, responded to students' unexpected interest in the map by reframing the exploration task to explicitly include the map as part of the object of inquiry alongside the nutrition dataset and other CODAP features. The fourth phase carried lessons learned from this brief cycle of instruction into longer-term design efforts as the curriculum team designed subsequent units to more centrally highlight the map tool as part of data inquiry. We also present a missed opportunity to co-construct Third Spaces with students who translanguaged as they made sense of data. Responsiveness to organically emerging productive data investigation, as well as to linguistically marginalizing dimensions that were later observed, were central to subsequent unit design.

Theoretical framework

This study explores the emergence of a Third Space wherein consequential data reasoning and curriculum design unfolded as a co-production of the teacher, students and researchers. Here, we briefly review theories related to Third Space and data reasoning to help ground these conceptualizations of learning and reasoning. The construct of a collective Third Space builds on an existing body of research and can be viewed as a particular kind of zone of proximal development. As an emergent and co-constructed environment, the Third Space is a particular social environment of development, in which students begin to reconceive who they are and what they might be able to accomplish academically and beyond. Learning in the Third Space has highlighted how its accomplishment is mediated by a range of tools and a reorganization in the hierarchies of classroom knowledge, as well as of the participation structures of more formal environments (Gutiérrez, 2008). In concert with the hybrid character of Third Space, consequential learning in the Third Space necessarily leverages both everyday (horizontal) and school-based (vertical) knowledge such that traditional notions of development generally defined along vertical dimensions (e.g., novice, competence) were challenged. Of significance, to this proposal, is that not only students, but the teacher and research team also began to jointly re-imagine and design for new curricular possibilities. As a social design-based experiment, this study's design also attuned to the co-participatory, iterative, and responsive potential of collaborative design and a shared practice (Gutiérrez & Jurow, 2016).

Our project seeks to support data reasoning as a way to understand both the world and oneself, and support Third Spaces in which new relationships between data, the world, and the self can emerge. Our conceptualization of data reasoning includes a number of practices central to data work, summarized by Rubin (2020) as: understanding the contexts in which observations are collected (and how valid/appropriate the data are for understanding a given system or situation); reasoning about mathematical features of the data including variability and aggregate patterns; flexibly visualizing data and understanding how they might be differently represented to reveal new trends and relationships; and drawing inferences from data back to the world. It also involves reasoning about one's personal relationships and situatedness relative to a given dataset and the systems it describes (Wilkerson & Polman, 2020), including locating or observing oneself within data; projecting self and community into aggregated social and historical data; and manipulating, critiquing, or generating datasets to better reflect one's own experiences. This case represents an instance in which we observed students engaging in many more personal, social, and representational explorations of data after a reorganization of activity co-designed by the students, teacher, and researchers.

Research questions

While the goals of the WDS project were to support the emergence of Third Spaces within the *classroom* as students worked with data, this cycle of instruction also reflects the emergence of a Third Space that extended into teacher-researcher relations and subsequent curricular design for supporting data reasoning. The cycle of instruction we report here involved new paths of exploration by students, and illuminated productive ways to reorganize goals, tool use, and researcher-teacher roles to enrich the coconstruction of curriculum. Given the power and implications this holds for curricular co-design efforts, it is important to better understand its emergence and how it was sustained. This yielded the questions:

1. How did the initial curricular goals in this cycle of instruction support the emergence of a Third Space in which relationships, roles and learning activities were reorganized to support students to use their everyday practices in data analysis?
2. What does this cycle of instruction suggest about how productive reorganization of the classroom activity system can be sustained over time?
3. How did this cycle of instruction inform future curricular design decisions and collaborative efforts?

Methodology

Our focal episode is drawn from a large corpus of data collected during our first, 21-day curricular enactment in multiple 7th grade class periods with a collaborating teacher we will refer to as Ms. Phillips. For each day of enactment, we captured audio-video recordings of whole-classroom interactions, audio and screen recordings of 2-3 focal groups of 2-3 students each per class, observer field notes, and audio-video recordings of mid-day debriefing sessions between researchers and the classroom teacher. We created activity logs, describing the general organization of activity for every 2 minute interval, from the whole-classroom and teacher debrief videos. We selected the events of Day 17 for deeper analyses after our codes helped us notice that multiple student groups demonstrated creative and unexpected data reasoning as they engaged with the data analysis tool on that day. After looking deeply at that student reasoning, we observed that it was grounded in how the teacher responded to an unexpected focus of students in the two periods she taught and observed earlier in the day. We chose to investigate this sequence of events more deeply as there seemed to be a significant reorganization of the intended classroom activity by the teacher and students.

Study context

Our episode is drawn from Year 1 of the WDS project, during which we engaged in collaborative curricular design and enactment with science teachers at a school that served predominantly Latinx, emergent multilingual middle school learners in California's Bay Area in the U.S. The first unit we co-designed focused on analyzing nutrition data about breakfast foods. The collaborating teacher saw the unit as an opportunity to extend work the class had previously done exploring the nutritional causes of diabetes, a health issue she felt was prominent in the community. In this unit, students reflect on and collect data on their own breakfast practices and the practices of family and friends. They then compare their personal and community practices with how breakfasts are described in advertisements. After critically reflecting on foods and values in ads, they explore a nutritional dataset about cereals and consider how it might be changed to better reflect the foods and factors that they care about (rather than only what's 'normalized') when choosing breakfast. Finally, students analyze and transform the dataset, including by adding new records and variables, using the Common Online Data Analysis Platform ("CODAP"; Finzer & Damelin, 2016). Based on an analysis of a now modified dataset, they identify and justify their own "ideal and accessible breakfast."

While designed to be accessible to middle school students, CODAP involves specific data representations and features that are novel to students. With this in mind, before students worked in the digital environment, we introduced some of the data representations they would encounter and be able to do by having students work in small groups with paper versions of different cereal nutritional fact cards (labeled "case" cards in CODAP). Students explored and compared the small set of approximately 5 printed nutrition fact 'cards' for cereals, adding written nutrition fact cards for their own foods, and annotating both the cereal cards and their own foods to include information about other important variables (e.g. cost, taste, accessibility). Thus, students had some experience with the nutritional data and data representations before exploring them in the CODAP digital format on the Day 17 cycle of instruction described below.

Analysis

We re-emphasize here our interest in Third Space at the curricular design and enactment level, as the emergence of a collective ZoPED in which new forms of learning are made possible through a fundamental reorganization of activity such that students coproduce their learning. In this analysis we describe four distinct phases of activity in which we observed this sort of reorganization along the lines of a collective Third Space as it unfolded across the classroom enactment and related curricular co-design.

Phase 1: Designed tool and dataset exploration put the map and data at odds

During the Day 17 cycle of instruction, students were first introduced in the digital environment to a nutritional dataset that included over 75 entries. The teacher and researchers had planned a day for students to openly explore the dataset and the CODAP environment. The goal was to help students develop confidence with the platform through centering students' interests and questions and elevating them as sensemakers. To do so, we included time for students to familiarize themselves with the larger nutrition dataset, and with useful features of CODAP including how to visualize and add new data and variables. The image to the left in Figure 1 provides an example of what we envisioned a student computer screen in CODAP would look like at the end of the exploration. The figure includes a nutritional "case card" for Maypo cereal and a graph of the sugar in all the cereals in the dataset. Given that geographical data was not a part of the dataset (note the blank map to the right of Figure 1), the teacher and researcher were surprised when a majority of students in the first two class periods reoriented from exploration with the nutrition data, and instead opened the blank map feature in CODAP to look for themselves. This move to position themselves in the map is consistent with research in data reasoning that students tend to first approach data in relationship to themselves (Kahn, 2020; Wilkerson & Laina, 2018).

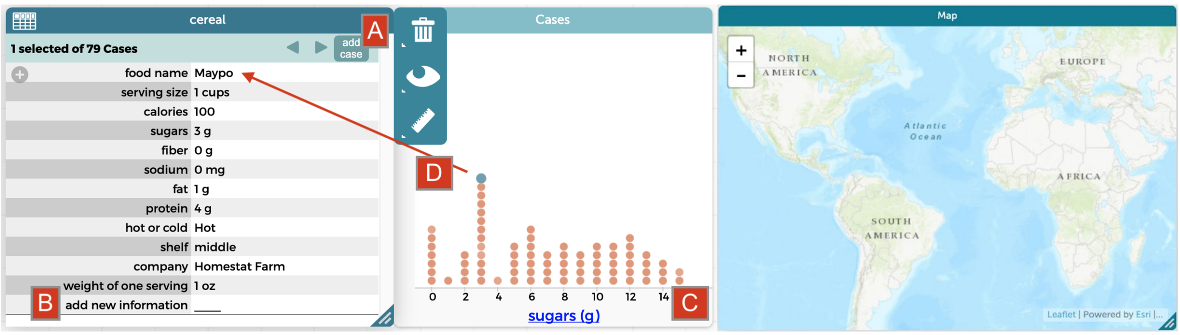

Figure 1. (left) CODAP environment with cereal dataset and anticipated features highlighted: add data (A), add variable (B), build graph (C), and selected data (D). (right) Map window in CODAP with no geographic data.

Phase 2: Teacher responsiveness to student interest in the map

After the first two class periods, during the mid-day debrief, the teacher and researcher discussed the unexpected and overwhelming student interest in the map. The researcher initially suggested redirecting students back to the cereal dataset and related CODAP functions, but the teacher wanted to support student interest. The teacher and researcher worked together to supplement an existing list of CODAP features on the whiteboard for students to explore (Figure 2, left side) with the prompts "any other helpful tool?" and "♡ How does the map represent your DATA STORY?" (Figure 2, right side). Her prompt on the board sanctioned use of the map and suggested that it could represent a "data story" that linked back to nutritional data.

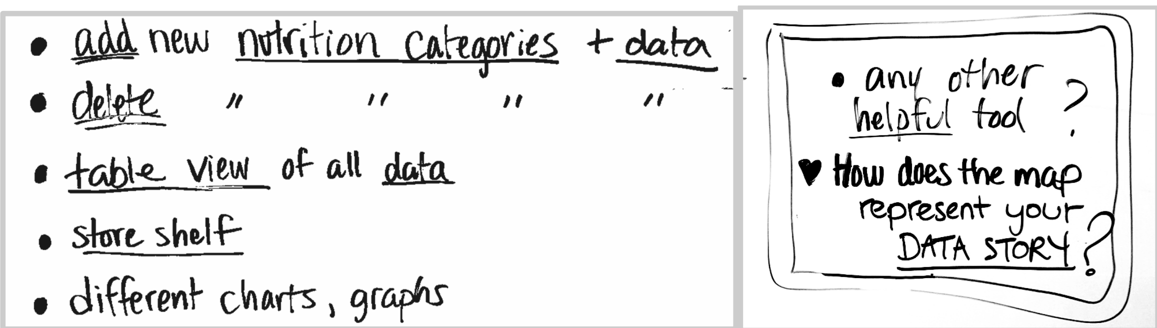

Figure 2. (left) Original CODAP exploration questions added at beginning of day. (right) Revised, map-focused exploration questions added to the board by Ms. Phillips after the mid-day debrief session.

During the debrief, Ms. Phillips' responsiveness as a teacher led her to reframe the task for class periods later that day. She felt that explicitly building on interest in the map would be generative for student learning. By leveraging student interest in the map, she encouraged deeper reasoning about data and students' use of evidence in scientific reasoning.

Phase 3: New conceptualizations of the dataset relative to the map

Following her decision to productively respond to student interest, in period 5, Ms. Phillips framed the map as a legitimate tool for exploration and investigation of data, health and nutrition. We observed unexpected consequential student data reasoning in two of our focal student groups. Initially they connected the nutrition focused dataset to the topic of diabetes and an organic interest in maps. Later they searched for evidence to support their claims that the map showed the location of people with diabetes. This path of inquiry, led to the development of a collective ZoPED wherein students co-constructed knowledge as they made a series of connections across prior investigations of diabetes and nutrition, personal interest in locating people on the map, and knowledge about how diabetes in lower income families may relate to the need to rely on inexpensive but sugar rich foods like cereal. Based on Ms. Phillips' reframing of the task in response to earlier interest in the map, several student groups began to reason about how nutrition related map might include geospatial information and patterns. Two of our focal groups proposed that the map could be a "diabetes map."

For example, one focal student pair in Period 5, upon exploring the map, speculated that it might provide a data visualization related to diabetes (which the class had studied earlier in the year). They spontaneously discovered the text box feature (Figure 3), and wrote reflections on important variables relevant to diabetes that were missing from the dataset. Ms. Phillips probed for specificity by asking what evidence they had to connect the map to diabetes rates. The pair wrote in the text box "I think the map could show where people with diabetes are around the world but we are looking for evidence." When they opened a graph window, it displayed a number of small dots scattered randomly. (This is a design feature, in which each dot represents an entry or "case" in the dataset which will be rearranged once the axes of the graph are defined by the user.) One student in this pair exclaimed upon seeing the scattered dots: "THESE probably are the people! The cases? [*mouse over scatterplot*] Like, the people?" Ms. Philips continued to encourage deeper exploration of how the data might be represented within different CODAP tools, asking "but are those dots on the map?" The pair looked for corresponding data points on the map, in the process reflecting aloud to each other about connections between geography, income, food access, and nutrition. They speculated that low income areas may be linked to higher cereal and sugar consumption, and thus higher diabetes rates. These ideas about a "diabetes map," which referenced units of study from earlier in the school year, connected geospatial information, reasoning about nutrition, and students' personal experiences in new, unexpected, and what we argue are profoundly productive ways. They also motivated these students to deeply consider what counts as a "case" and its "attributes" in the dataset, how data might be differently represented, and what the social context of the nutritional data might be; all fundamental components of data reasoning (Rubin, 2020).

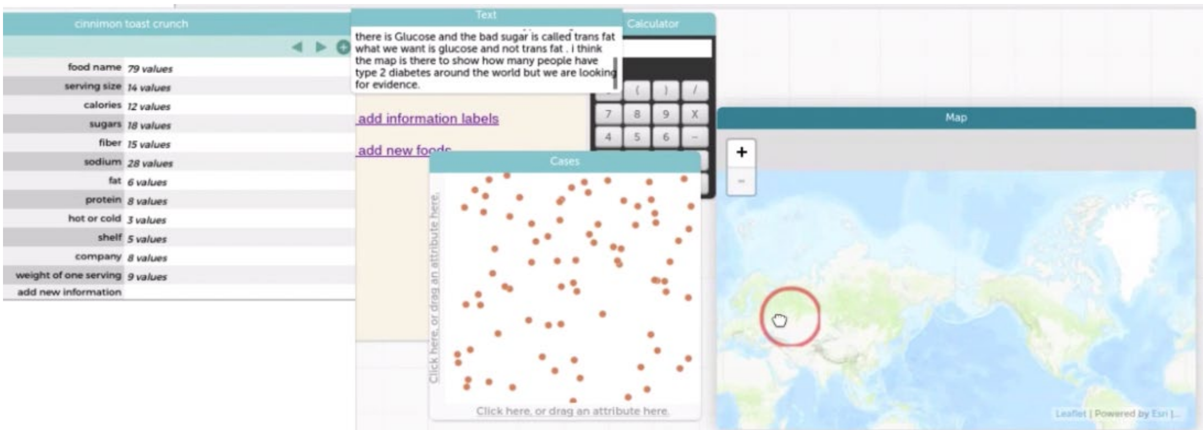

Figure 3. Screenshot featuring students' speculations about how nutrition related data might be visualized on a map. Their mouse click on the map is indicated with a red circle, and the text box reads "I think the map is there to show how many people have type 2 diabetes around the world but we are looking for evidence."

In working to reconcile the map with other features of the nutritional dataset and CODAP, this student pair deftly navigated a variety of tool features and potential data representations (case cards, scatterplots, and the map) as they worked to reconcile geography, broad views of nutrition, the more limited nutrition dataset, and their personal and social knowledge about how all of these might intersect. In the process, the pair also demonstrated several core elements of data reasoning: they worked to understand what counts as a *case* or observation in the dataset, especially as it might exist across multiple representations including geographic representations. In contrast to our intended explorations as highlighted in Figure 1, the investigation featured in Figure 3 is reorganized both in terms of how CODAP and its embedded tools are used (where a larger number and variety of tools are used), and in terms of the object of activity (which students expanded from a narrow comparison of nutrition facts about commercial cereals to instead consider how income affects consumers and how health is related to both geography and nutrition.

Another focal pair of students, similarly, began drawing connections between the nutrition dataset and broad themes of diabetes, geography, and visualization. As they opened and began to zoom and explore the map, one researcher approached the group to ask what they were doing. One student began, "We try to see how—" and the other continued "—like which state has the most diabetics in it." The researcher encouraged the pair to continue this line of exploration, asking, "what do you need to keep working on that?" They responded, "Say like, California's population is, like, 100 people? And like who has diabetes, and like Washington, 58? Something like that. We're not sure [if] that is what the map is used for." We interpret this to suggest that this pair, like the pair of students featured above, were expecting that the map could reflect proportions of people in different states who suffer from diabetes as an extension of the nutritional dataset.

Phase 4: Sustained curricular implications of students' map focus

We find it meaningful that this rich engagement with the map emerged despite our plans, and deepened as a result of both student and teacher actions. Analyzed in the context of researcher, teacher and student dialogue, students' expansive data reasoning had been prompted by Ms. Phillips' reframing of the task in response to student interest in the map in earlier periods. Although our original goal for this day was to support a Third Space between teachers and students, we found it increasingly valuable to envision our broader attention to collaborative curricular design as a part of this emergent Third Space.

To attune to the lessons learned from Day 17, we have made geospatial data visualization a core part of how students engage with datasets and science topics. As part of this map dataset engagement, we support and leverage the practice of locating one's social worlds on maps that are related to or a part of, in different ways and at different scales, the datasets under study. For example, a grounding theme in a climate change unit is for students to think about their own "special places" in the world, and to interview friends and family about their "special places"—including how the landscape, everyday experience, and livability of these places may have been impacted by climate change and pollution. Students then locate these places on the map, creating a personally relevant but geographically distributed framework around which broader examinations of global climate and emissions patterns can be explored. Similarly, we make space for exploratory activities related to data and tools that can provide similar serendipitous moments for student interest to guide the teacher and researchers to more opportunities for learning.

There were also practices we observed in our data that were not leveraged or integrated by teachers and researchers in the moment. Notably, despite our stated commitment to supporting multilingual students, we observed that several students engaged in translanguaging during Day 17, especially as they jointly looked for themselves on the map and told stories about various places or origin or import. However, this practice went unsupported and remained marginalized at the time. Since this time we have significantly altered the way we support translanguaging in subsequent units, explicitly providing fully bilingual (Spanish and English) materials and models of flexible language use. However, our failure to notice and respond to this opportunity in the moment also reveals the degree to which our own and the teachers' research and instructional priorities shape what gets reorganized, and along what dimensions of activity, in the moment of curriculum enactment.

Discussion

We introduced this case as a new way to think of Third Space as a context for collaborative design. In particular, we offer this case as an entry point to think about new ways of thinking about what it means to design for equitable and consequential learning. Our findings reveal a few important considerations that are especially relevant to considering generative collaborative design in the context of formal, STEM-focused settings. First, we noted that shifts in the object of activity led to important rethinking of the use of CODAP as an exploratory tool, the nutrition dataset as the object of study, and of the goals of curriculum as both teachers and students, and the teacher and researcher began to view their work as a shared practice—a practice marked by reciprocal relations of exchange. Second, we found that this example presents a new way of thinking about codesign not as receiving input or feedback either during the conceptualization or the design of an activity, but in the moment of enactment as new paths of exploration are revealed. This is particularly interesting within the context of a formal STEM classroom.

Finally, the case highlights how institutional, research, and teacher priorities can shape what sorts of reorganization is possible. Importantly, we observed the emergence of a Third Space and the reorganization of activity along the dimensions of tool use (the CODAP tool and its embedded maps, text boxes, graphs, and tables); the object of activity (from attending to patterns in data to also considering its connection to personal and social issues, including health topics previously studied in class); and social roles (as the teacher rejected researchers' recommendations in favor of following students' lead). At the same time, other student practices that were aligned with our purported goals and that co-occured with students' map use, such as translanguaging, were not taken up in the moment. This highlights the importance of communicating and revisiting project goals to elevate their priority. It also highlights the importance of reflecting on missing elements of reorganization to find "blind spots" and missed opportunities in design.

Future co-design efforts can learn from this case. Because students will initiate "counterscripts" and other "grammars of the Third Space" alongside and in tension with teacher-centered whole-class discourse (Gutiérrez, 2008), teachers should expect the emergence of such counterscripts and analyze them in real time to the best of our ability. As we saw in our project with student interest in the map, these counterscripts served as productive resources for learning that otherwise might have remained unnoticed and marginalized, but instead were productively leveraged for deeper learning in a collective ZoPED. If teachers and codesigners in other projects commit to actively searching for and uplifting student sensemaking to support a Third Space, they may also see a similarly productive reorganization of learning and see the emergence of another collective ZoPED.

References

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*(5-6), 302-318.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education*, *94*(6), 1008–1026.

Barton, A. C., Tan, E., & Rivet, A. (2008). Creating hybrid spaces for engaging school science among urban middle school girls.

Barton, A. C., & Tan, E. (2009). Funds of knowledge and discourses and hybrid space. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 46(1), 50-73.

Erickson, T., Wilkerson, M., Finzer, W., & Reichsman, F. (2019). Data Moves. *Technology Innovations in Statistics Education*, *12*(1).

Finzer, W., & Damelin, D. (2016). Design perspective on the Common Online Data Analysis Platform (CODAP). In *American Educational Research Association (AERA) conference. Washington DC*.

Fullerton, & P. Stecker (Eds.), 63rd Literacy Research Association Yearbook. (pp. 48-61). Alamonte Springs, FL: Literacy Research Association.

Griffin, P., & Cole, M. (1984). Current activity for the future: The zoped. In B. Rogoff & J.V. Wertsch (Eds.), *Children's learning in the "zone of proximal development": New directions for child development* (pp. 45-63). San Francisco: Jossey-Bass.

Gutiérrez, K. D., Baquedano-López, P., & Tejeda, C. (1999). Rethinking diversity: Hybridity and hybrid language practices in the third space. *Mind, culture, and activity*, *6*(4), 286-303.

Gutiérrez, K. D. (2008). Developing a sociocritical literacy in the third space. Reading Research Quarterly. 43(2), 148-164.

Gutiérrez, K. D.(2014). Integrative research review: Syncretic approaches to literacy learning.Leveraging horizontal knowledge and expertise. In P. Dunston, L. Gambrell, K. Headley, S.

Gutiérrez, K. D. (2016). Designing resilient ecologies: Social design experiments and a new social imagination. Educational Researcher, 45(3), 187-196.

Gutiérrez, K. D., & Jurow, S. (2016). Social design experiments: Toward equity by design. The Journal of Learning Sciences, 25(4), 565-598

Hawkins, J., & Pea, R. D. (1987). Tools for bridging the cultures of everyday and scientific thinking. *Journal for Research in Science Teaching*, *24*, 291-307.

Kahn, J. (2020). Learning at the intersection of self and society: The family geobiography as a context for data science education. *Journal of the Learning Sciences*, *29*(1), 57-80.

Martin, D. B. (2013). Race, racial projects, and mathematics education. *Journal for Research in Mathematics Education*, *44*(1), 316-333.

Moje, E. B., Ciechanowski, K. M., Kramer, K., Ellis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everyday funds of knowledge and discourse. *Reading research quarterly*, *39*(1), 38-70.

Rubin, A. (2020). Learning to Reason with Data: How Did We Get Here and What Do We Know? *Journal of the Learning Sciences*, *29*(1), 154-164.

Vick, M.E. (2018). Designing a third space science methods course. *Innovations in Science Teacher Education* *3*(1). Retrieved from: https://innovations.theaste.org/designing-a-third-space-science-methods-course/

Vygotsky, L.S. (1978). Mind in Society. The Development of Higher Psychological Processes. London: Harvard University Press.

Wilkerson, M. H., & Laina, V. (2018). Middle school students' reasoning about data and context through storytelling with repurposed local data. *ZDM*, *50*(7), 1223-1235.

Wilkerson, M. H., & Polman, J. L. (2020). Situating data science: Exploring how relationships to data shape learning. *Journal of the Learning Sciences*, *29*(1), 1-10.

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Using Anticipatory Diagrammatic Self-explanation to Support Learning and Performance in Early Algebra

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Abstract: Prior research shows that self-explanation promotes understanding by helping learners connect new knowledge with prior knowledge. However, despite ample evidence supporting the effectiveness of self-explanation, an instructional design challenge emerges in how best to scaffold self-explanation. In particular, it is an open challenge to design self-explanation support that simultaneously facilitates performance and learning outcomes. Towards this goal, we designed *anticipatory diagrammatic self-explanation*, a novel form of self-explanation embedded in an Intelligent Tutoring System (ITS). In our ITS, anticipatory diagrammatic self-explanation scaffolds learners by providing visual representations to help learners predict an upcoming strategic step in algebra problem solving. A classroom experiment with 108 middle-school students found that anticipatory diagrammatic self-explanation helped students learn formal algebraic strategies and significantly improve their problem-solving performance. This study contributes to understanding of how self-explanation can be scaffolded to support learning and performance.

Introduction

Self-explanation

Self-explanation is a learning strategy in which learners attempt to make sense of what they learn by generating explanations to themselves (Chi et al.,1989; Rittle-Johnson et al., 2017). A number of studies have provided evidence for the effectiveness of self-explanation across domains (Ainsworth & Loizou, 2003; Bisra et al., 2018). From a cognitive perspective, self-explanation helps learners integrate to-be-learned information with their prior knowledge, leading to deeper understanding of the content (Bisra et al., 2018). For example, in the context of problem solving in mathematics, learners may be asked to provide reasoning for their solved steps in order to deepen their conceptual understanding of the procedures. Although self-explanation activities may take different forms (e.g., explaining worked examples, explaining while solving problems, and explaining text passages), they share the core principle of supporting deeper understanding through connecting new content with existing knowledge.

Scaffolding self-explanation as a challenging design problem

The demonstrated effectiveness of self-explanation does not guarantee that effective self-explanation activities are easily designed. Self-explanation can be a demanding task for learners. It has been reported that scaffolding self-explanation activities facilitates learning (Rittle-Johnson et al., 2017). Prior studies have designed and tested various types of scaffolded self-explanation, such as presenting menu-based, multiple-choice explanations (Aleven & Koedinger, 2002; Berthold et al., 2011; Rau et al., 2015), providing training on self-explanation (Hodds et al., 2014), using visual representations (Ainsworth & Loizou, 2003; Nagashima, Bartel et al., 2020), using contrasting cases (Sidney et al., 2015), and providing feedback on self-explanation (Aleven & Koedinger, 2002).

All of these types of self-explanation support have been shown to be effective. Yet, there are still challenges in how best to design optimal scaffolding support for self-explanation. A first challenge lies in how to design scaffolded self-explanation to promote both conceptual *and* procedural knowledge. Acquiring both conceptual and procedural knowledge is fundamental to learning (Rittle-Johnson & Alibali, 1999); however, studies on scaffolded self-explanation have typically shown it to be effective for enhancing either conceptual knowledge *or* procedural knowledge, but not both (Berthold et al., 2011; Nagashima, Bartel et al., 2020; Rau et al., 2015, but see Aleven & Koedinger, 2002). Rittle-Johnson et al. (2017) explain that this disassociation may be due to the unique characteristics of specific forms of scaffolding. Self-explanation scaffolding designed to focus on one aspect of content may hinder learners' focus on other important aspects. For example, asking students to select a correct conceptual explanation from among a list of similar explanations in a multiple-choice format would encourage learners to focus on conceptual understanding of the content, but it would not give an opportunity for learners to develop their procedural skills (e.g., problem-solving skills).

A second challenge is how to design scaffolded self-explanation that enhances problem-solving performance when combined with, or embedded in, problem-solving activities. Self-explanation can be time-consuming, and because self-explanation requires learners to engage in additional cognitive activities, learners who receive self-explanation support may solve fewer problems in a limited amount of time compared to solving problems without self-explanation support. If scaffolded appropriately during self-explanation, learners' performance on the target task would improve. This would result in *efficient* learning (i.e., learners with self-explanation achieve similar learning gains with fewer problems or less time spent compared to those without self-explanation). Most prior studies of self-explanation do not report measures of the problem-solving performance and efficiency of learning with self-explanation, such as time spent on the task (Bisra et al., 2018; but see Aleven & Koedinger, 2002). In sum, there are persistent design challenges in how to design effective and efficient self-explanation that supports both learning and performance.

Designing evidence-based self-explanation scaffolding

To approach these challenges, we designed self-explanation support for a web-based educational software called an Intelligent Tutoring System (ITS) for algebra problem solving (Long & Aleven, 2014). In our design, self-explanation is *interleaved* with problem solving; learners are asked to *explain* the next strategic problem-solving step in the form of a diagram before doing the same step in symbols (Figures 1-3). They receive feedback from the ITS both on their *explanation* and their step using mathematical symbols. We designed the self-explanation support following several evidence-based principles from cognitive psychology, educational psychology, instructional design, and the learning sciences, which we describe below.

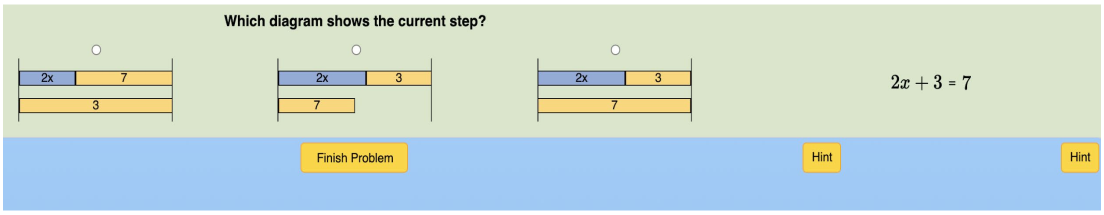

Figure 1. The ITS starts by asking a learner to select a correct diagram for the given equation. The ITS gives correctness feedback on the learner's choice of diagram.

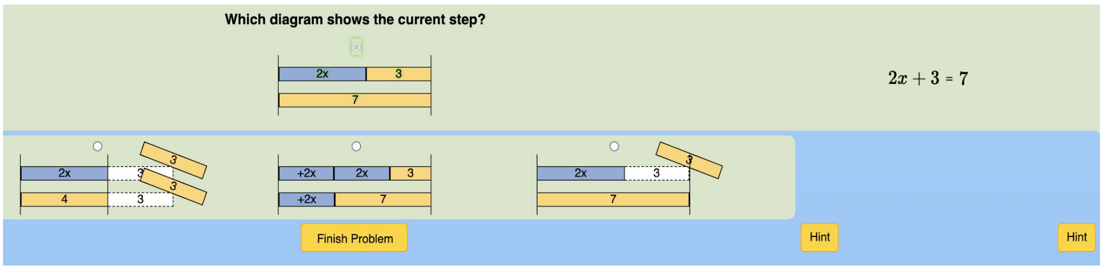

Figure 2. Next, the ITS asks the learner to *explain* (by selecting a diagram) what would be a correct and strategic step to take next. The ITS gives feedback on the choice of diagram.

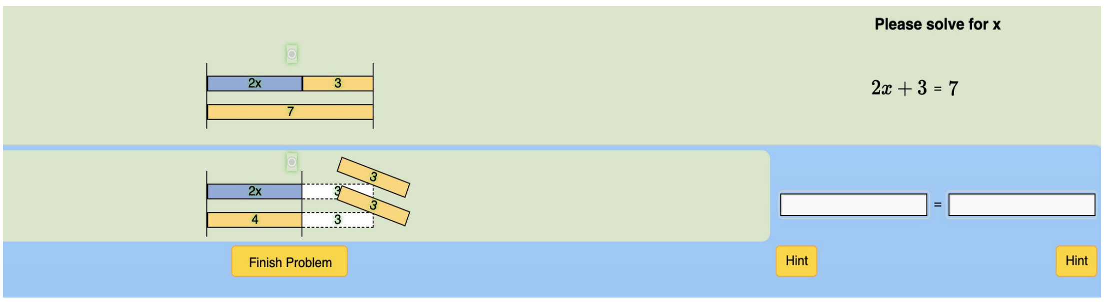

Figure 3. After selecting a correct and strategic step, the learner enters the step in symbols.

Visual representations designed to support students' conceptual understanding

Research has shown that visual representations can support conceptual understanding (Rau, 2017). Visual representations can depict information that is difficult to express through verbal means and can make important information salient. We chose a visual representation called *tape diagrams*, which are commonly used in algebra classrooms in countries such as Japan, Singapore, and the United States (Booth & Koedinger, 2012; Chu et al., 2017; Murata, 2008). Prior studies using tape diagrams in algebra problem solving show that tape diagrams help students gain conceptual understanding and avoid conceptual errors (Chu et al., 2017; Nagashima, Bartel et al., 2020). In particular, our own prior experiment found that diagrammatic self-explanation (in which students, after each equation-solving step, are asked to select, from three options, a diagram that corresponds to the step) helped learners gain conceptual knowledge in algebra (Nagashima, Bartel et al., 2020). In the present study, students are similarly asked to choose tape diagrams as a way to *explain* their steps, following the principle of *anticipatory* self-explanation (Bisra et al., 2018; Renkl, 1997), as explained next.

Anticipatory self-explanation to support understanding of problem-solving strategies

Anticipatory self-explanation is a type of self-explanation in which learners generate inferences about future steps. Previously, Renkl (1997) found that, when prompted to talk aloud while studying worked examples that provided solutions step-by-step, many successful self-explainers predicted solutions in advance. In algebra problem solving, such anticipatory self-explanation, rather than *post-hoc* self-explanation, can potentially support inference generation about strategic problem-solving steps (e.g., "what would be a good next step for the equation, $3x + 2 = 8$?"). If students consider the mathematical symbols as the target representation to learn, engaging in step-level anticipatory self-explanation could help students understand strategic next steps, which would improve both understanding of strategic solution steps and problem-solving performance. On the other hand, post-hoc self-explanation might not be particularly effective for helping students take strategic problem-solving steps.

Contrasting cases that differ on conceptual features and problem-solving strategies

The use of contrasting cases is an established instructional strategy in which learners are presented with contrasting examples that differ in meaningful conceptual aspects (Schwartz et al., 2011). Contrasting cases help learners notice meaningful differences. This instructional strategy is typically used with prompts for self-explanation, to encourage learners to cognitively and constructively engage with the cases (Sidney et al., 2015).

In the self-explanation support used in the current study, three options of tape diagrams are displayed, which differ in one conceptual aspect and one strategy-related aspect. For example, in Figure 2 the tutor displays three diagrams that represent a correct and strategic next step (diagram on the left), an incorrect option (diagram on the right, in which the subtraction is done on only one side of the equation) and an option that is correct but not strategic (diagram in the middle, in which $2x$ was added to both sides, which does not get the learner closer to the solution). This set of options allows learners to distinguish, not only between correct and incorrect steps, but also between *correct and strategic* steps and *correct but not strategic* steps. In problem states in which two correct and strategic steps are available (e.g., subtracting $2x$ from $8x = 2x + 6$ or dividing both sides by 2), the ITS shows those two options and one incorrect option. Engaging with contrasting cases prior to practicing the target problem-solving skill with symbols might be particularly meaningful, because students would be able to follow the selected diagram option when entering the solution step with symbols and thereby learn to use correct and strategic steps.

Present investigation and hypotheses

In the present study, we investigate the effectiveness of scaffolded self-explanation support on learning and performance. We hypothesize that (H1) the anticipatory diagrammatic self-explanation will promote students' conceptual understanding, enhance procedural skills, and help students learn formal algebraic strategies. We also hypothesize that (H2) the anticipatory diagrammatic self-explanation will enhance performance during problem solving in the ITS; students with the support will perform better on learning process measures (e.g., fewer hint requests and fewer incorrect attempts per step) while solving symbolic problem-solving steps, and they will solve a similar number of problems as students who do not receive the scaffolded self-explanation support.

Method

Participants

We conducted an *in vivo* experiment (i.e., a randomized controlled experiment in a real classroom context) at two private schools in the United States. Participants included 55 6th graders and 54 7th graders across nine class sections taught by four teachers. The experiment was conducted in October 2020, when both schools adopted a hybrid teaching mode in which the majority of students ($n = 102$) attended study sessions in-person and the rest of the students attended remotely (n = 7). Teachers reported that they had never focused their instruction on tape diagrams, although they indicated that some students might have seen tape diagrams in their learning materials.

Materials

Intelligent Tutoring System for equation solving

In addition to the anticipatory diagrammatic self-explanation ITS described above, we used a version that did not include tape diagrams (Figure 4) (Long & Aleven, 2014). In this No-Diagram ITS, students learn to solve equations step-by-step, but without diagrammatic self-explanation steps. All other features (e.g., step-level feedback messages and hints) are the same as in the version with tape diagrams. Both ITS versions had four different types of equations, which were chosen in consultation with the teachers (Table 1). We only used equations with positive numbers since tape diagrams were not found useful for representing negative numbers (Nagashima, Yang et al., 2020). Most of the participants in this study, per teachers' report, had seen or practiced Levels 1 and 2 problems, but had not learned Levels 3 and 4 problems.

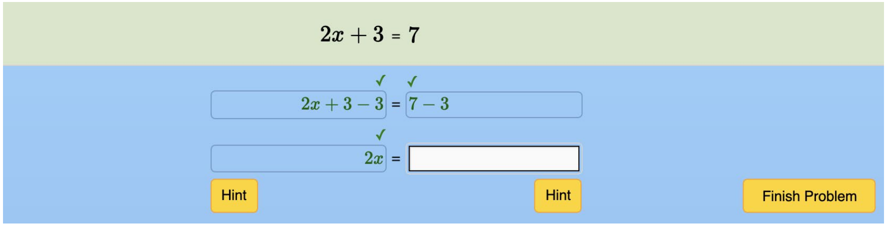

Figure 4. A version of ITS with no diagrammatic self-explanation.

Table 1: Types of equations the tutor contained and the number of problems in the tutor

	Equation type	Example	Number of problems in the ITS
Level 1	$x + a = b$	$x + 3 = 5$	4
Level 2	$ax + b = c$	$2x + 3 = 7$	5
Level 3	$ax + b = cx$	$5x = 3x + 2$	6
Level 4	$ax + b = cx + d$	$5x + 2 = 3x + 8$	13

Test instruments

We developed web-based pretest and posttest assessments to assess students' conceptual and procedural knowledge of basic algebra. The tests contained several items drawn from our previous work (Nagashima, Bartel et al., 2020) as well as new items. The conceptual knowledge items consisted of eight multiple-choice questions and one open-ended question, which assessed a wide range of conceptual knowledge constructs, including like terms, inverse operations, isolating variables, and the concept of keeping both sides of an equation equal. We also included four problem-solving items (e.g., "solve for x: $3x + 2 = 8$"), including two items that were similar to those included in the ITS and two transfer items involving negative numbers. We developed two isomorphic versions of the test that varied only with respect to the specific numbers used in the items; participants received one form as pretest and the other as posttest (with versions counterbalanced across subjects).

Procedure

The study took place during two regular mathematics classes. The classes were virtually connected to the experimenters and remote learners through a video conferencing system. Students were randomly assigned to either the Diagram condition or the No-Diagram condition. In the Diagram condition, students used the ITS with anticipatory diagrammatic self-explanation. In the No-Diagram condition, students used the ITS with no self-explanation support. The only difference between the Diagram and No-Diagram conditions was whether students self-explained their solution steps in the form of tape diagrams or not.

On the first day, all students first worked on the web-based pretest for 15 minutes. Then a teacher or the experimenter showed a 5-minute video describing how to use the ITS and what tape diagrams represent to all students. Next, students practiced equation solving using their randomly-assigned ITS version for approximately 15 minutes. On the second day, students started the class by solving equation problems in the assigned ITS for approximately 15 minutes. After working with the ITS, students took the web-based posttest for 15 minutes. Students were given access to both ITS versions a week after the study.

Results

Pre-post test results

One 6th grader was absent for the second day and excluded from the analysis; therefore, we analyzed data from the remaining 108 students, namely, 54 6th-graders (28 Diagram, 26 No-Diagram) and 54 7th-graders (27 Diagram, 27 No-Diagram). Open-ended items were coded for whether student answers were correct or incorrect by two researchers (*Cohen's kappa* = .91). Table 2 presents raw pretest and posttest performance on conceptual knowledge (CK) and procedural knowledge (PK) items. The maximum scores were 9 and 4, respectively.

Table 2: Means and standard deviations (in parentheses) for CK and PK on the pretest and posttest

	CK (maximum score: 9)		PK (maximum score: 4)	
	Pretest	Posttest	Pretest	Posttest
Diagram	3.53 (1.56)	3.80 (1.94)	1.51 (1.17)	1.73 (1.39)
No-Diagram	3.42 (2.02)	4.01 (2.27)	1.55 (.92)	1.83 (1.57)

We first tested hypothesis H1 (benefits of anticipatory diagrammatic self-explanation with respect to learning *outcomes*). We analyzed the data using hierarchical linear modeling (HLM) because the study was conducted in nine classes taught by four teachers at two schools. According to both AIC and BIC, a two-level model showed the best fit, in which students (level 1) were nested in classes (level 2). The inclusion of teachers (level 3) and schools (level 4) did not improve the model fit. We ran two HLMs with posttest scores on CK and PK as dependent variables, type of ITS assigned as the independent variable, and pretest scores (either CK or PK given the dependent variable) as a covariate. For both CK and PK, there was no significant effect of the Diagram/No-Diagram condition (CK: $t(99.3) = -1.030$, $p = .31$, PK: $t(99.4) = -0.292$, $p = .77$). We also ran two additional HLMs, regressing pretest-posttest gains for CK and PK (dependent variables) on type of ITS. There was a significant gain from pretest to posttest for CK ($t(108) = 2.778$, $p < .01$) but not for PK ($t(106) = 1.153$, $p = .26$), and no significant effect of ITS type. This suggests that students in both ITS conditions improved in conceptual knowledge but not in procedural knowledge.

We then analyzed the strategies that students used to solve the problem-solving items on the pretest and posttest. We adopted a coding scheme by Koedinger et al. (2008), which identified both formal (algebraic) and informal (non-algebraic) ways of solving equations (*Cohen's kappa* = .73; Table 3). We were primarily interested in the Algebra strategy because the goal of the ITS was to help students learn the formal algebraic strategy. We performed the strategy coding independent of the correctness coding used to calculate students' test scores. On the pretest, 11 students in the Diagram condition and 17 students in the No-Diagram condition used the Algebraic strategy on one or more problem-solving items. More students did so on the posttest; 26 students in the Diagram condition and 23 students in the No-Diagram condition used the Algebraic strategy. We used McNemar's test to compare the frequency of use of the Algebra strategy at pretest and posttest for each condition. The increase in frequency was significant ($p < .01$) for students in the Diagram condition but was not significant ($p = .11$) for students in the No-Diagram condition. This pattern also held when we limited the analysis to problems involving negative numbers (transfer problems); there was a pretest-posttest increase of only 1 student in the No-Diagram condition, but 12 students in the Diagram condition ($p < .01$). These findings suggest that, although students who learned with anticipatory diagrammatic self-explanation did not have greater gains on tests of conceptual and procedural knowledge, they were more likely to learn the formal algebraic strategy and to apply it to problems with no diagram support, even for problem types that they did not practice in the ITS (H1 partially supported).

Table 3: Strategies used to solve equations, adapted from Koedinger et al. (2008)

Strategy name	Description	Example answer for $3x + 2 = 8$
Algebra	Student uses algebraic manipulations to find a solution	$3x = 6$ $x = 6/3 = 2$
Unwind	Student works backward using inverse operations to find a solution	$8 - 2 = 6$ $6/3 = 2$
Guess and Check	Student tests potential solutions by substituting different values	$3*2 + 2 = 8$ $6 + 2 = 8$
Other	Student uses other non-algebraic strategies	$3 + 2 = 5$ $8/5 = 1.6$

Answer Only	Student provides an answer without showing any written work	$x = 2$
No Attempt	Student leaves problem blank or explicitly indicates that she/he does not know how to solve the problem	"I don't know"

Log data analysis on students' learning processes

Next, we tested hypothesis H2 (benefits of anticipatory diagrammatic self-explanation with respect to learning *processes*), using log data from the ITS. Specifically, we looked at "learning curves", which plot students' performance within the ITS over time (Rivers et al., 2016). Figure 5 depicts learning curves for the two conditions. The y-axis shows the error rate on steps in tutor problems, averaged across students and skills, and the x-axis shows the sequence of opportunities for practicing each skill. Learning curve analysis assumes that learning occurs when a curve starts with a relatively high initial error rate and gradually goes down as students practice the target skills. The curves are fit to student performance data using the Additive Factors Model (AFM), a specialized form of logistic regression (Rivers et al., 2016). In our study, students practiced a variety of equation-solving skills (e.g., subtracting variable terms). We expected that students who learned with diagrammatic self-explanation support would perform better in the ITS than their peers who did not receive the support (H2). On the symbolic problem-solving steps in the ITS (i.e., excluding the performance on the self-explanation steps, which only occurred in the Diagram condition), students in the Diagram condition had a lower error rate than students in the No-Diagram condition. Figure 5 shows learning curves averaged across all symbolic equation-solving skills students in both conditions practiced. Students in the Diagram condition made fewer errors than those in the No-Diagram condition, especially on the earlier opportunities. Both groups improved as they solved more problems (i.e., both curves show a gradual decline). After much practice, the No Diagram condition eventually lowered their error rate to the same level as the Diagram condition.

In parallel to the trend observed in the learning curves, we found that, when restricting the analysis to symbolic steps only (i.e., excluding diagrammatic self-explanation steps), students who received the self-explanation support trended toward using fewer hints ($t(89.52) = -1.812$, $p = .07$) and spent significantly less time on each symbolic problem-solving step ($t(99.51) = -2.238$, $p = .03$) than students who did not receive the self-explanation support (Table 4). The average number of problems solved in the ITS during the (fixed amount of) available time did not differ significantly across conditions, ($t(99.30) = -0.528$, $p = .60$) (Table 4).

In summary, the students in both conditions practiced a similar number of problems in the ITS in a similar amount of time overall, and the anticipatory diagrammatic self-explanation helped students spend less time and ask for fewer hints on symbolic steps (H2 partially supported). In addition, the learning curves indicate that students in both conditions learned equation-solving skills eventually, but the students in the Diagram condition learned them faster and had a smoother experience, with fewer errors.

Table 4: Average number of problems solved, number of incorrect attempts, number of hint requests, and average time spent on symbolic steps in the ITS (standard deviation).

	Average number of problems solved	Average number of hints requested per step	Average time spent per step
Diagram	15.40 (9.02)	0.68 (0.96)	15.99 (9.91)
No-Diagram	16.17 (11.16)	1.02 (1.38)	20.27 (13.95)

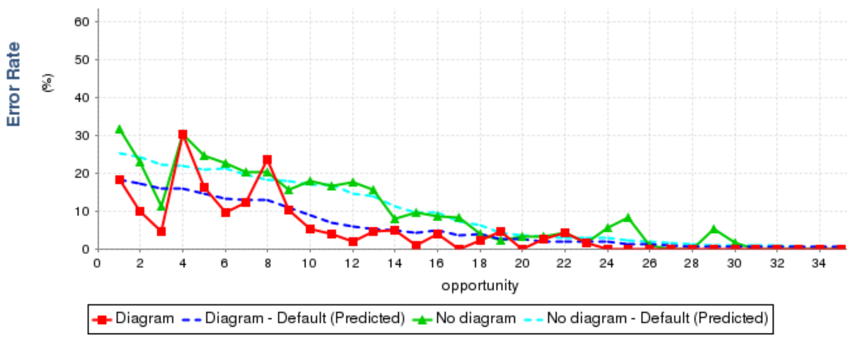

Figure 5. Learning curves for the Diagram condition (red) and the No-Diagram condition (green) averaged across the skills students practiced during the symbolic problem-solving steps. Dark and light blue lines show predicted curves based on the AFM (dark blue: Diagram condition, light blue: No-Diagram condition).

Discussion and Conclusion

Self-explanation has been shown to support student learning in various domains, but it is not easy to design appropriately-scaffolded self-explanation activities. Our study investigated the effectiveness of anticipatory diagrammatic self-explanation as a proposed approach to enhancing both learning and performance. We found that anticipatory diagrammatic self-explanation embedded in an Intelligent Tutoring System (ITS) helped students learn to apply a formal, algebraic problem-solving strategy to problems outside the ITS and to transfer problems involving negative numbers (H1). Anticipatory diagrammatic self-explanation also supported student performance within the ITS, measured by lower learning curves, less frequent use of hints, and less time spent on each symbolic equation-solving step (H2). Anticipatory self-explanation did not lead to differences in posttest scores, contrary to H1, but it helped students learn more efficiently; students learned the formal algebraic strategy while solving a similar number of problems with less time and fewer errors and hint requests, and they achieved similar gains on conceptual knowledge (H2).

We attribute these findings to the design and learning principles used in supporting anticipatory diagrammatic self-explanation. Specifically, we reason that the process of selecting the next correct-and-strategic problem-solving step, depicted diagrammatically, helped students perform better and faster on the corresponding step with symbols. On steps with symbols, students had a diagrammatic representation of the step available to them on the screen. They could refer to this representation as they sought to express the step using mathematical symbols. Engaging in this cognitive process may have helped students understand step-level formal strategies in a visual form (e.g., visually seeing that constant terms are taken out from both sides of an equation). Comparing and contrasting the different tape diagrams may have supported students in selecting steps that were both correct and strategic, and it may have helped them avoid using informal strategies, such as guessing. It may be, as well, that the better performance resulting from the anticipatory diagrams gave students a bit more confidence to take on the challenge of moving towards formal algebra.

An intriguing question is why the ITS with anticipatory diagrammatic self-explanation did not lead to greater gains in conceptual and procedural knowledge than the ITS with no diagram support. Regarding procedural knowledge, students did not make gains from pretest to posttest in either condition. Further, there was no difference in solving equations correctly between the conditions at post-test, even though students with diagrams exhibited greater use of formal problem-solving strategies. It is possible that students in the Diagram condition might need more practice in *correctly* applying the formal strategy they acquired in the ITS without the help of diagrams. In other words, it seems that students in the Diagram condition developed further towards formal use of algebra than their counterparts in the No-Diagram condition, but not yet to the extent that the use of the more challenging formal strategies paid off in terms of improved correctness. Regarding conceptual knowledge, it might be that the anticipatory use of diagrams in the ITS focused students primarily on *strategic* issues, as the diagrams were used in planning problem-solving steps. It may be that students need to engage in "principle-based explanation" (Renkl, 1997) to facilitate acquisition of conceptual knowledge (e.g., verbally explaining *why* the selected diagram is correct and strategic). It might also be that students with varying levels of prior knowledge benefit from diagrammatic self-explanation differently (Booth & Koedinger, 2012). Future studies should examine the effects of anticipatory diagrammatic self-explanation with students having varying degrees of prior knowledge and experience in algebra.

Our study has several limitations. First, the study was conducted with one specific type of diagrams, tape diagrams, and it focused on one specific task domain, equation solving in algebra. To understand how the results could generalize across domains and types of visual representations, more research is needed to examine the effects of anticipatory diagrammatic self-explanations. Also, it is possible that students were not very motivated to work on the posttest, especially given that the study was conducted remotely during the COVID-19 pandemic. This may have contributed to the absence of pretest-posttest gains in procedural knowledge, even though the learning curves suggest that learning occurred.

In summary, we designed a novel self-explanation scaffolding support for students in middle-school algebra, namely, anticipatory diagrammatic self-explanation. We investigated the effectiveness of this support embedded in an Intelligent Tutoring System, in a classroom study. We found that anticipatory diagrammatic self-explanation helped students learn formal algebraic strategies and perform better on problem solving, while making similar conceptual gains as students who did not receive the support. Our study contributes to the theoretical and practical understanding of how visual representations, contrasting cases, and anticipatory self-explanation can be integrated into scaffolding support that helps students learn and perform effectively and efficiently.

References

Ainsworth, S., & Loizou, A. (2003). The effects of self-explaining when learning with text or diagrams. *Cognitive Science, 27*(4), 669-681.

Aleven, V. A., & Koedinger, K. R. (2002). An effective metacognitive strategy: Learning by doing and explaining with a computer-based cognitive tutor. *Cognitive Science, 26*(2), 147-179.

Berthold, K., Röder, H., Knörzer, D., Kessler, W., & Renkl, A. (2011). The double-edged effects of explanation prompts. *Computers in Human Behavior, 27*(1), 69-75.

Bisra, K., Liu, Q., Nesbit, J. C., Salimi, F., & Winne, P. H. (2018). Inducing self-explanation: A meta-analysis. *Educational Psychology Review, 30*, 703-725.

Booth, J. L., & Koedinger, K. R. (2012). Are diagrams always helpful tools? Developmental and individual differences in the effect of presentation format on student problem solving. *British Journal of Educational Psychology, 82*(3), 492-511.

Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., & Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science, 13*(2), 145-182.

Chu, J., Rittle-Johnson, B., & Fyfe, E. R. (2017). Diagrams benefit symbolic problem-solving. *British Journal of Educational Psychology, 87*(2), 273-287.

Hodds, M., Alcock, L., & Inglis, M. (2014). Self-explanation training improves proof comprehension. *Journal for Research in Mathematics Education, 45*(1), 62-101.

Koedinger, K. R., Alibali, M. W., & Nathan, M. J. (2008). Trade-offs between grounded and abstract representations: Evidence from algebra problem solving. *Cognitive Science, 32*(2), 366-397.

Long, Y., Aleven, V. (2014). Gamification of joint student/system control over problem selection in a linear equation tutor. In S. Trausan-Matu, K. E. Boyer, M. Crosby, & K. Panourgia (Eds.), *Proceedings of the 12th International Conference on Intelligent Tutoring Systems* (pp. 378-387). New York: Springer.

Murata, A. (2008). Mathematics teaching and learning as a mediating process: The case of tape diagrams. *Mathematical Thinking and Learning, 10*(4), 374-406.

Nagashima, T., Bartel, A. N., Silla, E. M., Vest, N. A., Alibali, M. W., & Aleven, V. (2020). Enhancing conceptual knowledge in early algebra through scaffolding diagrammatic self-explanation. In M. Gresalfi & I. S. Horn (Eds.), *Proceedings of International Conference of the Learning Sciences* (pp. 35-43). Nashville, TN: International Society of the Learning Sciences.

Nagashima, T., Yang, K., Bartel, A. N., Silla, E. M., Vest, N. A., Alibali, M. W., & Aleven, V. (2020). Pedagogical Affordance Analysis: Leveraging teachers' pedagogical knowledge to elicit pedagogical affordances and constraints of instructional tools. In M. Gresalfi & I. S. Horn (Eds.), *Proceedings of International Conference of the Learning Sciences* (pp. 1561-1564). Nashville, TN: International Society of the Learning Sciences.

Rau, M. A. (2017). Conditions for the effectiveness of multiple visual representations in enhancing STEM learning. *Educational Psychology Review, 29*(4), 717-761.

Rau, M. A., Aleven, V., & Rummel, N. (2015). Successful learning with multiple graphical representations and self-explanation prompts. *Journal of Educational Psychology, 107*(1), 30.

Renkl, A. (1997). Learning from worked-out examples: A study on individual differences. *Cognitive Science, 21*(1), 1-29.

Rittle-Johnson, B., & Alibali, M. W. (1999). Conceptual and procedural knowledge of mathematics: Does one lead to the other?. *Journal of Educational Psychology, 91*(1), 175.

Rittle-Johnson, B., Loehr, A. M., & Durkin, K. (2017). Promoting self-explanation to improve mathematics learning: A meta-analysis and instructional design principles. *ZDM, 49*(4), 599-611.

Rivers, K., Harpstead, E., & Koedinger, K. R. (2016). Learning curve analysis for programming: Which concepts do students struggle with? In *Proceedings of the 2016 ACM Conference on International Computing Education Research* (pp. 143-151).

Schwartz, D. L., Chase, C. C., Oppezzo, M. A., & Chin, D. B. (2011). Practicing versus inventing with contrasting cases: The effects of telling first on learning and transfer. *Journal of Educational Psychology, 103*(4), 759.

Sidney, P. G., Hattikudur, S., & Alibali, M. W. (2015). How do contrasting cases and self-explanation promote learning? Evidence from fraction division. *Learning and Instruction, 40*, 29-38.

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Designing a Workshop to Support Teacher Customization of Curricula

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Abstract: We report on design-based research to refine a professional development workshop that supports teachers to customize online curricula. We iteratively design representations to make the knowledge integration pedagogy of the curricula visible. We study ways to make the work of students using the curricula actionable for participating teachers. We analyze participants' trajectories across the three iterations of the workshop. Initially, when participants realized they could customize the online curriculum, they developed feelings of ownership. Then, as participants deepened their understanding of the pedagogy, they began to use it to evaluate their own instruction. The trajectory culminated in participants connecting the pedagogy to student work from their own classroom. This led to a shift from focusing on remedies for misconceptions to seeking opportunities for building on students' nascent ideas when customizing. The workshop refinements empowered teachers to mobilize the pedagogy to interpret their students' work to inform their customization decisions.

Keywords: professional development, design-based research, technology-enhanced learning

Major issues and objective

When teachers implement new materials, they often customize instruction to align with existing classroom practice, particularly when the materials are designed based on a different pedagogical framework (Matuk, et al., 2016; Remillard, 2000; Schneider, et al. 2005). We explore the design and impact of a professional development workshop that takes advantage of technology to make curriculum designers' pedagogical design intentions visible alongside the curriculum and to enable teachers to use student work to plan customizations. We investigate how these supports enable teachers to appreciate the instructional goals of the materials and make connections to their students' ideas. The workshop supported teachers to customize instruction while attending to contextual constraints such as available classroom time and new standards. Furthermore, we designed technologies to help teachers with limited time to efficiently gather data to inform their customizations. Teachers often lack time to gather and respond to data they perceive as relevant (Kerr, et al., 2006) leading to mixed outcomes for students (e.g., Bismack et al, 2015; Davis, et al., 2017; McNeil, 2009). When teachers anchor their customizations in evidence, particularly from student work, they are able to make better customizations (Gerard, et al. 2010).

The workshop design draws on the notion of educative materials (e.g., Davis and Krajcik, 2005) to support the development of teachers' pedagogical design capacity (Brown, 2009; Brown & Edelson, 2003). To support teachers' pedagogical design capacity, we used a visual representation of the curriculum to make visible the pedagogical intention behind each activity in the units visible. The representation supports teachers to consider pedagogical implications as they planned revisions customizations to the curriculum. Because attending to student work and ideas has been shown to lead to more impactful instruction (e.g., Carpenter, et al., 1989; Coffey, et al., 2011; Fennema, et al., 1996), the workshop design guides teachers to examine student work collected in their own classrooms before they plan and implement their customizations. Specifically, the workshop design engages teachers in goal setting, analyzing student work to identify possible revisions, and designing customizations to the content and assessments embedded within the curriculum based on the analysis. The teachers then implement the customized units and return for a subsequent workshop. We refined the workshop based on the researcher and teacher reflections. We describe the three design iterations and the impact design changes had on teachers' use of student work and pedagogy. Our research questions are:

- How do improvements in the representation of the pedagogical framework underlying the curriculum facilitate teachers' consideration of pedagogy while customizing?
- How do refinements in providing access to student work support teachers to analyze that work as they customize the curriculum and their instructional approach?

Workshop design and iterations

Knowledge Integration framework

The Knowledge Integration (KI) Pedagogical Framework (Linn & Eylon, 2011) informs both the design of the interactive online science units and the workshop for teachers. The KI framework builds on constructivist perspectives (Inhelder & Piaget, 1958) that acknowledge that learners bring multiple prior ideas about scientific phenomena into the classroom and engages students in exploring their own and new ideas as they develop coherent understanding. In the context of the online science units, each lesson in the unit follows the research-based KI processes (Linn & Eylon, 2011). Units might start with activities where students make predictions about phenomena to *elicit* their prior knowledge. Next students might *discover* new ideas by engaging with interactive scientific models and discussing ideas with peers. Having accumulated a repertoire of ideas, students then *distinguish* among their ideas by testing their hypotheses in new scenarios or sorting which ideas are relevant under certain circumstances. Finally, students *reflect* on how their new ideas fit with their initial ideas.

We designed the professional development workshops following the same pedagogy as the interactive online science units and implemented the workshops with an online unit using the same technology as the online science units. By using the same technologies and pedagogy, the workshop modeled the instructional approach that it also advocated. Applying the KI framework to the workshop design, we first elicit teachers' ideas about their goals for student learning and what they hope to achieve using the unit. Next, we support the teachers to discover new ideas about how the unit is functioning in their classrooms through analysis of student work from the unit they are customizing. Teachers analyze student written explanations from key assessments embedded within the unit in conjunction with their recollections of student learning while teaching to determine areas of the unit that need to be strengthened in order for students to achieve mastery of aligned standards. This spurs the teachers to think of ways to customize the unit to strengthen student learning. Next, we introduce the idea of KI pedagogy as a means to distinguish which customizations to make and to consider where new activities fit with existing activities. By considering the pedagogical intention of the activities already in the unit, teachers can distinguish how best to integrate new activities. Finally, teachers teach the customized version of the unit and reflect on the efficacy of their customizations.

Making the Knowledge Integration pedagogy visible

At the workshop, we made the KI pedagogy in the unit visible. We made the KI pedagogy underlying the curriculum design visible in two ways. First, we supported teachers to connect KI processes such as distinguishing ideas to examples of activities in their existing practice. This deepened understanding of the pedagogy and of the characteristics of their own practice. Second, we used a visual representation of the KI processes underlying each activity in each unit to illustrate the interactions across processes (Figure 1). Lastly, we designed the workshop following the same pedagogical framework, KI, in order to model the instructional approach for teachers.

<u>Connecting KI to teacher practice</u>

In the first workshop we introduced the KI processes and some examples of activities from the units that engaged each process. Then, teachers brainstormed examples of their own activities and classroom practices, recorded them on post-it notes and sorted the examples by KI process. For example, teachers sorted their use of Know-Want to Know-Learned (KWL) charts as eliciting students' ideas and their use of Venn diagram graphic organizers as helping students distinguish among their ideas. In the second workshop, researchers similarly demonstrated examples from the units, and illustrated how each lesson of the unit engages students in each of the KI processes. Then teachers, many of whom were now familiar with the KI processes from the first workshop, met in small groups to discuss how their initial customization ideas aligned with the KI processes. In the third workshop, we supported the teachers to connect the KI pedagogy to their classroom assessment. We generated a sample of their students' responses from the log files and annotated the responses by their students' degree of integrated understanding.

<u>Visual representation of KI in the unit</u>

In the first workshop we used notecards to represent the lessons in each unit and color-coded post-it notes to represent the individual KI processes in each activity in the unit. Teachers found the notecards and post-its useful for understanding the design of the units and inserting their own activities. However, they were difficult to use during collaboration and hard to share. In the second workshop, we transitioned to using online technology to represent the units. We created an online version of the notecard and post-it approach using Google slides. We initially created one slide for each lesson, with colored boxes representing the processes in the activities. Teachers found this approach frustrating because they could not easily add their own activities and the activities were organized only by KI process and not sequential order.

(a) (b) (c)

Figure 1. Progression of the planning tool: (a) Year 1, (b) Year 2 and (c) Year 3. The color of each post-it/text box/slide represents the KI process engaged by the activity written on it: Pink for eliciting ideas, orange for discovering ideas, green for distinguishing ideas, and blue for reflecting on ideas.

The third representation improved the use of Google slides. Each activity in the lesson was assigned a separate slide, making it easy to rearrange the sequence and to add new activities. As shown in the figure, a black slide was used to indicate a new lesson. Each step in the lesson was then represented with a slide color-coded for the KI process it represented. This enabled participants to appreciate the overall structure of the unit as well as the role of each activity. Teachers could easily add new activities from color-coded template slides, prompting them to consider the KI process engaged by the activity they intended to add. This representation enabled greater collaboration among teachers customizing the same unit. It also gave teachers the ability to move between focusing on the details of one activity and focusing on the composition of the unit as a whole.

Making student work accessible

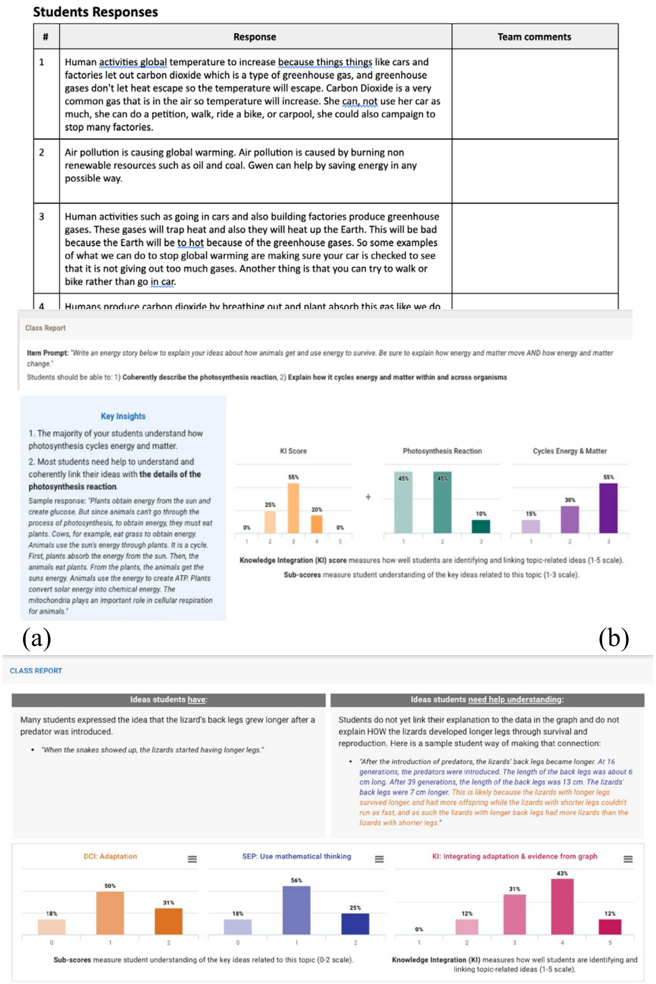
We engaged teachers in analysis of student work to help inform the customization decisions they make and refined our design for accessing student work across the three workshops (Figure 2). In the first workshop, teachers were grouped by unit. Each group received a spreadsheet with a random selection of student responses to an open explanation question in the unit. For each unit, we selected an open explanation question that assessed one of the standards addressed by the unit and came at a point after students had engaged in a full KI cycle around that standard. Teachers found the examples informative for discussing the unit and student understanding with their peers. They were reluctant to use these examples when customizing their own instruction, preferring to rely on their classroom observations (e.g. Kerr, et al., 2006). This motivated a redesign to connect teachers to their own students' work. In the second workshop, we developed learning analytics that summarized student work on an open explanation question in the unit and created personalized summaries for each teacher, based on the responses of their students. Teachers found the summary useful for explaining their students' progress and highlighting specific ideas that students needed more support to develop. They continued to also rely on their own recollections. In the third workshop, we enabled teachers to examine their student work immediately during instruction as well as during the workshop. During instruction, we used the learning analytics to generate the summary of student work as the teacher implemented the unit. Some teachers began identifying ways to build on their students' ideas when they got the summary during instruction and further developed their ideas during the workshop. At the workshop, we also engaged teachers in sorting a sample of their own students' responses by the level of KI to deepen their understanding. After they scored the responses, we had teachers compare their sorting with researchers' annotated comments on their students' responses. Thus, across the three workshops, we increased access to the specific student work generated in each teachers' classroom. We also helped teachers contextualize their student work by analyzing it at the same time as they were teaching the unit.

Methods

To answer our research questions, we analyzed teacher reflections across the three workshops held over three years. We connect themes from their reflections to the design iterations. We examine how teachers take advantage of their students' work and connect it to the KI pedagogy to strengthen evidence-based instruction. We had to omit analysis of a third aspect of the workshops, authoring technologies, due to space limitations. A subsequent paper will describe our refinements of the authoring technologies for teachers and the teacher reflections on it.

Participants

Seventeen teachers attended the first workshop, 19 teachers attended the second workshop, and 23 attended the third workshop. Only teachers who attended at least two of the workshops were included for analysis: twenty-five teachers representing 10 schools participated in at least two of the customization workshops. 56% of teachers were present during all three workshops.



(c)

Figure 2. Representation of students work to guide teacher customization in (a) year 1, (b) year 2 and (c) year 3.

Data sources and analytic procedure

Our data comes from teacher written reflections and researcher field notes from each of the three workshops, taking place in June of three consecutive years. At the end of each workshop teachers were asked to write reflections on their experience of the customization process. The online unit guiding the workshop logged teachers' responses to the reflection questions. Teacher responses to the following questions were used in our analyses:

- What are some things you learned or have taken away from engaging in this customization process and sharing with other teachers?
- Was this customization process and reflecting on the KI cycle helpful for you in thinking about how to achieve your NGSS and other curricular goals?
- Do you think you could use this process again to customize another unit you'd like to run?
- Please share any other reflections of feedback you have from the workshop

Teacher responses to all four questions in each year were combined to represent each teacher's reflection for that year. We began coding with three a priori categories reflecting our research questions and design focus on making pedagogy visible and using student work: *Value of KI Pedagogy,* which were statements about the affordances of considering KI during customization; *Use of Student Work*, which were statements about the utility of student work for customization; and *Value of Technology,* which were statements about engaging with the technology to author their customizations in the online units (omitted for this paper). We used inductive coding (Thomas, 2006) to determine themes within each of these categories to uncover trends in how teachers' reflections within the categories evolved over time. The themes represent the most common ideas teachers expressed in each category of reflection. The themes for each category can be found in Table 1. While analyzing the reflections, we noticed teachers expressing a sense of ownership of the curriculum, so we added *Sense of Ownership* as a category in our coding scheme. Changes in the way themes were represented and discussed at each workshop illustrate the ways in which the refinement of the workshop activities have shaped the teachers' experiences of and approach to customization.

Table 1: Coding scheme and emergent themes for teacher reflections on the workshops

Sense of Ownership	**Value of KI Pedagogy**	**Use of Student Work**	**Value of Technology**
Customization is possible	KI clarifies unit learning objective	Identify misconceptions	Newly aware of tool
Able to meet own goals	KI provides insight into unit design	Identify areas where students struggle	Need individual support to use tools
Able to meet student needs	KI informs customization decisions	Find student ideas to build on	Time consuming to use the tools
Opportunity to integrate resources	KI supports reflection on own practice	Customize to address student needs	Tools make customization accessible

Results and discussion

Teacher trajectory across three years

As we refined the workshop design, the focus of the teachers' reflections shifted (Figure 3). In the first year of the workshop, the most prominent category of teacher reflection was a newfound sense of ownership reflected in the possibility of engaging in customization. In year two, the focus shifted to the use of student work, which aligns with the redesign that provided teachers with student work from their own classroom. Finally, in year three, the focus shifted to the usability of the customization technology, the details of which are beyond the scope of this paper. We analyze the themes of workshop reflections within each category across the three years to connect workshop design features to the customization focus.

Sense of ownership

Ownership emerged as a focus of teacher reflections at the first workshop. The teachers were excited to realize that they could customize the online units. When expressing their sense of ownership after the first workshop, 43% of the 17 teachers present at that workshop wrote that the customization process had enabled them to envision a way to integrate the rest of their successful classroom activities into the online curriculum unit. For example, one teacher wrote that the customization process was "A bit overwhelming also, but very helpful to really make it part of the curriculum, intertwined with the actual curriculum, instead of using the WISE projects as separate from the curriculum." Another 33% expressed that engaging in the customization process enabled them to meet their own goals. One teacher wrote, "Yes, this process made it realistic to reach our curricular goals. I liked reflecting on what in the project is addressing what we want and thinking of ways to add offline [activities]." By the second and third years, there were fewer direct mentions of ownership. This decrease most likely reflects the teachers experiences in the preceding workshops. It became less of a novelty to customize online materials.

Value of KI pedagogy

Over the course of the three workshops, teachers shifted the way they spoke about the relevance of KI for their customization process. Knowledge integration was explicitly mentioned the most during the first year of the workshop. This reflects the amount of workshop time dedicated to developing an understanding of the pedagogical framework and the success of the activity where teachers connected the processes to their existing practice. During the first year, nine teachers mentioned insights from knowledge integration in their reflections. Teachers expressed a variety of insights afforded by the activities to make knowledge integration visible. Thirty percent of teachers described KI as useful for clarifying the learning objectives associated with each unit. Another 30% said the KI framework provided insight into the design intentions of the unit. Thirty percent also described KI as useful for deciding where and how to make customizations.

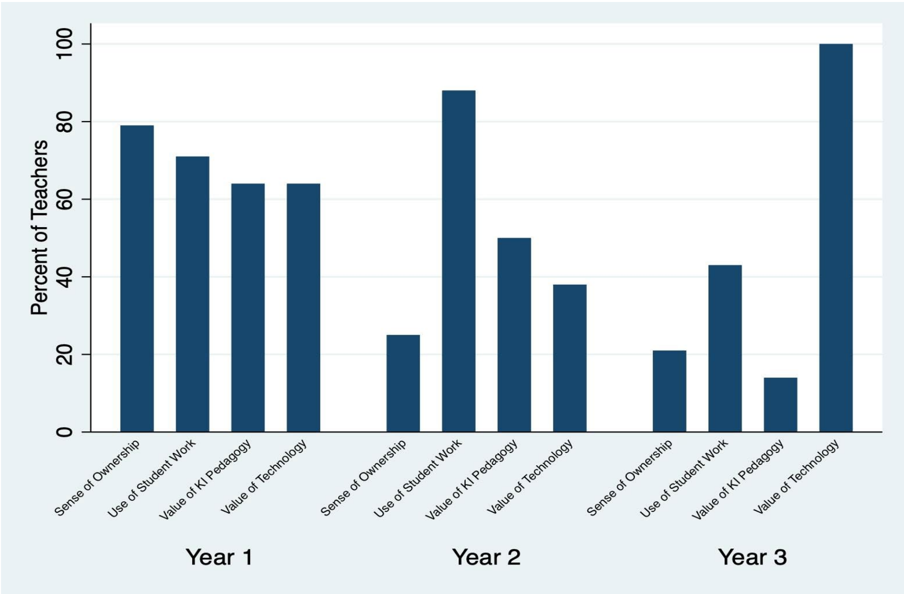


Figure 3. Percent of teachers in attendance during each workshop with reflections in each category

In the second and third years of the workshop, fewer teachers mentioned KI directly, consistent with their increased familiarity with KI and how it informs the units. Furthermore, evidence emerged that teachers had internalized the framework into their goal setting processes since half of the mentions of KI during the second year and all of the mentions during the third year consisted of teachers reflecting on how they implemented KI processes in their own practice. For example, one teacher in the second year wrote "I feel my teaching practice is strong in terms of eliciting ideas, good in terms of adding ideas, and fair in terms of reflecting. I would really like to work on the distinguishing part of the cycle" and another said, "I appreciate time to reflect on my practice and how to be more effective. Rarely do you get a chance during the year to think so deeply about the exact steps of how students connect new information to what they already know."

Thus, the workshop activities supported teachers to reflect on how their own pedagogy interacts with the pedagogy of the units and consider how to improve the units to facilitate student knowledge integration. As teachers considered the KI process of the activities in the units and the activities they were adding, they were supported to reflect on the types of thinking they were asking students to do in their own activities. Prior research shows that teachers typically neglect providing students with opportunities to distinguish among their ideas (Wiley, et al. 2019). By increasing teacher awareness of how their own classroom practices can engage each of the KI processes and supporting teachers to visualize the pedagogical design intention for each activity in the unit, the teachers were better able to evaluate their own practice using the pedagogy. As one researcher overheard during a workshop, a group of teachers exclaimed "We need more green [color of distinguishing activities]!" when evaluating their unit customizations.

Teacher use of student work

Across the three workshops, we refined the activities to guide teacher engagement with student work, increasing access to the specific student work generated in each teacher's own classroom. Teachers shifted how they discussed the relevance and utility of student work for informing their customizations as the workshops progressed. These shifts corresponded with the changes in how we engaged teachers with student work during the workshop. While only one teacher mentioned the use of student work during the first workshop, student work was the most prominent category during the second workshop. This prominence corresponds with our change to showing teachers student work from their own students and introducing learning analytics to provide each teacher with a summary of the ideas in their class. In year two, 55% of teachers found the summaries of student work to be helpful for identifying areas where students were struggling or for identifying misconceptions. This is notable given the open-ended nature of the reflection questions and teachers' specific focus on understanding their students' struggles. One teacher reflected, "Students are struggling to incorporate evidence from models in their explanations." A smaller percentage of teachers (22% each) mentioned in their reflections that analyzing student work was useful for identifying productive student ideas to build on or expressed a direct connection between the ideas in their students' work and their plans for how to customize.

By year three, we were excited to note, teachers' reflections shifted away from identifying incorrect ideas towards using student work to find productive ideas to build on to help students develop more integrated perspectives. The majority of teachers' reflections on student work (86%) expressed a connection between the ideas they saw and the customizations they were planning. The remaining 14% said they found ideas to build on. For example, one teacher wrote, "I love the reflective time and the strategies you teach me to become a wiser user of my student responses/data. I also love the ways you present for thinking about teaching to the needs of my students. I think being able to customize the units to address my preconceptions in student knowledge integration and/or ways of teaching will empower my students to become stronger explainers and reasoners." Another teacher reflected, "due to the sorting activity, I was able to recognize the gaps in student achievement, which spurred me to create scaffolds and re-plan steps for the unit." This shift towards viewing student ideas as productive was more pronounced as the teachers had the opportunity to review their class summary during instruction and to use it for in-the-moment teaching customizations. When they saw it again during the workshop, they were able to reflect on their customization goals. This reaction is consistent with the multiple opportunities to reflect on the same student work. It also aligns with the opportunity to use the class summary during instruction to incorporate the classroom context as teachers got started on building on students' ideas.

Conclusions

We iteratively designed a professional development workshop intended to support customization by making the pedagogy behind our curriculum visible and engaging teachers in analysis of their students' work. We found that the activities designed to make KI visible were initially successful and, as they were improved, became more useful to the teachers. The representation in the first workshop made the instructional goals of each unit explicit and enabled teachers to articulate the connections to their own goals. The move to Google slides and the improvements in the representation provided a more robust view of the KI pedagogy, supported multiple perspectives on the unit, and increased opportunities for teachers to collaborate on customizations. Furthermore, refining the representation of the pedagogy strengthened teachers' ability to integrate their own activities into the unit and led to increased sophistication of the reflections on their own pedagogy as they customized the units

Our methods for making student work accessible increased the likelihood that teachers considered student work as evidence to inform their customizations. This was especially true if the student work was from their own classroom and was directly related to their interactions with students while teaching. In addition, teachers reported that access to the class summary during instruction enabled them to build on their students' ideas. Further, the combination of the class summary and examples of their students' responses provided teachers with a coherent picture of their students' needs and shifted them away from a deficit view of students' ideas as misconceptions or wrong to a KI view of the value of building on student ideas to encourage coherent understanding.

These results illustrate the challenges and value of careful design of teacher workshops. They show that making the pedagogy visible when engaging teachers in customizing curricula has the potential to extend beyond the unit being customized. Teachers reported using the KI pedagogy in their own planning and to connect their offline activities to the online curriculum. These results show the benefit of making student work accessible to help teachers incorporate all their students' ideas rather than only those they recollect at the workshop. The results support viewing the customization process as a trajectory. It starts with ensuring that teachers feel ownership of the customization process. It continues by deepening understanding of the pedagogy behind the instructional design so that the participants integrate it into their own pedagogy. It culminates in connecting the pedagogy to the learning activities of the students. In this case, illustrated by a shift from a focus on addressing misconceptions to a focus on building on the nascent ideas developed by the learners.

References

Bismack, A. S., Arias, A. M., Davis, E. A., & Palincsar, A. S. (2015). Examining student work for evidence of teacher uptake of educative curriculum materials. *Journal of Research in Science Teaching, 52*(6), 816-846.

Brown, M. W. (2009). The teacher-tool relationship. *Mathematics teachers at work: Connecting curriculum materials and classroom instruction*, 17-36.

Brown, M., & Edelson, D. (2003). *Teaching as design: Can we better un- derstand the ways in which teachers use materials so we can better design materials to support their changes in practice?* (Design Brief). Evanston, IL: Center for Learning Technologies in Urban Schools.

Carpenter, T. P., Fennema, E., Peterson, P. L., Chiang, C. P., & Loef, M. (1989). Using knowledge of children's mathematics thinking in classroom teaching: An experimental study. *American educational research journal, 26*(4), 499-531.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of research in science teaching, 48*(10), 1109-1136.

Davis, E. A., & Krajcik, J. S. (2005). Designing educative curriculum materials to promote teacher learning. *Educational researcher*, 34(3), 3-14.

Davis, E. A., Palincsar, A. S., Smith, P. S., Arias, A. M., & Kademian, S. M. (2017). Educative curriculum materials: Uptake, impact, and implications for research and design. *Educational Researcher*, *46*(6), 293-304.

Fennema, E., Carpenter, T. P., Franke, M. L., Levi, L., Jacobs, V. R., & Empson, S. B. (1996). A longitudinal study of learning to use children's thinking in mathematics instruction. *Journal for research in mathematics education*, 403-434.

Gerard, L. F., Spitulnik, M. W., & Linn, M. C. (2010). Teacher use of evidence to customize inquiry science instruction. *Journal of Research in Science Teaching*, 47, 1037–1063.

Kerr, K. A., Marsh, J. A., Ikemoto, G. S., Darilek, H., & Barney, H. (2006). Strategies to promote data use for instructional improvement: Actions, outcomes, and lessons from three urban districts. *American journal of education, 112*(4), 496-520.

Linn, M. C., & Eylon, B. S. (2011). Science learning and instruction: Taking advantage of technology to promote knowledge integration. Routledge.

Matuk, C., Gerard, L., Lim-Breitbart, J., & Linn, M. (2016). Gathering requirements for teacher tools: Strategies for empowering teachers through co-design. *Journal of Science Teacher Education*, *27*(1), 79-110.

McNeill, K. L. (2009). Teachers' use of curriculum to support students in writing scientific arguments to explain phenomena. *Science Education, 93*(2), 233-268.

Inhelder, B., & Piaget, J. (1958). *The growth of logical thinking from childhood to adolescence: An essay on the construction of formal operational structures* (Vol. 22). Psychology Press.

Remillard, J. T. (2000). Can curriculum materials support teachers' learning? Two fourth-grade teachers' use of a new mathematics text. *The Elementary School Journal, 100*(4), 331-350.

Schneider, R. M., Krajcik, J., & Blumenfeld, P. (2005). Enacting reform-based science materials: The range of teacher enactments in reform classrooms. *Journal of Research in Science Teaching, 42*(3), 283-312.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. *American journal of evaluation, 27*(2), 237-246.

Wiley, K., Bradford, A., & Linn, M. (2019). Supporting Collaborative Curriculum Customizations Using the Knowledge Integration Framework. In Lund, K., Niccolai, G. P., Lavoué, E., Hmelo-Silver, C., Gweon, G., & Baker, M. (Eds.), A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 1 (pp. 480-487). Lyon, France: International Society of the Learning Sciences.

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Promoting Epistemic Understanding and Collective Knowledge Advancement through a Design Trajectory of Knowledge Building

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Abstract: This study presents a two-year design trajectory of knowledge building and examines the process of how students' epistemic understanding of knowledge building promoted knowledge advancement under the mediation of their engagement on Knowledge Forum, a computer-supported environment. Four iterative studies on the same cohort (*n* =211) from four large Grade-Four classes in China were conducted based on increasing complex knowledge-building designs over two years. Quantitative results obtained from the semantic network analysis of word networks show collective knowledge advancement over time. Qualitative analyses of interviews and questionnaires reveal the developmental trajectory of students' epistemic understanding started from idea-sharing to theory building, collective cognitive responsibility, and finally to progressive knowledge building. As indicated by further path analysis, students' epistemic understanding of knowledge building predicted their Knowledge Forum interaction and depth of Knowledge Forum discourse, which in turn exerted influences on collective knowledge advancement and individual scientific understanding. This study sheds light on the design trajectory of knowledge building to promote epistemic changes and collective knowledge advancement.

Introduction

Recent science education reforms have emphasized the need to engage students in authentic, real-world scientific practices (NGSS Lead States, 2013). Despite the great interest in this field, such engagement is often superficial and limited to fixed and pre-designed activities (Chinn & Malhotra, 2002). Thus, designing an environment that engages students in authentic scientific practices and promotes collective knowledge advancement becomes a major challenge.

In the learning sciences, the focus has long been put on the creation of authentic environments that mirror the practices of specific disciplines (Danish & Gresalfi, 2018). *Knowledge Building*, a major research theme in the learning sciences, relies on the creation of scientific communities (Bereiter et al., 1997). It aims to transform education by introducing the concept of knowledge-building communities (Scardamalia & Bereiter, 2014). Specifically, members of a knowledge-building community work together to foster collective knowledge advancement (Scardamalia, 2002). An online platform Knowledge Forum was developed to support such creative communities' work, which allows students to post problems, co-construct explanations, and conduct sustained inquiries for collective knowledge advancement. The community created by knowledge building plays a vital role in meeting the need for knowledge creation and education innovation. This is particularly important with regard to science education when authentic scientific practices are emphasized. However, most of the knowledge-building studies in the literature lasted a few months or even weeks, while students' engagement in knowledge building has not been investigated over a long time, even though the sustained practice is an important step to examine knowledge building. Thus, two considerations were inspired: (1) how to sustain a long-term development of knowledge-building communities to deploy students' high-level epistemic agency in Knowledge Forum engagement; (2) how to engage students in the kind of knowledge building carried out by scientists, who progressively extend existing knowledge.

As pointed out by Bereiter et al. (2019), the high-level epistemic agency requires students to view their work from a broader perspective, which can be achieved through students' meta-knowledge of knowledge building. Just as knowledge about knowledge (e.g., the nature of science) is necessary for scientific practice, knowledge about knowledge building lays a foundation for students to achieve collective knowledge advancement. Bereiter et al. (2019) discussed the importance of discourse as both an epistemic object of inquiry and a form of explicit knowledge on knowledge building. Several studies have explored how students gain meta-knowledge from knowledge-building discourse (Chan et al., 2019; Tong et al., 2018) and found that students with better insights into knowledge building had a deeper scientific understanding, while those with a deeper understanding of knowledge-building principles had deeper Knowledge Forum engagement.

Accordingly, this study developed a design trajectory and investigated how knowledge building of the same cohort progressed over the two years, focusing on their epistemic understanding of knowledge building.

Specifically, whether and to what extent students made collective knowledge advancement across studies, how their epistemic understanding changed over time, as well as what was the interplay among students' epistemic understanding, Knowledge Forum engagement, collective knowledge advancement, and individual scientific understanding were explored. The research questions are: (1) Did students improve on collective knowledge advancement over time with progressive designs? (2) What characterized students' epistemic understanding of knowledge building, and what was the developmental trajectory of their epistemic understanding across studies? (3) What characterized students' engagement on Knowledge Forum, and what was the interplay among their epistemic understanding, Knowledge Forum engagement, and knowledge advancement?

Methods

Participants

A total of 211 students from four Grade Four (initially) classes participated in this research: Class A (n = 54), Class B (n = 53), Class C (n = 51), and Class D (n = 53). They had no experience of online discussion before the first study. The first author also took on the role of the teacher in the study.

Design trajectory of knowledge building

Four iterative studies were conducted following increasing complex knowledge-building designs over two years. After establishing a basic knowledge-building culture by using Knowledge Forum (KF) (Study 1), the meta-discourse aspect was developed for productive KF discourse (Study 2), followed by the use of *Idea-Friend Maps* (IFM, external representations of a learning analytics tool present data and evidence exported from KF) for collective cognitive responsibility (Study 3). Finally, the refined IFM design supported students along their co-designed collective journey for progressive knowledge building (Study 4). From Study 2, experimental and comparison conditions were included to examine the effects of the knowledge-building designs. Figure 1 depicts the progressive design of KF views combined with the design trajectory of knowledge-building across studies. Figure 2 shows the original and refined IFM used in Studies 3 and 4. Details of the role of IFM designs in scaffolding knowledge building have been reported in Feng et al. (2020).

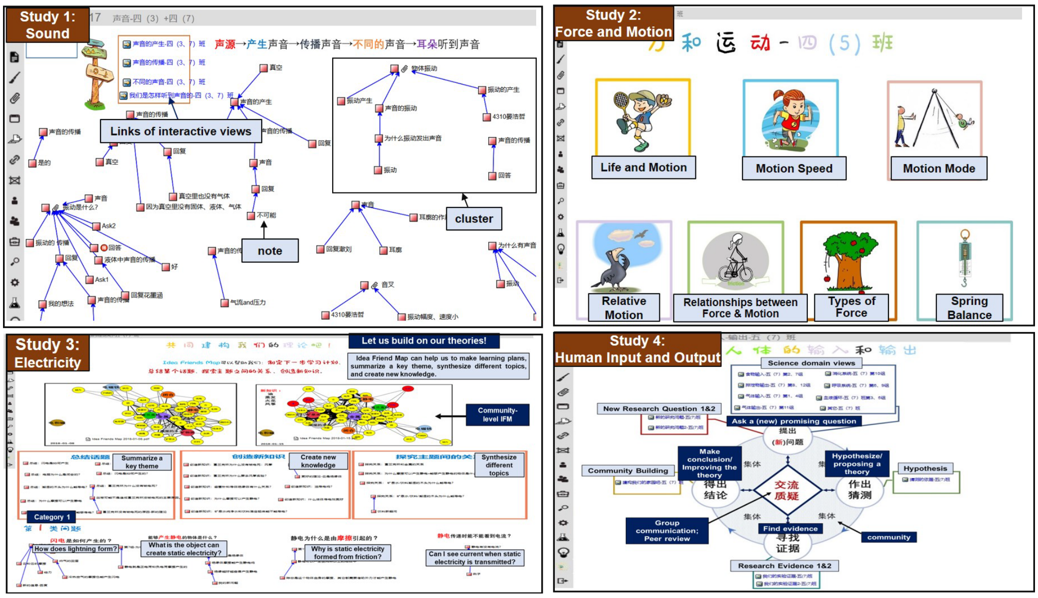


Figure 1. Progressive design of KF views across studies

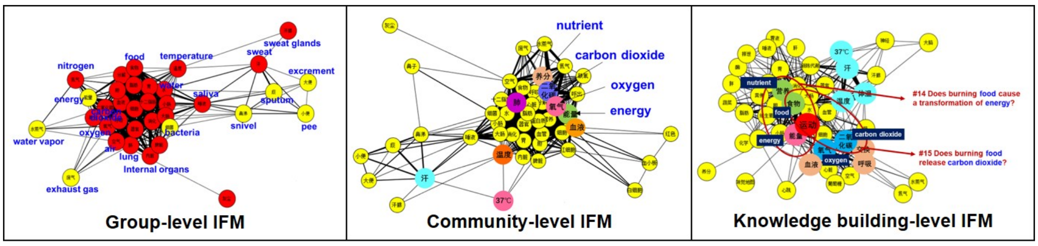


Figure 2. Original IFM: group and community-level IFM. Refined IFM: all three levels of IFM

Study 1 (November 2016 – January 2017)
This study aimed to implement knowledge building as an initial attempt in four classes in China. Students learned *Sound* in each class received the same pedagogy, which encouraged idea-sharing and idea improvement.

Study 2 (April 2017 – June 2017)
The insights gained from Study 1 informed this study, which was aimed at promoting knowledge-building discourse through meta-discourse when studying *Force and Motion*. A face-to-face whole classroom meta-discourse of knowledge-building was first designed as an intervention and focused on theory building and collective cognitive responsibility. A face-to-face offline group meta-discourse was also designed to provide opportunities for students to practice theory building and collective cognitive responsibility. The experimental classes (Classes A and C) received both designs, whereas the comparison classes (Classes B and D) only took part in the whole-class meta-discourse.

Study 3 (November 2017 – January 2018)
Based on the first two studies' findings, this study expected to promote students' collective cognitive responsibility when they were learning about *Electricity*. Students worked like scientists as a community to pursue different but related ideas and conceptualize the community's current state and future direction. Two experimental factors were included. Factor 1 is the IFM (Figure 2), which provides external representations using the learning analytics tool KBDeX (Oshima et al., 2012). Factor 2 refers to a community view (Figure 1) created on KF in the final phase to help conceptualize collective ideas and promote theory building (Zhang et al., 2009). A 2 (*IFM* vs. no *IFM*) × 2 (*Community view* vs. no *Community view*) factorial experiment was conducted to explore these two factors' influences. Class A used neither of the two factors, Class B used Factor 2, Class C used Factor 1, and Class D used both factors.

Study 4 (April 2018 – June 2018)
This study was an extension of Study 3 and aimed to enhance progressive knowledge building using the refined IFM and a co-designed collective journey of knowledge building, which were applied when students were learning *Human Input and Output*. Classes A and B were the comparison classes and used the original IFM, which provided the same learning environment as Class C in Study 3, whereas Classes C and D, as experimental classes, used the refined IFM and took part in the co-designed collective journey of knowledge building.

Table 1 illustrates the design challenges, learning problems, knowledge-building goals, and key designs of the design trajectory.

Table 1: Design trajectory of knowledge building over two years

Study	Challenge	Learning problem	Knowledge-building goal	Key design
1	Knowledge building culture	How to work like researchers to collaborate with peers?	Idea-sharing and idea improvement	• Engagement in sharing and improving ideas
2	Intensive thread building	How to work like research groups to develop specific research topics?	Theory building	• Whole classroom meta-discourse • Offline group meta-discourse
3	Extensive thread building	How to work like researchers as a community to pursue different but related ideas?	Symmetric knowledge advancement	• Fixed/interactive/opportunistic collaboration • The group-level IFM for visualizing similarities and differences in ideas of different groups
	Collective ideas mapping	How to identify the current state and future direction of community knowledge?	Collective cognitive responsibility	• The community-level IFM for visualizing collective ideas • Design of a community view in the Knowledge Forum
4	Progressive knowledge building	How to sustain progressive knowledge building?	Progressive knowledge building	• A co-designed collective journey of knowledge-building • The knowledge building-level IFM for visualizing boundaries of ideas

Data sources
Multiple data sources were collected across the four studies, including pre-/post-science learning tests, KF notes, interviews, and questionnaires.

Analyses and results

RQ1: Did students improve on collective knowledge over time with progressive designs?

Based on knowledge-building research on KBDeX (Oshima et al., 2012), a higher Total Degree Centrality (TDC) means a denser network of domain keywords and discourse, denoting more collective knowledge advancement (Oshima et al., 2017). Using the KBDeX word networks, we can track how different groups evolved in their collective KF work across phases and studies. Figure 3 shows the changing word networks of Class D exported from KBDeX across studies, with an upward trend in the TDC and network density. Class D shared the same pedagogy design with all the other classes in Study 1; acted as a comparison class in Study 2 (adopting the whole classroom meta-discourse rather than the offline group meta-discourse); used both IFM and the rising-above community view in Study 3; and employed both the co-designed collective journey of knowledge building and the refined IFM in Study 4. More interestingly, Class D's network was more decentralized before Study 3 when it acted as a comparison class. Afterward, both its TDC and network density increased over time. These results indicate that students promote collective knowledge advancement over time, particularly in the last two studies.

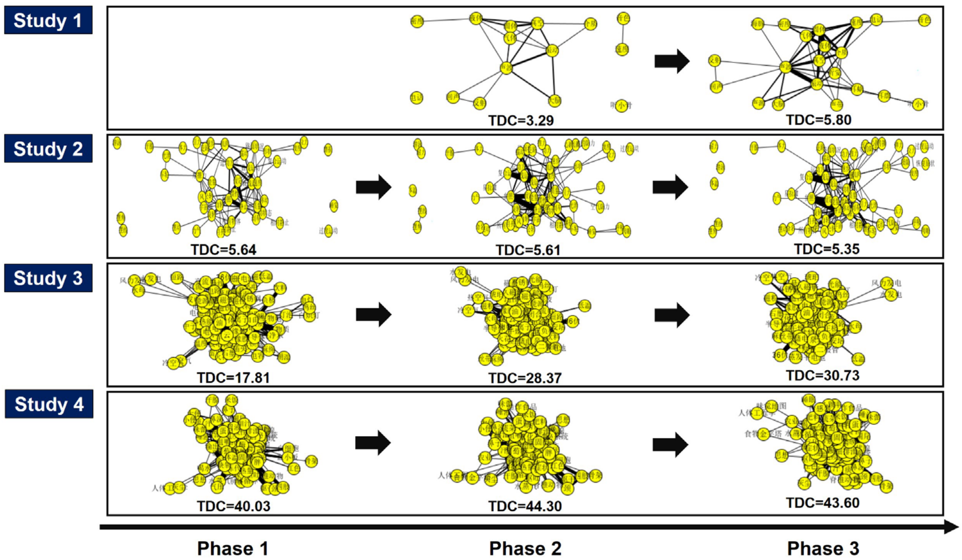


Figure 3. Changing word networks of Class D across studies

RQ2. What characterized students' epistemic understanding of knowledge building, and what was the developmental trajectory of their epistemic understanding across studies?

To investigate epistemic understanding and specifically, how students understood the goals and processes of knowledge building, and challenges they faced and solutions proposed, we interviewed around 30 students in the first three studies and collected written questionnaires using similar questions from 211 students in the final study. A set of codes was then developed and used by a second-rater to code all the transcriptions of students' answers. The inter-rater reliability was .79 for goals and processes and .80 for challenges and solutions (Cohen's kappa).

Understanding of knowledge building goals and processes

Students were required to answer several similar questions in each study, including "What did you think knowledge building is?" and "What is your biggest change in the process of knowledge-building learning?" Qualitative coding of students' responses resulted in five major levels (Table 2).

Table 2: Levels of epistemic understanding of knowledge-building goals and processes

Level	Goal	Process
1	Gain more knowledge	Like a *solitaire game*: ask a question, answer it, and then ask a new question.
2	Get the right answer	Like *climbing stairs*: ask a question, answer it, and then ask a new question at a higher level.
3	Develop ideas	Solve problems, improve ideas, and pursue sustained inquiries.
4	Collective cognitive responsibility	Promote the advancement of collective knowledge, such as synthesis, shared regulation, and lending support.
5	Progressive knowledge building	Ask a question → Hypothesize/Propose a theory → Find evidence → Make a conclusion/Improve the theory → Ask a new question. Every process was conducted in the community through group communication and peer review.

Reflection on knowledge-building challenges and solutions

Students were required to answer similar questions in each study, such as “What impressed you most in the learning process?” “What experiences make you like a scientist?” “If other students want to conduct knowledge-building learning, what advice do you want to give them?” and “What do you want to get from knowledge building for your future study?” Qualitative coding of students’ responses also resulted in five major levels, which were consistent with Table 2. Three considerations for progressive knowledge building were also identified as synthesis and sustained inquiry, group communication and peer review, and community and individual development.

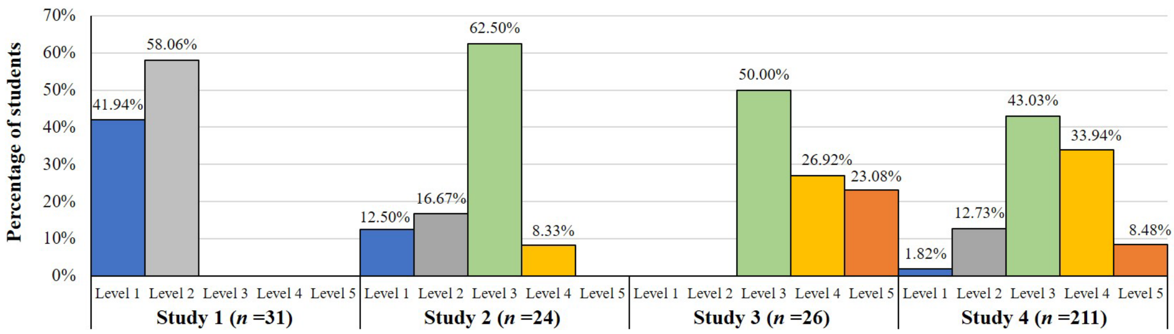
Synthesis and Sustained Inquiry. Some students answered that they should focus on synthesizing collective ideas. For example, when being asked, “Which experiences make you like a scientist in the process of knowledge-building learning?” student c707 answered that “Synthesize ideas as much as possible.” Some students perceived knowledge-building challenges as creating new questions and hypotheses. For instance, concerning the question “If other students want to conduct knowledge-building learning, what advice do you want to give them?” students c724 and c338 answered, “You have to learn to ask questions and do not obey authorities” and “Hypothesize like a little scientist, do not be afraid of making mistakes” respectively. More profoundly, student c703 unpacked the relationship between synthesis and sustained inquiry, “When conducting knowledge-building learning, they (new learners) should build on our existing knowledge (KF writings) and spend more time in new fields, to create new knowledge better.” These results indicate that conducting a sustained inquiry based on the synthesized ideas might be effective in progressive knowledge building.

Group Communication and Peer Review. Some students reported that the challenge was to enhance group communication and collaboration. For instance, in terms of the question “What impressed you most in the learning process?” student c752 claimed that “Conduct an experiment with other groups and discuss with classmates.” More profoundly, some students believed the challenge was to conduct a peer review on the theory’s scientific nature through communication and collaboration. For instance, when being asked, “If other students want to conduct knowledge-building learning, what advice do you want to give them?” student c740 proposed that “Each student first asks a question, then the students who ask the same questions are assigned to the same group. After a few weeks, students from different groups can communicate and question each other.” These results indicate conducting group communication for peer review as another possible way of progressive knowledge building.

Community Development and Individual Development. Some students perceived that the challenge was to promote collective knowledge advancement. For example, student c703 reported that “When learning *Human Input and Output,* they (new learners) should build on our existing knowledge (KF writings) and spend more time in new fields, to create new knowledge better.” In contrast, some focused on individual development. For instance, student c733’s answer to the question “What do you want to get from knowledge building for your future study?” was, “I want to create a model to promote my knowledge-building learning.” More profoundly, student c729 revealed how to deal with the relationship between the community and individual development by answering that “I want to create a new KF view to visualize my learning process.” These results demonstrate that contributing to collective knowledge advancement would benefit individual learning, while a clear understanding of individual learning processes would, in turn, promote progressive knowledge building.

Developmental trajectory of epistemic understanding

We calculated the percentage of each level from each study to identify the developmental trajectory of students’ epistemic understanding (Figure 4).



Note. Level 1: gain more knowledge; Level 2: get the right answer; Level 3: develop ideas; Level 4: collective cognitive responsibility; Level 5: progressive knowledge building.

Figure 4. Percentages of different levels of students’ epistemic understanding across studies

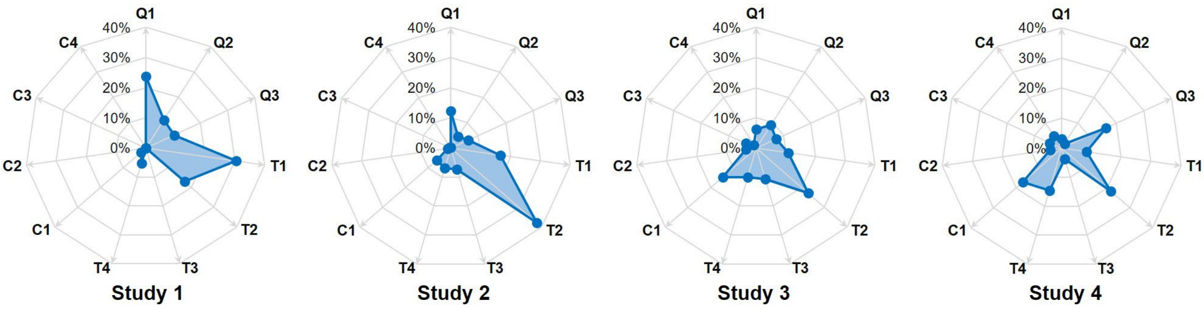
Results show that students understood knowledge building at relative lower levels in Study 1 (i.e., gaining more knowledge or getting the right answer). More than half of students considered it as a process of developing ideas in Study 2, while a significant quarter perceived it as collective cognitive responsibility or progressive knowledge building in Study 3. Notably, even in the large sample-size questionnaire analysis in the final study, a significant one-tenth of students identified knowledge building as progressive knowledge building. These results suggest that students' epistemic understanding developed from idea-sharing to theory building, collective cognitive responsibility, and finally to progressive knowledge building.

RQ3. What characterized students' engagement on Knowledge Forum, and what was the interplay among their epistemic understanding, Knowledge Forum engagement, and knowledge advancement?

Student engagement on KF in iterative studies (Studies 1-4)

We adopted KF log data (e.g., #notes created) to assess students' KF participation and interaction. Take Class D as an example who created an average of less than 2 KF notes in Study 1 and less than 7 notes in Study 2, while around 15 notes in Studies 3 and 4. In the final study, the average numbers of notes created, notes built on, notes read, scaffolds used, views worked, and references used were 13.67, 6.92, 110.02, 21.62, 6.77, and 3.83, respectively. These figures reveal students' improved KF participation and interaction over time.

We also examined the depth of KF discourse with a coding scheme composed of several categories, including *Questioning*, *Theorizing*, and *Community*. These categories depict cognitive, metacognitive, social, and community aspects of knowledge building (Figure 5). Two raters independently coded about 30% of all the notes. The inter-rater reliability was .75 for *Questioning*, .88 for *Theorizing*, and .79 for *Community* (Cohen's kappa). According to Figure 5, students showed low-level *Questioning* (Q1) and *Theorizing* (T1) in Study 1, an improvement of *Theorizing* (T2) in Study 2, usage of *Community* in Study 3, and the abilities to use high-level *Questioning* (Q3), *Theorizing* (T4), and *Community* (C3 and C4) in the final study. These results indicate students' engagement in progressively deepening discourse over time. Previous qualitative analyses of Studies 3 and 4 also demonstrate the developmental patterns of students' KF discourse, such as *Community-bridging knowledge* (C1) → *Community-synthesis* (C3) → *Questioning-sustained inquiry* (Q3) → *Theorizing-improving an explanation* (T4) (Feng et al., 2020). This analysis can be used to examine longitudinal changes for 4 studies.



Note. *Questioning*: Q1= *fact-oriented;* Q2= *explanation seeking;* Q3= *sustained inquiry. Theorizing:* T1= *simple claim;* T2= *proposing an explanation;* T3= *supporting an explanation;* T4= *improving an explanation. Community:* C1= *bridging knowledge;* C2 = *shared regulation;* C3= *synthesis;* C4= *lending support.*

Figure 5. Percentages of knowledge-building discourse moves used by Class D across studies

Relationships among epistemic understanding, KF engagement, and knowledge advance (Study 4)

Correlation Analysis. We focused on Study 4 and examined the interrelationships among epistemic understanding, KF engagement, collective knowledge advancement, and scientific understanding. Table 3 shows the correlations among students' epistemic understanding, KF engagement, collective knowledge advancement, and scientific understanding of Study 4, involving students who participated in the questionnaires on epistemic understanding (n = 211). Students' epistemic understanding of knowledge building referred to scores of the combination of students' understanding of knowledge building goals and processes and challenges and solutions. Their engagement on KF included: (1) KF *interaction* (i.e., #notes created, #build-on notes, #notes read, #scaffolds used, #views worked) and KF *metacognition* (i.e., #reference used) based on factor scores of KF log data derived from factor analysis, and (2) depth of KF discourse scores based on the coding of KF writings, including the higher-level scores (i.e., Q3, T3, T4, C1, C2, C3, and C4). Collective knowledge advancement was denoted by students' contribution to collective knowledge advancement based on TDC derived from the KBDeX note network. Moreover, students' scientific understanding and prior scientific understanding were represented by their post-test and pre-test results, respectively.

Table 3: Correlations among epistemic understanding, KF engagement, and knowledge advancement (n = 211)

Variable	1	2	3	4	5	6
1.Epistemic understanding	-					
2.KF *interaction*	.36***	-				
3.KF *metacognition*	-.09	.00	-			
4.Depth of KF discourse	.36***	.18*	.11	-		
5.Collective knowledge advancement	.23**	.68***	.10	.30***	-	
6.Prior scientific understanding	.10	.01	-.11	.02	.13	-
7.Scientific understanding	.44***	.36***	.00	.30***	.34***	.42***

Students' contribution to collective knowledge advancement showed significant correlations with their epistemic understanding ($r(120) = .23$, $p = .010$), KF *interaction* ($r(184) = .68$, $p < .001$), and depth of KF discourse ($r(184) = .30$, $p < .001$). These results suggest that higher epistemic understanding, KF *interaction*, and deeper usage of discourse moves were related to collective knowledge advancement.

Students' scientific understanding displayed significant correlations with their prior scientific understanding ($r(187) = .42$, $p < .001$), their contribution to collective knowledge advancement ($r(174) = .34$, $p < .001$), and their epistemic understanding ($r(133) = .44$, $p < .001$). These findings indicate that students' epistemic understanding and their contribution to collective knowledge advancement were correlated with scientific understanding.

Path Analysis. We also employed a path analysis testing the interplay among students' epistemic understanding, KF engagement, collective knowledge advancement, and scientific understanding. As predicted, these variables might be related, as shown by the path model in Figure 6. With a sample size of 211, the hypothesized path model was analyzed by AMOS 19. Results show a good fit: TLI and CFI were above .95, Chi-square was not significant, and RMSEA was less than .08 (Table 4). According to Figure 6, students' epistemic understanding predicted their KF *interaction* and depth of KF discourse, which further influenced collective knowledge advancement and scientific understanding. Furthermore, students' epistemic understanding also directly predicted their scientific understanding.

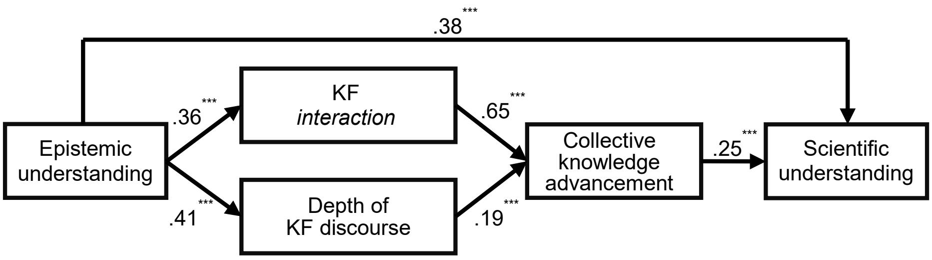


Figure 6. A path model indicating the prediction of epistemic understanding on knowledge advancement mediated by KF engagement

Table 4: Goodness of fit indices of the path analysis model

	$\chi2$	*df*	*p*	TLI	CFI	RMSEA	RMSEA 90% CI
Path model	6.73	4	.15	.95	.99	.06	.00-.13

Note. Structural equation modeling was applied to the analysis. TLI = Tucker-Lewis index; CFI = comparative fit index; RMSEA = root-mean-square error of approximation; RMSEA = 90% confidence interval of RMSEA.

Conclusion and discussion

Most knowledge-building studies are typically conducted within one semester or several months/weeks on one specific curriculum topic. Differently, this study is one of the few studies with the same cohort that spanned two years with evolving knowledge-building designs. This study built on current knowledge-building research and examined the specific role of epistemic understanding in examining how young students identified higher-level learning challenges in knowledge building. Results demonstrate that even elementary school children could propose new approaches to progressive knowledge building, such as synthesis and sustained inquiry, group communication and peer review, and community and individual development. They also presented an improved epistemic understanding of knowledge building over the four iterative studies, following a developmental trajectory of viewing knowledge building as a way to gain more knowledge, get the right answer, develop ideas, take collective cognitive responsibility, and then conduct progressive knowledge building.

The findings also reveal the positive influence of epistemic understanding on KF *interaction* and depth of KF discourse, which further promoted collective knowledge advancement and individual scientific understanding. It supports the argument of Bereiter et al. (2019) that meta-knowledge about knowledge building is needed for research advance, and this study has identified the epistemic understanding of knowledge building as one such area and illuminates on its trajectories and developmental patterns in a longitudinal design study. Epistemic understanding would be effective in strengthening epistemic agency, and students with deeper epistemic understanding are more likely to engage in productive KF discourse. Students' continued knowledge-building experience was possibly intertwined with epistemic understanding, and such reciprocal effects may facilitate their knowledge advancement. Further inquiry into how trajectories of knowledge-building designs for promoting students' epistemic understanding and progressive knowledge building will be conducted.

References

Bereiter, C., Chan, C. K. K., Hong, H.-Y., Lee, J., Khanlari, A., Lin, P. Y., Chai, C. S., Tsai, C. C., Scardamalia, M., Tan, S. C., Tong, Y., van Aalst, J., Zhang, J., & Zhang, Y. (2019). The roles of knowledge in knowledge creation. In K. Lund, G. P. Niccolai, E. Lavoué, C. Hmelo-Silver, G. Gweon, & M. Baker (Eds.), *A wide lens: Combining embodied, enactive, extended, and embedded learning in collaborative settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019* (Vol. 2, pp. 767-774). International Society of the Learning Sciences. https://bit.ly/3codUXo

Bereiter, C., Scardamalia, M., Cassells, C., & Hewitt, J. (1997). Postmodernism, knowledge building, and elementary science. *The Elementary School Journal*, *97*(4), 329-340. https://doi.org/dg498w

Chan, C. K. K., Tong, Y., & van Aalst, J. (2019). Progressive dialogue in computer-supported collaborative knowledge Building. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge international handbook of research on dialogic education* (pp. 469-484). Routledge. https://doi.org/d9s5

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175-218. https://doi.org/b24g7f

Danish, J. A., & Gresalfi, M. (2018). Cognitive and sociocultural perspectives on learning: tensions and synergy in the learning sciences. In F. Fischer, C. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International handbook of the learning sciences* (pp. 34-43). Routledge. https://doi.org/d9s7

Feng, X., van Aalst, J., Chan, C. K. K., & Yang, Y. (2020). Co-designing a collective journey of knowledge creation with Idea-Friend Maps. In M. Gresalfi & I. S. Horn (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020* (Vol. 3, pp. 1429-1436). International Society of the Learning Sciences. https://bit.ly/3rjhqIE

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. The National Academies Press. https://doi.org/drgp

Oshima, J., Ohsaki, A., Yamada, Y., & Oshima, R. (2017). Collective knowledge advancement and conceptual understanding of complex scientific concepts in the jigsaw instruction. In B. K. Smith, Borge, M., Mercier, E., and Lim, K. Y. (Ed.), *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017* (Vol. 1, pp. 57-64). International Society of the Learning Sciences. https://bit.ly/2RRp1id

Oshima, J., Oshima, R., & Matsuzawa, Y. (2012). Knowledge Building Discourse Explorer: a social network analysis application for knowledge building discourse. *Educational Technology Research and Development*, *60*(5), 903-921. https://doi.org/f39tjb

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (Vol. 97, pp. 67-98). Open Court. https://bit.ly/3013EQ8

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 397-417). Cambridge University Press. https://doi.org/d9tv

Tong, Y., Chan, C. K. K., & van Aalst, J. (2018). Developing productive discourse among low achievers in a knowledge building environment. In J. Kay & R. Luckin (Eds.), *Rethinking learning in the digital age: Making the learning sciences count, 13th International Conference of the Learning Sciences (ICLS) 2018* (Vol. 2, pp. 879-886). International Society of the Learning Sciences. https://bit.ly/3mKs89Q

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Short Papers

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Picturing Worlds of Inclusion: Visual Analysis of Preservice Teachers' Representations

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Abstract: Visual representations are one modality that can afford unique pedagogical opportunities for learning and as a data source in scholarship. This paper compares visual representations (drawings) and written descriptions of inclusion and disability created by preservice teachers. Analysis of the descriptions revealed the participants often noted principles and stances toward inclusion while the drawings showed how inclusion manifested in power structures, social relationships and interactions, pedagogy, and inclusive practices. The lenses of figured worlds and visual analysis were used to unpack how the participants assigned significance to students, teachers, acts, and outcomes. This paper discusses how representations revealed key nuances into how preservice teachers understood inclusion that were not apparent from written descriptions alone. This paper extends prior uses of representations in the Learning Sciences in math and science contexts to consider their application in addressing issues such as inclusion and disability, and as a tool for exploring figured worlds.

Introduction

Different modalities convey and afford different types of information and meaning making processes. Visual representations, such as drawings, are one modality that has received relatively limited attention in the Learning Sciences, particularly outside of science and mathematics contexts. Representations offer unique ways for students to construct meaning and understanding as well as researchers in interpreting students' perspectives.

This paper reports on how student generated representations and visual discourse analysis combine in revealing rich insights into students' perspectives, that may not be apparent through other modalities. In particular, I compare preservice teachers' representations of inclusion with their written descriptions of inclusion as part of their teacher training at a Canadian university. I use figured worlds as an organizing framework to identify how preservice teachers understand inclusion as conveyed through their representations and written texts. This continues prior efforts in the Learning Sciences to use representations in mathematics and science education (diSessa, 2004; Medina & Suthers, 2013) to support engagement with complex content as well as investigations of representational processes in autobiographical digital art production (Halverson, 2013).

This work contributes to investigating more about preservice teachers' emergent understanding (Walkoe & Luna, 2019), by using representations as in-progress snapshots of preservice teachers' perspectives toward inclusion. Teachers' beliefs, worldviews, and perspectives shape teaching practices (Santagata et al., 2018; Silverman, 2007), warranting the need for opportunities for preservice teachers to consider and reflect on their perspectives alongside training on inclusive strategies and policies. Previous research indicates preservice teachers have positive sentiments toward inclusion (Markova et al., 2016) but less is known about the nuances of preservice teachers' perspectives such as how inclusive practices address social interactions or how epistemological perspectives shape inclusive practices. As Savolainen et al. (2012) found, while teachers can be positive toward inclusion, how inclusion could manifest in practice can vary considerably. Representations offer an opportunity for preservice teachers to better understand their own perspectives, advances in teacher education, and contributions to scholarship.

Purpose

This paper builds on prior work (diSessa, 2004; Halverson, 2013; Medina & Suthers, 2013) in the Learning Sciences around representations to apply a sociocultural lens to topics, such as inclusion, and how representations reflect figured worlds. Comparing preservice teachers' visual representations with their written descriptions highlights different aspects of their thinking and understanding of inclusion. This paper addresses two questions: How do preservice teachers understand inclusion? What do preservice teachers' visual representations and written descriptions convey about figured worlds of inclusion?

Theoretical framework

More than a playful activity, creating representations is an intentional act of design, "arising out of the cultural, social and psychological history of the sign-maker, and focused by the specific context" (Kress & van Leeuwen, 2006, p. 7) in which it is produced. Creating representations requires decisions about what to include and what to leave out, and real cognitive work to abstract ideas and convey them in visual forms (Halverson, 2013). Whether simple or complex, a representation shows not only direct meanings and ideas through depiction but also the histories and experiences of the creator that informed their artistic decisions. As a form of discourse, representations are "a structure of messages within which are embedded social conventions and/or perceptions, and which also present the discourse communities … [of the] maker" (Albers, 2007, p. 84). Like written texts, conventions have formed around how representations are created and interpreted, which Kress and van Leeuwen (2006) referred to as visual grammar to encompass how "depicted elements – people, places and things – combine in visual 'statements' of greater or lesser complexity and extension" (p. 1). Moreover, visual grammar is independent of skill or expertise in fine arts, making it useful for studying preservice teachers' representations.

With visual grammar to interpret representations, figured worlds are a way to organize their meanings. Figured worlds are "socially and culturally constructed realm[s] of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (Holland et al., 1998, p. 52). Figured worlds reflect taken for granted assumptions about contexts, their participants, and what happens within them. For instance, in the world of schooling there are recognizable norms about how students and teachers interact, what classrooms look like, and what teachers and students do. I use figured worlds as a lens to examine how preservice teachers represent figured worlds of inclusion. Figured worlds is a useful framework to understand how people assume orientations to participate in a given context (Jurow, 2005), such as preservice teachers' orientations to inclusion.

Methods of data collection and analysis

As part of a larger design-based research project (Ostrowdun, 2020), preservice teachers enrolled in a Bachelor of Education course were tasked with creating drawings (representations) of inclusion. This paper reports on drawings preservice teachers created during a 50-minute session, using paper and markers, in the first week of the semester. The preservice teachers were instructed to "draw inclusion within a learning context" and provide a brief (<150 words), written description of their drawing. The prompt was intentionally open-ended with no stipulations of what should be drawn. Preservice teachers then discussed their drawings and perspectives toward inclusion with peers in small groups. Drawings from 34 consenting preservice teachers (who were also interviewed in the larger study) were collected and scanned for analysis. Note, to align with the larger study, my analysis was delimited to drawings with a focus on inclusion in terms of disability.

The drawings were analyzed using semi-open coding for attributes, adapted from Albers (2007) and Kress and van Leeuwen (2006), such as people, activities, locations, size of drawn elements, colours, composition, and relationships between elements. These components make up a visual grammar based on historic conventions and patterns in visual design independent of specialized artistic skills or talents. I similarly examined the written descriptions for how the participants described and assigned value to people, locations, actions, principles in terms of inclusion. The drawings and descriptions were then compared for how each modality represented aspects of figured worlds of inclusion. Data from the larger study was also used to triangulate and substantiate the findings.

Findings

While all participants expressed a positive sentiment (e.g., depictions of smiles, collaboration, hearts) toward inclusion, there were subtle, yet meaningful, differences among the drawings and descriptions. Most drawings (n = 23) conveyed inclusion through a narrative or scene, such as what someone might see if they walked into a classroom in-action. The remaining 11 drawings showed more static or abstract principles and perspectives, such as multicoloured shapes connected with rainbows.

Among the 26 drawings that included people, the drawings conveyed hierarchies between students and teachers that were often unspecified in the written descriptions. Such power structures and assignments of roles can have epistemological implications, such as between teacher-centred and student-centred approaches. For instance, one drawing of a classroom depicted the teacher larger than students, fitted with masculine apparel, and in greater detail than students (a defined body shape versus stick-figures), implying a hierarchical relationship of power or expertise (Kress & van Leeuwen, 2006). The same drawing also showed some students working alone using specific resources (i.e., a computer, alternative seating, smartboard) around the edges of the classroom while the teacher and other students were in the centre, positioning users of such resources at the margins. Following conventions of composition, this arrangement assigns value to the central elements (Kress & van Leeuwen, 2006). The written description mentioned supporting diversity and facilitating teacher-led and independent learning, but it did not address the potential sociocultural implications of placing certain students at the margins. This was a figured world that valued access to tools and resources but gave less consideration for social interactions or positions among students and the teacher.

Five drawings also "assign[ed] functions and meanings to space and spatial arrangements … [as a] form of social control" (van Leeuwen, 2008, p. 97). For example, one drawing showed a teacher standing in front of a board, two students at a desk in front of a smiling teacher, and one student leaving the room. The description explained the student leaving was upset, and one of the seated students as struggling. The struggling student was also sitting hunched over the desk on an exercise ball, while the other seated student was in an upright posture looking toward the teacher and in a chair. This conveys a narrative of students with accommodations as also struggling and physically disengaged, while the other students without accommodations do not struggle and are engaged with the teacher. As well, depicting the upset student as leaving the room establishes a figured world that privileges certain emotions within inclusive environments while excluding others, such as frustration.

The abstract drawings tended to convey more high-level principles and metaphors related to inclusion. Figure 1 depicted two brains to contrast people with a learning disability and neurotypical people. The description associated the latter with organization, time management, "proper sleep," and "the right amount of anxiet[y]." They described the former as being disorganized and a "battle … against themselves." The drawing not only matches these descriptors but amplifies them. The drawing follows a given-new, left-right composition structure (Kress & van Leeuwen, 2006). In this case the participant, who identified as having attention deficit disorder, placed their experiences on the left as *given*, while on the right was an experience novel to them. As Holland et al. (1998) noted, some worlds may be inaccessible because of social positions or identities. A neurotypical identity was not just novel but also inaccessible within the existing figured world.

The participant attributed greater value and desire to the right half, using colour (Kress & van Leeuwen, 2006), fitting text within the boxes/brain in the high-normal-low anxiety graph, and a shorter checklist (showing only checkmarks). Also communicated through the drawing is a negative association with music and television, with them appearing only on the left side, while the right side conveyed narrative of order and structure. Together, the drawing and description portrayed a figured world that ascribed value to academics and organization and that inclusion was an antidote to a deficit narrative (left) toward a desired narrative (right).

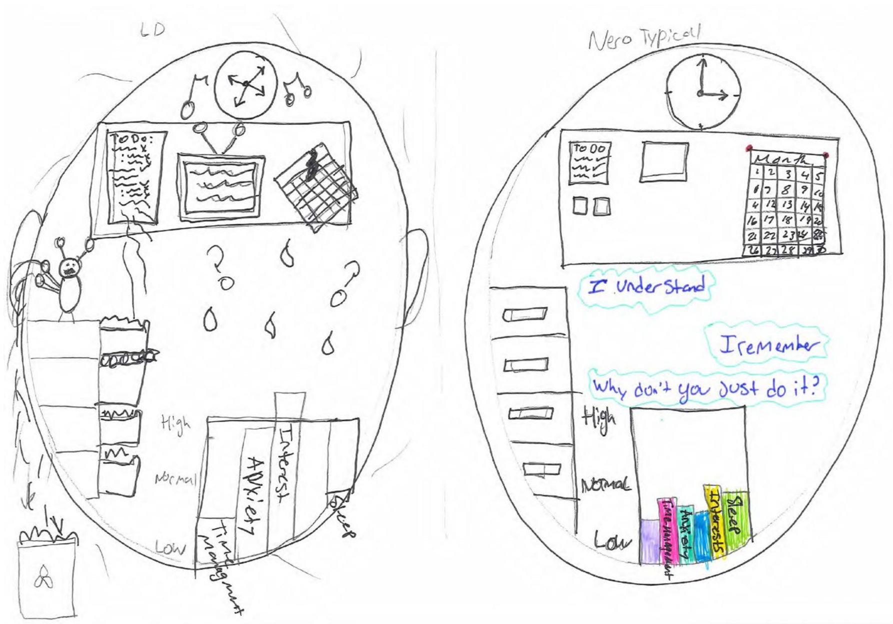

Figure 1. Abstract representation of a learning disabled brain (left) and neurotypical brain (right).

All participants expressed broad support for inclusion through their drawings and descriptions. Deviations became apparent upon closer inspection of the drawings and descriptions with each conveying different aspects of figured worlds. The written descriptions often made statements about principles, dispositions, and general stances toward inclusion such as "support all learners," "embracing differences," "equal opportunit[ies] to learn," and "accommodate … varying needs." The drawings, particularly of classrooms, showed how the participants envisioned their perspectives might manifest in specific scenarios. Through examining composition, proportions, spatial positioning, and rendered elements, the drawings conveyed insights about power structures, relationships, epistemological stances, and teaching practices. These fleshed out key details of how the participants understood figured worlds and the types of narratives associated with them. The descriptions articulated elements of inclusion while the drawings showed relationships among the elements and which elements were prioritized over others.

Implications and conclusion

Complementing prior efforts examining (preservice) teachers' perspectives toward inclusion (Loreman & Earle, 2007; Markova et al., 2016), representations can offer additional insights into how they characterize figured worlds. Analysis of the representations reveals nuances not only about how preservice teachers understand inclusion but also how they conceive enacting inclusion. In particular, the representations show how power was wielded and conveyed by teachers in terms of disability, which is a growing area of focus in the Learning Sciences when developing theories and innovations of learning (Esmonde & Booker, 2017). With figured worlds as orientations to every-day actions, representations offer a rich layer of understanding into how preservice teachers consider "which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (Holland et al., 1998, p. 52). As a pedagogical tool, creating and discussing representations can also encourage preservice teachers to bring awareness to their emerging perspectives and to reflect on implications for practice (Phillipson & Forlin, 2011). Collectively, the findings extend previous uses of representations in the Learning Sciences to contexts beyond science and mathematics as an insightful modality and approach to supporting student learning and scholarly understanding.

References

Albers, P. (2007). Visual discourse analysis: An introduction to the analysis of school-generated visual texts. In D. W. Rowe, R. T. Jimenez, D. L. Compton, D. K. Dickinson, Y. Kim, K. M. Leander, & V. J. Risko (Eds.), *57th yearbook of the National Reading Conference* (pp. 81–95). National Reading Conference.

diSessa, A. (2004). Metarepresentation: Native competence and targets for instruction. *Cognition and Instruction*, *22*(3), 293–331. https://doi.org/10.1207/s1532690xci2203_2

Esmonde, I., & Booker, A. N. (Eds.). (2017). *Power and privilege in the learning sciences: Critical and sociocultural theories of learning*. Routledge. https://doi.org/10.4324/9781315685762

Halverson, E. R. (2013). Digital art making as a representational process. *Journal of the Learning Sciences*, *22*(1), 121–162. https://doi.org/10.1080/10508406.2011.639471

Holland, D., Lachicotte Jr., W., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds*. Harvard University Press.

Jurow, A. S. (2005). Shifting engagements in figured worlds: Middle school mathematics students' participation in an architectural design project. *Journal of the Learning Sciences*, *14*(1), 35–67. https://doi.org/10.1207/s15327809jls1401_3

Kress, G. R., & van Leeuwen, T. (2006). *Reading images: The grammar of visual design* (2nd ed.). Routledge.

Loreman, T., & Earle, C. (2007). The development of attitudes, sentiments and concerns about inclusive education in a content-infused Canadian teacher preparation program. *Exceptionality Education International*, *17*(1), 85–106.

Markova, M., Pit-Ten Cate, I., Krolak-Schwerdt, S., & Glock, S. (2016). Preservice teachers' attitudes toward inclusion and toward students with special educational needs from different ethnic backgrounds. *The Journal of Experimental Education*, *84*(3), 554–578. https://doi.org/10.1080/00220973.2015.1055317

Medina, R., & Suthers, D. (2013). Inscriptions becoming representations in representational practices. *Journal of the Learning Sciences*, *22*(1), 33–69. https://doi.org/10.1080/10508406.2012.737390

Ostrowdun, C. P. (2020). Representations of inclusion: How pre-service teachers understand and apply inclusion across situations. *Exceptionality Education International*, *30*(3), 102–123. https://doi.org/10.5206/eei.v30i3.13509

Phillipson, S., & Forlin, C. (2011). Newly qualifying teachers' perspectives of diversity and inclusion: Understanding through visual representations. *International Journal of Whole Schooling*, *7*(1), 1–19.

Santagata, R., Yeh, C., & Mercado, J. (2018). Preparing elementary school teachers to learn from teaching: A comparison of two approaches to mathematics methods instruction. *Journal of the Learning Sciences*, *27*(3), 474–516. https://doi.org/10.1080/10508406.2018.1441030

Savolainen, H., Engelbrecht, P., Nel, M., & Malinen, O.P. (2012). Understanding teachers' attitudes and self-efficacy in inclusive education: Implications for pre-service and in-service teacher education. *European Journal of Special Needs Education*, *27*(1), 51–68. https://doi.org/10.1080/08856257.2011.613603

Silverman, J. C. (2007). Epistemological beliefs and attitudes toward inclusion in pre-service teachers. *Teacher Education and Special Education*, *30*(1), 42–51. https://doi.org/10.1177/088840640703000105

van Leeuwen, T. (2008). *Discourse and practice: New tools for critical discourse analysis*. Oxford University Press.

Walkoe, J. D. K., & Luna, M. J. (2019). What we are missing in studies of teacher learning: A call for microgenetic, interactional analyses to examine teacher learning processes. *Journal of the Learning Sciences*, *29*(2), 285–307. https://doi.org/10.1080/10508406.2019.1681998

Elementary Science Teachers' Use of Representations to Build Shared Understanding from Students' Diverse Ideas and Practices

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Abstract: Multiple representations of a phenomenon can support science learning. Legitimizing diverse representational resources can also create more equitable learning environments. In this paper, we present cases from a year-long professional development with in-service elementary teachers designed to support science teaching with representations, and we closely analyze how two teachers prioritized making space for students' diverse ideas and practices as a foundation for these understandings. Through this work, we identified practices and purposes for connecting representations and illustrated how teachers addressed tensions between accountability to standards and creating space for students' resources.

Objectives and significance

Leveraging multiple representations (e.g., language, gesture, drawing) can support science learning by deepening students' conceptual understanding and disciplinary engagement (Lehrer & Schauble, 2015). Cycles of experimentation and discussion can help learners build explanations of phenomena as they re-represent phenomena in new ways (Danish, 2014). Moreover, working with multiple representations shapes inquiry (Gouvea & Passmore, 2017), because different representations foreground different concepts and practcies. Legitimizing diverse resources (e.g., languages other than English, non-linguistic representations) can also create more equitable learning environments for students from non-dominant backgrounds, including students classified as "English learners (ELs)," because expanding the range of resources considered "appropriate" for science learning allows students to access their full representational repertoires for sensemaking (García & Li, 2014).

To support students' work with representations, researchers have explored teachers' perceptions (e.g., Reiser et al., 2017) and use (Thompson et al., 2019) of representations. Teaching with representations can be challenging, because it requires teachers to unpack features of representations (Eilam & Gilbert, 2014) and establish and refine relationships between representations (Schwarz et al., 2012). Moreover, teachers often experience tensions between accountability to science standards (e.g., NGSS Lead States, 2013) and creating learning environments that are meaningful for students (Manz & Suárez, 2018). These tensions arise from time constraints and concerns about reinforcing "misconceptions," and they can be homogenizing forces that lead teachers to emphasize canonical ideas, suppressing diversity in students' ideas as legitimate resources for sensemaking (Guy-Gaytán et al., 2019). In this paper, we present cases from professional development (PD) with in-service teachers designed to support teaching with representations. Rather than distinguishing between types of representations, our focus is on how teachers leveraged multiple representations in service of science learning.

Methods

We analyze data from a PD that was designed and facilitated by the authors and members of a larger research team. Rather than evaluating specific features of the design, we analyze data as a collection of cases (Yin, 2014) to consider how teachers used representations to support learning, and, in some cases, create more equitable opportunities for learning. Nine in-service elementary teachers from a metropolitan public school district in the southeastern US participated in the PD during the 2019-20 school year. After a five-day summer workshop teachers participated in four after-school PD sessions during the academic year. In these sessions, teachers engaged in student work analysis (Little et al., 2003) during *gallery walks* and discussed video of their classrooms during *video clubs* (Sherin & Han, 2004). In this paper, we analyze video recordings of PD, classroom observations, and interviews with teachers. Our analysis considers each teacher's practices as an exploratory case of how teachers used multiple representations. From teachers' discourse, we developed codes for their purposes and practices for using multiple representations. Then, we looked for trends in our codes across cases, as well as examples of unique practices.

Findings

In the full study, we look across all nine elementary teachers' practices and purposes for connecting representations. Here, we focus on two of the third-grade teachers (Jack and Sarah), because they prioritized students' diverse ideas and practices as a foundation for building shared, canonical science understandings.

Jack: Amplifying fit between experiment and phenomenon with questioning

In a unit about magnets, Jack invited students to explore their unique ideas about a phenomenon by designing an experiment to model the phenomenon. Jack connected students' ideas to canonical understandings with questioning and modeling; he encouraged students to share their ideas as they worked on their experiments, and he used questioning to press students to more closely map their ideas and experiments to the phenomenon. In PD sessions and in interviews, he explained that as students worked to revise their experiments, they also revised their ideas about the phenomenon and about magnets, supporting canonical understandings aligned with standards.

Jack's unit was anchored with a phenomenon from a news video: a reporter showed that a car parked at the bottom of "Magnetic Hill" would roll backward uphill when in neutral. In fact, the car rolling "uphill" was an optical illusion. Though the phenomenon is *not* caused by magnets, Jack explained that investigating these claims allowed students to explore concepts like magnetic fields, attraction, and repulsion. Jack used several tools to track students' theories. Collectively with students, Jack created and revised a list of theories about the phenomenon on a shared model of their evolving thoughts posted on a board visible to students. Individually, students tracked their theories in science journals. Combining the list with the journals was one way that Jack created space for students to explore unique ideas while building a shared understanding.

In the lesson we observed, Jack created space for students' ideas and practices by inviting students to design experiments. Jack opened the activity by reminding students students of the five theories the class had suggested about why the car rolled uphill. Jack prompted students with, "which [theory] is most true to you, and which do you want to prove today?" Although they tested different ideas, students used the same experiment design template, a graphic organizer for attending to science practices. In class discussions and one-on-one, Jack repeatedly asked students about parts of the template: "what do [the materials] represent?" and "how does that help you prove your theory?" This questioning helped students develop and make progress on individual experiments and build a shared understanding of a disciplinary practice – experimental design. Throughout the lesson, Jack used questioning to press students to consider fit between their experiments and the phenomenon. When one student shared his progress (by moving a horseshoe magnet above his car, he could move his car uphill), Jack asked, "the magnet you're holding is what?" The student replied, "asteroid." Jack said, "but the asteroid is under the road," challenging the student to more closely model his idea by placing the horseshoe magnet below the ramp rather than above the car. Not all of the students were testing the same theory; still, this feedback could be generalized to their experiments as they considered how their model mapped to their idea and the phenomenon.

Later, students connected the experiments to their ongoing work by annotating their journals with their results. In his post-observation interview and in PD, Jack explained that he brought these representations together because they helped students build understanding from a foundation of personally meaningful ideas and practices. He said the experiment "really challenged their thinking to change their opinion." He explained, "They really had to think, what am I going to do with this stuff? How am I going to use it to prove the phenomenon?…it's really connecting for them about how the magnets are used, of them being able to use the magnets now, not just *see* them in action but *feel* them." Jack saw these experiences as crucial – each student needed to explore ideas individually to revise ideas and contribute to the classroom's shared understanding of magnets. In addition, Jack emphasized having students use journals to bring together representations, including the experiment, to track their thinking. Tracking theories helped students "compare and contrast their thinking… to define the holes in their thinking." Thus, Jack used multiple representations to invite students to explore their unique ideas by designing and carrying out experiments and to help students build a shared understanding of magnets. As a bridge between students' ideas and canonical understandings, Jack used questioning to help students critically examine their models and to map their ideas to the phenomenon, simultaneously making sense about magnets more broadly.

Sarah: Amplifying students' representations

Like Jack, Sarah invited and valued students' diverse ideas. However, rather than using questioning and modeling to press students toward canonical ideas, Sarah elicited students' representations, and she selected representations that aligned with canonical ideas to share with the class. In this way, she used students' unique experiences and ideas as a bridge to standards. In a unit about pollination and the structure-function relationship between bees and flowers, Sarah used multiple representations to support students' understanding. To connect activities in the lesson, Sarah used phrases and embodiments (full-body movements that enacted parts of the phenomenon). During the lesson, most sensemaking was done through talk, although students also had opportunities to write (making predictions) and participate in an experiment. At the end of the lesson, students completed exit tickets that connected multiple lessons by asking the same questions daily, allowing students and Sarah to trace how the students' ideas about pollination changed as they interacted with representations.

In this lesson, Sarah supported canonical science learning by leveraging students' ideas and representations, focusing on students' language. For example, Sarah used a phrase from one student's exit ticket to guide sensemaking. She opened the lesson by reminding students of their anchoring phenomenon. She then projected the exit ticket on the board and encouraged students to discuss what they saw, focusing students on the drawing that depicted and labeled a bee's "hair" as a "scratchy sweater." Sarah asked students what a scratchy sweater feels like, and they decided it doesn't feel good ("hairy" or "pokey"). When Sarah asked what students thought "scratchy sweater" was about, they said it might describe how the bee picks up pollen. Sarah later performed a "scratchy sweater" embodiment (shrugged her shoulders in discomfort). This combination of a phrase and embodiment offered students resources for sensemaking about pollination grounded in their experiences. Sarah continued to use phrase-embodiment pairs in students' work with other representations (video, experiment) and throughout the lesson. For example, as Sarah and the students were making sense of how bees get pollen on their bodies, students suggested that "because the bee tries to go down" to the center of the flower it "bumps into the [pollen duster]" and "rubs against it." Sarah encouraged students to embody the bee "buzz buzzing" and used a student's language ("rubbing against it") to embody the bee "rubbing against" the pollen duster. In this way, Sarah used students' language as a starting point to engage in imaginative embodiment as the class tried to make sense of the bee's role in pollination. Throughout, she was drawing on language students were using to create a shared repertoire of embodiments and phrases guiding their collaborative sensemaking as a classroom.

In PD and interviews, Sarah explained that she designed this lesson to capitalize on students' shared histories and to build new histories of sensemaking. Sarah said representations should "build on each other, elicit things from kiddos" to pull out "science concepts along the way" and to "give really good opportunities for kids… to show what they're thinking." She described how the exit ticket and students' prior experiences with scratchy sweaters laid groundwork for sensemaking during the experiment and shifted authority from herself to the students for identifying and naming ideas; student-generated representations allowed students to "teach the class" so students could "learn through [each other] versus me telling them." Her emphasis was not on assessment, but the process of sensemaking: students making connections to science ideas "along the way" and discussing their thinking. Thus, Sarah used representations as a way to elicit students' ideas as resources, offer students opportunities to learn from each other (rather than positioning the teacher as the sole authority in science), and to connect students' lived experiences to natural phenomena as a way to build explanations.

Discussion, conclusions, and implications

Both Jack and Sarah's cases show potential for creating more equitable opportunities for science learning. In Jack's case, third graders were given the option to use multimodal resources when designing their experiments, an approach that has been shown to support learning for multilingual students in particular (Williams, 2020). In addition, Jack encouraged students to explore their unique ideas in their experiments. This approach could communicate to students that each of their ideas was a valuable starting point for sensemaking. Jack hoped that this lesson would build students' confidence in themselves "as scientists," because they controlled the design and interpretation of their experiment (Haverly et al., 2020). Rather than reinforcing "misconceptions," playing out their initial ideas in the context of Jack's questions enabled students to bridge from their initial ideas to canonical understandings. However, Jack also identified challenges associated with this approach. He acknowledged that this process took a lot of time, because each student needed to individually test their ideas multiple times. It is possible that in such a student-driven context, some students might have more opportunities to test their ideas (and receive feedback from Jack) than others, and some students could be overlooked by their teacher. Questioning about their individual experiments could also be intimidating for students, who might be reluctant to share "incorrect" ideas. While we did not observe these issues in Jack's classroom, we recognize that with this approach it would be important to attend to *who* is participating and *how* they are participating (McKenney, 2018).

In Sarah's case, third graders also had the opportunity to use multimodal representations to express unique ideas (specifically, drawing and writing on their exit ticket). However, students' responses were slightly more constrained, because they needed to produce a more formalized response on paper (rather than through talk and "hands-on tinkering," as in Jack's lesson). Because students turned in this assignment at the end of class, they might also have felt more pressure to use "academic" (formal English) language (Flores & Rosa, 2015). These restrictions could suppress ideas if students are not confident in expressing their ideas in this way. In addition, because Sarah selected certain students' phrases or drawings to amplify for the class, it is possible that some students might have felt that their work was not as valuable as their peers' because their work was not shared. At the same time, Sarah's approach offers a more efficient way to address the tension between accountability to standards and students' ideas and practices. In Sarah's classroom, students had the opportunity to express their ideas, and Sarah used these ideas as a foundation for shared sensemaking. Sarah explicitly drew upon ideas that she thought were likely to be familiar to students, providing opportunities for students to see their experiences as relevant to science. Because Sarah selected specific ideas to share (rather than working from all students' ideas), she could more quickly move from students' ideas to canonical ideas. Moreover, by creating shared embodiments and phrases to discuss with the whole class, it was likely easier for Sarah to check on students' engagement and understanding. Thus, these shared representations might have made it easier for Sarah to monitor and respond to students' thinking and to build on their experiences as resources for science learning.

We presented these two cases because each offers an approach for building shared, canonical understandings from students' diverse ideas and practices. These approaches can inform the design of learning environments and PD programs that support teachers' work with representations. To realize this potential, further research is needed to address tensions that arise from standards that prioritize canonical knowledge and practices and dominant ideologies about "appropriate" resources for learning. While it is difficult to shift disciplinary ideologies and values, this work is critical for creating equitable learning opportunities in science classrooms.

References

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. Journal of the Learning Sciences, 23(2), 100-148.

Eilam, B., & Gilbert, J. K. (2014). The significance of visual representations in the teaching of science. In B. Eilam & J. K. Gilbert (Eds.), Science Teachers' Use of Visual Representations (pp. 3–28). Springer International Publishing.

Flores, N., & Rosa, J. (2015). Undoing Appropriateness: Raciolinguistic Ideologies and Language Diversity in Education. Harvard Educational Review, 85(2), 149-171.

García, O. & Li Wei. (2014). Translanguaging: Language, bilingualism and education. Macmillan.

Gouvea, J., & Passmore, C. (2017). Models of versus Models for. Science & Education, 26(1-2), 49–63.

Guy-Gaytán, C., Gouvea, J. S., Griesemer, C., & Passmore, C. (2019). Tensions Between Learning Models and Engaging in Modeling. Science & Education, 28(8), 843-864.

Haverly, C., Calabrese Barton, A., Schwarz, C. V., & Braaten, M. (2020). "Making Space": How Novice Teachers Create Opportunities for Equitable Sense-Making in Elementary Science. Journal of Teacher Education, 71(1), 63-79.

Lee, O., Miller, E., & Januszyk, R. (2014). Next Generation Science Standards: All standards, all students. Journal of Science Teacher Education, 25(2), 223-233.

Lehrer, R., & Schauble, L. (2015). The development of scientific thinking. In R. M. Lerner (Ed.), Handbook of child psychology and developmental science (pp. 1–44). Hoboken, NJ: Wiley.

Little, J. W., Gearhart, M., Curry, M., & Kafka, J. (2003). Looking at student work for teacher learning, teacher community, and school reform. Phi delta kappan, 85(3), 184-192.

Manz, E., & Suárez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. Science Education, 102(4), 771-795.

McKenney, S. (2018). How Can the Learning Sciences (Better) Impact Policy and Practice?, Journal of the Learning Sciences, 27(1), 1-7, DOI: 10.1080/10508406.2017.1404404

NGSS Lead States. (2013). Next Generation Science Standards: For States, By States (Appendix F - Science and Engineering Practices in the NGSS). The Next Generation Science Standards. Washington, DC.

Reiser, B. J., Michaels, S., Moon, J., Bell, T., Dyer, E., Edwards, K. D., McGill, T. A. W., Novak, M., & Park, A. (2017). Scaling up three-dimensional science learning through teacher-led study groups across a state. Journal of teacher education, 68(3), 280-298.

Schwarz, C., Reiser, B. J., Acher, A., Kenyon, L., & Fortus. (2012). MoDeLS: Challenges in defining a learning progression for scientific modeling. In A. Alonzo & A. W. Gotwals (Eds.), Learning progressions in science: Current challenges and future directions.

Sherin, M. G., & Han, S. (2004). Teacher learning in the context of a video club. Teaching and Teacher Education, 20: 163-183.

Thompson, J. J., Hagenah, S., McDonald, S., & Barchenger, C. (2019). Toward a practice-based theory for how professional learning communities engage in the improvement of tools and practices for scientific modeling. Science Education, 103(6), 1423-1455.

Williams, M. (2020). Fifth graders' use of gesture and models when translanguaging during a content and language integrated science class in Hong Kong. International Journal of Bilingual Education and Bilingualism, 1-20.

Yin, R. K. (2014). Case study research: design and methods. Fifth edition. Los Angeles: SAGE.

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Ambitious and Equitable Science Teacher Noticing in Distance Learning

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Abstract: Teacher noticing is immensely challenging during remote instruction mandated by the COVID-19 pandemic. I document one science teacher's noticing while teaching over Zoom using an approach inspired by Nicole Louie's (2018) work based in two theoretical frameworks – a cognitive perspective and a political and social perspective based in Professional Vision. Drawing on observational field notes, post-instruction debriefs and a retrospective interview, I identify five social practices of noticing – coding, highlighting, identifying, connecting and using knowledge. Three themes emerged to describe the potential and purpose of teacher noticing: legitimizing what student experiences "belong" in science class, normalizing the struggles faced by minoritized students during distance learning and bridging past and future lessons. My findings suggest that teacher noticing from in-person instruction does not translate to distance learning and that the practice of noticing must be re-imagined to support ambitious and equitable science teaching.

Keywords: teacher noticing, science education, distance learning

Introduction

Teachers face immense challenges to creating learning opportunities for students via Zoom instruction while distance learning is required during the COVID-19 pandemic. With many students' cameras off and microphones muted, one specific challenge is being able to anchor instruction within a detailed and comprehensive observation and understanding of students' immediate response to instruction. Noticing is an essential practice of teaching and efforts to support ambitious and equitable learning opportunities require that we understand how and what teachers are noticing as they improvise distance learning and how teachers can learn noticing to improve their practice.

Noticing is a dynamic process that involves attending to and making sense of particular events in an instructional setting (M. G. Sherin, Jacobs, & Philipp, 2011) which is profoundly influenced by a teacher's philosophical stance on their profession (Erickson, 2011) and has major consequences on the learning opportunities afforded to students (Luna, 2018; B. L. Sherin et al., 2010). Studies of noticing in classroom settings underscore the "blooming, buzzing confusion of sensory data" (B. L. Sherin & Star, 2011, p. 69) that teachers encounter; this is still true but wildly different in distance learning. Rather than students' expressions and utterances, teachers largely hear silence and see small black boxes on their computer screens particularly when those students do not have adequate access to technology. But teachers are not staring into a void; for many teachers the Zoom window sits alongside numerous applications windows that teachers use in instruction and through which students participate.

In this exploratory study, I document the noticing of one science teacher, Ms. B, as she supports her 10^{th} grade Black and Latinx chemistry students in distance learning. Rather than narrow the scope of investigation to her noticing about disciplinary ideas or identity development, I aim to identify broadly what Ms. B notices in her students' engagement and how she reasons about that noticing. This broad focus on engagement and participation allows for methodological and theoretical flexibility that can later be refined and expanded to support teachers in learning to notice in more expansive ways.

Theoretical framework

This investigation is grounded in two dimensions of noticing that distinguish the goals and commitments of science teaching. First, ambitious, reform-oriented education and noticing take students ideas seriously to guide instruction, and the reform driven by the Next Generation Science Standards (NGSS) requires teaching and noticing drastically different than historically dominant model of "teacher dominated discourse, textbook based lessons, and coverage as the main curricular principle" (Skyes, Bird, & Kennedy, 2010, p. 465). Ambitious science instruction, as proposed by Windschitl and colleagues (2012), relies on core instructional practices that are inherently social and interactional. For example, eliciting students' ideas about a puzzling scientific phenomenon can allow teachers to adapt instruction to students' interests. Second, building on work in mathematics education, equitable noticing expands the foci to participation, identity and multiple knowledge bases, and challenges systemic disenfranchisement (Hand, 2012). Equitable noticing attends to sociopolitical processes such as positioning students as capable or not and privileging some forms of participation over others. For example, Hand

(2012) describes a teacher highlighting the subjective nature of assessment practices to open a broader space to critique how competence is determined. Anchored in these two facets of noticing, I will describe an approach to theoretical triangulation that I hope will open expansive possibility for understanding teacher noticing. I plan to analyze this data using first a cognitive approach to noticing, which is more established in research, and second using a sociopolitical lens, responding to and building upon Louie's (2018) effort to revive analysis of culture and power embedded in Goodwin's (1994) Professional Vision framework. It is important to note that technology plays a major role in Ms. B's noticing. She is extremely technologically proficient and uses a wide range of digital tools, which is not true for all teachers. Additional conceptual frameworks anchored in technology and teaching could be useful for future investigations of noticing during remote instruction but are outside the scope of this exploratory study.

Cognitive perspective

To analyze teacher noticing, first I will use the conceptualization established by van Es and Sherin (2008). These scholars describe noticing as an individual cognitive process situated in the complex classroom context based on teachers determining what is worthy of attention and reasoning about what to notice. van Es and Sherin's framework includes three aspects: a) *identifying* what is important or noteworthy about a classroom situation, b) *making connections* between the specifics of classroom interactions and the broader principles of teaching and learning they represent, and c) *using what one knows* about the context to reason about the interactions. A benefit of this approach is that it emphasizes the learnability of noticing and can be used to explore teachers' learning trajectories in becoming experts at noticing. To understand Ms. B's efforts to support equitable and ambitious science learning, I analyze her noticing in terms of *identifying* student participation as noteworthy, *connecting* student participation to her objectives for learning and equity, and *using knowledge* of students and both the distance learning context and interactional moment for reasoning about the interaction.

Culture, power and professional vision

In addition to the drawing on the cognitive perspective on noticing, I aim to take up Louie's (2018) project of analyzing culture and power in teacher noticing to further describe the challenges Ms. B faces in navigating and overcoming structures of marginalization embedded in schooling and science instruction. Louie draws on the social and political facets of Goodwin's (1994) concept of Professional Vision that involves "ways of seeing and understanding events that are answerable to the distinctive interests of a particular social group" (p. 606) and "distinct patterns of noticing" (p. 170) shared by groups of professionals.

First, Goodwin portrays noticing as socially and culturally constructed as professionals use tools that make sense in their shared experiences and serve their similar goals. And second, Goodwin describes noticing as reproducing social arrangements that privilege some and marginalize others. Noticing is not politically neutral as Professional Vision is "answerable to" power, such as "what kinds of talk can and cannot be heard, who is qualified to speak the truth, and the conditions that establish the rationality of statements" (p. 626). Louie identifies Goodwin's social practice of *coding*, or "transforming phenomena observed in a specific setting into the object of knowledge that animates the discourse of a profession" (p. 606), as a type of noticing practice that reduces complexity and synchronizes individual noticing with culturally established standards. For example, teachers use the coding scheme of grades to interpret students and their behavior. In addition to continuing Louie's work with coding, I will also draw on the social practice Goodwin describes as *highlighting* which "makes specific phenomenon in a complex perceptual field salient by marking them in some specific fashion" (p. 606). For example, Goodwin's writing on Professional Vision describes how the police officers involved in the Rodney King trial used the practice of highlighting to link features of the trial setting to the activities being performed in the trial in order to shape the domain of scrutiny for the jury. Goodwin's third social practice of producing and articulating material representations will not be included. In this study, I draw on the concept of *coding* and *highlighting* to identify what and how Ms. B draws attention to, simplifies and foregrounds from the complex engagement of her students.

Methods

Ms. B teaches at an urban public school in a west coast city serving low-income Black and Latinx youth. The school follows a "community school" model within the district and is in a partnership with a university, but despite these resources the school (and the district as a whole) struggled with the transition to distance learning. As has been well documented, many minoritized students do not have the resources or support for schooling at home. Ms. B and I have been collaborating on co-planning community-based, equity-oriented climate change learning since 2018, and this investigation is part of an on-going, broader study of climate change teaching and learning.

Data for this study comes from three sources. First, I wrote observational fieldnotes during four class sessions focused on when Ms. B responded to student participation, including a timestamp of the interaction, the student(s) involved, a paraphrase of the utterances, a summary of visible gestures, and notes of the digital resources involved. Ms. B also saved the Zoom chat generated during class as an artifact. After each class Ms. B and I debriefed the lesson in a conversation focused on narrating the noteworthy interactional moments. These conversations were audio recorded and unscripted with Ms. B offering observations and me asking simple questions like "what happened here?". Last, a retrospective interview explored broad patterns in noticing across the classes. These data sets are inherently incomplete in much more significant and obvious ways than collecting video data of a traditional classroom setting. To describe Professional Vision, Goodwin writes that he "requires data records that preserve not only sequence of talk but also body movements of the participants and the phenomenon to which they are attending" (p. 607) which simply was no possible for me to collect. As a result, the scope of analysis is limited.

Data analysis proceeded in three steps of coding. The unit of analysis in this study is *noteworthy moments*, which are episodes of teacher-talk in response to a student idea or participation identified (either in the moment or in a post-lesson debrief) as worthy of discussion between Ms. B and me. My first step in coding was to prepare transcripts of the conversations from the post-lesson debriefs and interview and to compile discussions of each noteworthy moments across conversations with available artifacts. My second step was a preliminary, descriptive round of coding in which I identified who Ms. B interacted with, what digital platform was in use and the topic of the interaction. My third step was to look for the features described in my theoretical framework–coding, highlighting, identifying, connecting and using knowledge – to identify emerging themes for the purpose and potential of these practices.

Findings

Noteworthy moments occurred almost entirely when Ms. B responded to something a student wrote in the Zoom chat privately to her. After consolidating across my five a priori codes from the two theoretical frameworks, I have identified three themes of the purpose and potential of Ms. B's noticing. Below I describe one example noteworthy moment per theme to demonstrate how the five practices support teacher noticing.

Categorize student experiences as legitimate scientific resources

One day Ms. B was discussing air pollution as related to combustion chemistry. The Zoom chat at the moment was busy with a range of questions and comments, some on topic and some not, but two students wrote her privately in the Zoom chat about their personal experiences with air pollution and she read out loud (akin to revoicing) their contribution. One student shared that he had asthma and another shared that she has seen the city look ugly, dirty and gray. In this interaction, Ms. B is *identifying* important student participation as noteworthy from the range of participation. By revoicing and making the private public, Ms. B is *coding* these contributions as belonging in class. These practices were used to categorize student experiences as legitimate scientific resources. Ms. B's noticing drew on both her pedagogical content knowledge and her cultural and social knowledge of her students to expand the boundaries of what belongs in chemistry class to include community and family-based ideas and experiences.

Normalize the obstacles and frustrations of distance learning

Another class activity modified a participation structure that Ms. B used in-person to allow students to rotate through "stations". After explaining the activity, Ms. B asked if there were questions and student neither responded nor dove into the lesson. Ms. B identified this lack of participation as an indication that the activity was not framed well enough for students to understand the tasks, and rather than forge ahead, she *used her knowledge* of students' circumstance and took the opportunity to share how difficult it is for her to transform lessons for remote learning. In our debrief session, Ms. B described worrying about if students were logging in to Zoom on their phones rather than the preferred Chromebook, if they had poor internet connection, or if they were in a distracting space. By foregrounding her own struggles, she normalized the obstacles and frustrations of distance learning and created space for students to express their struggles. In reflecting on this moment and practice, Ms. B explained her reasoning in connection to her stance as a social justice educator and her commitment to nurturing student well-being.

Bridge past, present and future lessons

Ms. B re-visited a "word cloud" students had previously built of associations with the phrase "climate change" and one student wrote in the Zoom chat that she had contributed the phrase "pollution". Ms. B took this opportunity to call the student out by name and asked if she now knew what the chemical name of the pollutant was. The student then unmuted herself and identified the pollutant as carbon dioxide. This is an example of Ms. B *making connections* that bridge past, present and future lessons and *highlighting* the past learning that is relevant to a current activity. This required Ms. B to use her knowledge of all lessons as well as the ultimate goals for student learning outcomes. When I asked Ms. B's about highlighting previously covered concepts, she explained that she was both spiraling back and scaffolding for future lessons when a concept would be relevant again. She also explained this moment as related to her belief that her students were capable of succeeding in distance learning with the appropriate scaffolds.

Significance

The themes identified in this study suggest the ways in which Ms. B's noticing supports ambitious and equitable science teaching. Bridging lessons is a strategy for creating cohesive storylines that supports students in generating coherent explanation of phenomena which is a high-leverage practice of ambitious science instruction. Normalizing the struggles faced by minoritized students demonstrates how Ms. B's noticing attends to her students' identities and lived experience. And last, legitimizing community-based resources as scientific supports equity by disrupting the hierarchy of Western epistemologies associated with the canon of science and the NGSS. What Ms. B noticed and how she responded was shaped by a) dynamic in-the-moment interactions, b) cultural, social and political forces stretching into the past and the future, and c) her technological proficiencies. Further investigations are needed to expand an understanding of how the five identified practices of noticing shape students' experiences; I hope this exploratory study can be part of an emerging conversation and research on remote teaching and learning.

Noticing has the purpose and potential to enhance meaningful learning possibilities (Luna, 2018); supporting teachers in learning to notice in the distance learning environment can have tremendous implications for students. Of the many systemic changes that are needed in supporting low-income students of color, helping teachers anchor their teaching in students' response to instruction is essential. Findings based in both a cognitive perspective and socio-political perspective of noticing suggest that noticing used for in-person teaching does not translate to distance learning and noticing. The modalities through which students and teachers engage with each other is vastly differently and the three themes identified in this study suggest the need to re-think how teachers learn to notice. Instead of trying to replicate schools and schooling and the inequalities in these systems, the challenges of distance learning present opportunities to re-imagine how to support teachers in equitable and ambitious noticing.

References

Erickson, F. (2011). Mathematics teacher noticing: Seeing through teachers' eyes. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 17-34). New York, NY: Routledge.

Goodwin, C. (1994). Professional vision. *American Anthropologist, 96*(3), 606-633.

Hand, V. M. (2012). Seeing culture and power in mathematical learning: Towards a model of equitable instruction. *Educational Studies in Mathematics, 80*(1-2), 233-247.

Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics, 97*(1), 55-69.

Luna, M. J. (2018). What does it mean to notice my students' ideas in science today?: An investigation of elementary teachers' practice of noticing their students' thinking in science. *Cognition and Instruction, 36*(4), 297-329.

Sherin, B. L., Sherin, M. G., Colestock, A. A., Russ, R. S., Luna, M. J., Mulligan, M., & Walkoe, J. (2010). *Using digital video to investigate teachers' in-the-moment noticing.* Paper presented at the Learning in the Disciplines: Procedeeings of the 9th International Conference of the Learning Sciences (ICLS 2010), Chicago, IL.

Sherin, B. L., & Star, J. (2011). Reflections on the study of teacher noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 66-78). New York: Routledge.

Sherin, M. G., Jacobs, V. R., & Philipp, R. A. (Eds.). (2011). *Mathematics teacher noticing: Seeing through teachers' eyes*. New York, NY: Routledge.

Skyes, G., Bird, T., & Kennedy, M. (2010). Teacher education: Its problems and some prospects. *Journal of Teacher Education, 61*(5), 464-476.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Education, 24*(2), 244-276.

Windschitl, M., Thompson, J., Braaten, M., & Stroupe, D. (2012). Proposing a core set of instructional practices and tools for teachers of science. *Science Education, 96*(5), 878-903.

What pedagogy feels like: Using rehearsal debriefs to develop pedagogical empathy

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Abstract: Teachers must attend and respond to students' emotions, as emotions are inherently intertwined with learning and disciplinary identity. In this study, we forward a theory that the development of *pedagogical empathy* is an inherent component of adaptive expertise, because pedagogical decision-making should be sensitive to students' emotional responses to teaching. We examine how teachers generated and used emotional data during debrief discussions following rehearsals in support of the development of pedagogical empathy. These results have implications for understanding the role of pedagogical empathy in adaptive expertise.

Teaching is characterized by the need to make in-the-moment decisions that respond to emergent student thinking and classroom conditions (Lampert et al., 2010), a capacity known as adaptive expertise. Adaptive expertise involves collecting and using a constant stream of data to make both routine and adaptive decisions about how to respond (Hatano & Inagaki, 1986). Developing adaptive expertise requires time and deliberate opportunities to learn, with attention to when routine responses are sufficient and when innovation is required (Kavanagh et al., 2020). Rehearsals of teaching, in which teachers are either rehearsing teachers (RTs) or students (non-rehearing teachers, NRTs), offer rich opportunities for developing adaptive expertise. The debrief discussions following rehearsals are also a venue for developing adaptive expertise, as participants generate data about the rehearsal experience and consider adaptations (Baldinger & Munson, 2020).

The process of developing adaptive expertise is necessarily dependent on accessing and interrogating multiple streams of data, such as students' mathematical thinking. We argue that teachers must also consider how students feel, which we refer to as *emotional data*. Emotions matter for teaching because they are inherently intertwined with learning, regulating how students engage, think, and learn (Hascher, 2010). We posit that empathy, or the capacity to notice, interpret, predict, and respond to the emotional states of others, is necessary for developing adaptive expertise in teaching. Here, we forward a theory that the development of *pedagogical empathy* (Uhing, 2020) is an inherent component of adaptive expertise, because pedagogical decision-making should be sensitive to students' emotional responses to teaching.

Principles of pedagogical empathy

Uhing (2020) defined pedagogical empathy as having two central pillars: (1) teachers understand the evolving emotions of students, and (2) this understanding influences teaching decisions. To develop adaptive expertise, it is pivotal that teachers not just understand student emotions, but that they know how those emotions influence learning. Knowing the consequences of emotions positions teachers to respond to and foster particular emotional states. For instance, if teachers notice that sharing ideas with the class triggers anxiety in some students and they understand that anxiety is an emotional state that can inhibit learning, teachers are positioned then to adapt their instruction to avoid or mitigate that anxiety. We characterize pedagogical empathy as the professional capacity to understand and use the following principles, which, together, support the development of adaptive expertise:

1. Pedagogical situations generate emotions among students (Debellis & Goldin, 2006).
2. Emotions influence learning and the development of disciplinary identities (Debellis & Goldin, 2006).
3. Under the same pedagogical situations, different students may experience different emotions (Hascher, 2010), contributing to different learning opportunities and different disciplinary identities
4. Teachers' knowledge of student emotions can productively influence pedagogical choices (Uhing, 2020) to increase opportunities to learn and support the development of productive disciplinary identities.
5. Teachers must actively seek opportunities to collect emotional data (Uhing, 2020).

Teaching with pedagogical empathy necessitates understanding and valuing the role of student emotions in learning. However, how teachers gain access to emotional data is not straightforward.

Accessing emotional data

To develop pedagogical empathy, teachers must have reliable access to emotional data; they must know how their students feel under different pedagogical conditions, data they can best gather through interactions with students (Uhing, 2020). However, in real classrooms, there are many practical and social reasons why accessing emotional data may be difficult. Rehearsals of practice can support teacher learning in part because they offer a lower-risk environment for examining teacher decision-making (e.g., Lampert et al., 2010). We argue that the debriefs following rehearsals offer a space for gaining access to student emotions, when students are being played by teachers who are co-invested in learning from the rehearsal experience. Simplifying access to emotional data could enable teachers to develop pedagogical empathy and bring it to the more complex spaces of their classrooms.

Our data indicate that rehearsal debriefs can be venues for collecting rich veins of emotional data. NRTs regularly shared how they felt during the rehearsal under particular pedagogical conditions. This enabled all participants to project how actual students might feel under those or imagined conditions. The prevalence of emotional data and its uptake within the debrief discussion motivated us to investigate the potential of debriefs to support the development of pedagogical empathy. We examined eight rehearsal debriefs with in-service teachers to determine how participants generated, considered, and drew implications from emotional data to develop pedagogical empathy. We asked: How were emotional data *made visible* and *used* in rehearsal debriefs?

Method

This study took place within a two-year professional development fellowship for early-career (2nd-7th year) secondary mathematics teachers serving lower-income schools. Participants included 22 high school mathematics teachers from schools across the US. The second summer institute focused on facilitating collaborative group work and culminated in all participants rehearsing this practice, whose debriefs we investigate here. Teachers were randomly assigned to one of two rehearsal rooms. Four rehearsals were conducted in each room (eight total rehearsals), so that each teacher had the opportunity to rehearse once and participate as an NRT three times. After each rehearsal, the teacher educator (TE) prompted the group to debrief the experience, with RTs and NRTs sharing their reflections. While generating and using emotional data is the focus of the current study, it was not a focus of the professional development program, the rehearsal process, or the debrief discussions. We draw on audio and video recordings of the debriefs following each rehearsal. Each was transcribed for analysis.

All RT and NRT talk turns were segmented and coded based on the ways they generated and used data: attending, interpreting (Sherin et al., 2011), or implicating (Baldinger & Munson, 2020). During this process, *interpreting* talk turn segments, in which the speaker moved beyond observable events and offered an internally constructed understanding of them, were sub-coded to identify interpretations which were emotive (e.g., "I felt overwhelmed…"). We then shifted our analytic lens from the talk turn segment level to the *emotion vignette*: a series of one or more talk turn segments in which student emotions (those of NRTs in their position as students in the rehearsal or the projected emotions of real students) were explicitly considered. To identify vignettes, we first contextualized all instances of emotive interpretation. Vignettes were bounded as starting and ending with topic shifts, in which NRT emotions were a component of the topic. In a second pass, we searched for instances in which student emotions were discussed. These instances were similarly contextualized into vignettes.

Memos for each vignette were constructed to record how emotional data arose, the content of the emotional data, and how those data were used, leading to the development of emergent codes. Each vignette was coded, and codes were expanded, collapsed, and added until all vignettes could be represented using the coding scheme. Where emotional data were made visible or used in multiple ways, multiple codes were applied.

Findings

We found 48 vignettes in which RTs, NRTs, and TEs considered student emotions. In no debrief discussion were student emotions absent. Speakers in all roles participated in uncovering and considering student emotions.

How emotional data were made visible in debriefs

Emotional data arose in the debrief discussions in four ways: (1) requests for emotional data, (2) offers of emotional data from NRTs, (3) noticing of NRTs' emotional responses, and (4) drawing implications from emotional data that had been made public. Thirty vignettes included more than one code. For instance, a vignette might include a request for emotional data by an RT followed by an offer of that data from an NRT.

Requests for emotional data occurred when an RT or TE asked NRTs in their role as students to report their own emotional responses to the rehearsal. Thirteen of the vignettes included a request, often at the beginning of the rehearsal debrief when RTs framed what they hoped to learn from NRTs. For instance, an RT opened a debrief by making a request for emotional data, saying, "For me I think it would be helpful to know, when we did come over and confer, what was useful? What was obstructive? How did that feel?" The RT explicitly elicited NRTs' emotional experiences, indicating that such data would be useful feedback on their pedagogical decisions.

NRTs *offered emotional data* when they reported emotions they experienced as students during the rehearsal. These emotional interpretations of the rehearsal were one of the primary ways emotional data surfaced, occurring in 30 of the 48 vignettes. NRTs reported a wide range of emotions, including anxiety, security, confusion, excitement, and pleasure. These offers were typically highly-specified to the conditions in which the emotions arose. For instance, one NRT reported on their emotional response to an interaction with an RT, saying, “When you [RT] were like, ‘I’m gonna walk away and I’m gonna come back and check in on you.’ That was when I felt like I could breathe and go, ‘Okay, wait. What did I not get?’ So I had a moment of tension when I felt like you were quizzing me and I was like, ‘I really don’t know.’” The NRT described a complex emotional situation, with confusion about the mathematical work, anxiety from being quizzed, and then a sense of relief when the RT gave the NRT time to think. Emotional data were often embedded in the retelling of salient events, and those events were often salient precisely because they generated an emotional response.

Noticing emotional data occurred when any participant identified an emotion that they inferred was experienced by an NRT during the rehearsal; emotional data arose this way in 9 vignettes. For instance, one RT pointed out a moment that caused him to think about his pedagogical choices during the rehearsal, saying, “There was one situation where I saw two people talking and then there was one person kinda left out. And I was trying to think like, maybe it was a strategic move that the group did, or maybe it was just because of the nature of the problem. Like, they’re just so excited and someone got left out.” In nearly half of these instances (4 of 9), noticing emotional data was coupled with a request for additional emotional data.

Emotional data surfaced when any participant *drew implications related to emotional data* that extended beyond the rehearsal events (33 of the 48 vignettes). In these instances, the speaker(s) built on previously offered emotional data to consider on how those data might inform their thinking about teaching and learning. For instance, in a vignette in which speakers discussed the “quiet anxiety” felt during a rehearsal, one NRT mentioned that in his own teaching he had thought about asking students in similar moments, “What is hard about this task?” but he never had. Now, in reflection, he stated that, “If somebody would’ve asked me that, I’d be like, ‘Okay. So this is hard. I don’t get that. This is confusing.’ Like, it would’ve given me that sigh of relief to be able to say that.” The emotion of relief described here is a projected one, rather than one felt in the actual rehearsal.

How emotional data were used in debriefs

Emotional data that surfaced in the debriefs were used to inform teachers’ sensemaking of the rehearsal and, often, classroom practice more generally. We identified six ways emotional data were used by participants: (1) providing feedback to RTs, (2) contrasting emotional interpretations, (3) connecting instances of shared emotions, (4) projecting student emotions, (5) examining teacher decision-making, and (6) drawing implications for classroom practice. Vignettes often included multiple uses, supporting robust understandings of pedagogy.

The most prevalent function of emotional data (34 of the 48 vignettes) was for NRTs to *provide feedback* to the RTs. NRTs used emotional data to address RTs’ questions or to provide information about the function of RTs’ instructional decisions. Emotional data were thus viewed as a relevant lens for interpreting the impact of pedagogical decisions. For example, one NRT shared that she felt left out when everyone in her group was recognized except her. The RT took up this feedback, saying “I’m glad I got the chance to experience that now and not with my students, because that could burn a bridge pretty quickly.” NRTs and RTs viewed emotional data as a valid form of feedback on the consequences of pedagogical choices.

In 23 vignettes, participants used emotional data to provide *contrasting emotional responses* to the same event. For instance, one NRT reported feeling excited by a structure that felt “like a race”, while others indicated that this same situation induced anxiety because of the language used by the RTs in the rehearsal. These moments illustrated how different emotional responses are possible to the same situation. In this way, pedagogical decisions could be viewed as creating complex emotional terrain, rather than just positive or negative responses.

A small number of vignettes (2 of 48) included moments where the sharing of emotional data triggered another NRT to offer a different event in which they felt the same emotion. In these instances of *connecting emotional data*, what was common was the emotional response. Participants sought to make connections between the pedagogical choices that generated similar emotional experiences. For example, during a discussion about checkpoints, an NRT expressed anxiety and security, saying “I felt really pushed [...]. As much as I know this content, I still was pushed and I still learned.” Another NRT picked up this idea, saying, “To build off that, I felt I was pushed by each one of you,” and gave an example of the kind of question that pushed their thinking.

In 14 of 48 vignettes, emotional data were used to *project student emotions* – to hypothesize how students in the classroom might feel under particular pedagogical conditions. These included instances in which the speakers anticipated that students might and might not feel the same way an NRT did during the rehearsal. For instance, one NRT shared how she felt supported when the RT checked on her after she had gotten distracted. She went on to project that “the student might feel overwhelmed in that moment.” In these vignettes, participants attempted to leverage the emotional experience of the rehearsal to predict, anticipate, and understand their students’ emotional experiences of pedagogy.

RTs followed up on emotional data in 8 vignettes to *examine their decision-making* process during the rehearsal. For instance, after two NRTs offered interpretations of a teacher move, the RT shared, “Can I comment on my intention? It's just, I wanted to connect with you guys as humans. I just wanted to make sure you felt safe. […] But like, you're right. I should've waited for maybe a more appropriate time to…build that connection or that trust with you." The RT made her thought process in the moment visible, connecting the intent directly to student emotion – in this case security – and then reconsiders how best to implement that pedagogical move.

One critical use of emotional data (27 of 48 vignettes) was to consider how that data might inform decision-making in the classroom. In these vignettes, speakers *drew implications for classroom practice* by suggesting ways to adapt pedagogical moves used in the rehearsal, describing general principles for teaching and learning that they extracted form the experience, or reconsidering their own previous pedagogical choices. In each of these cases, implications were offered directly in response to emotional data, showing how an understanding of student emotions could be used to influence future teacher decision-making.

Discussion

To develop pedagogical empathy, teachers must first recognize that pedagogical situations generate emotions among students, a recognition evident in our data through the repeated requests for emotional data. Moreover, NRTs offered to make their own emotional reactions to the pedagogy they experienced in the rehearsal public both in response to specific requests and spontaneously. Projecting student emotions, drawing implications for the classroom, and examining teacher decision-making all contributed to participants developing understanding of how student emotions might influence learning opportunities and mathematical identities, which NRTs could articulate in a way that students themselves may not. Contrasting or connected emotional experiences generated a nuanced impression of the emotional terrain of the classroom, where individual decisions could have differential impacts on students. Not all of these emotional responses were intended, as several RTs stated, and participants discussed intent and the emotional consequences side-by-side. As RTs tried out new pedagogical techniques as part of the rehearsal, the discussion of student emotional responses fed considerations of how to refine these practices for use in the classroom. NRTs were positioned to name both what they felt and to suggest alternatives that could mitigate negative emotions or elevate positive ones.

While NRTs were a particularly fruitful source of emotional data during rehearsal debriefs, teachers' need for emotional data did not end with the rehearsals. We identified several instances where participants considered how they might elicit similar data from their own students. This suggests that participants were developing the capacity to actively collect emotional data in their own classrooms as an ongoing practice.

This study demonstrates the nuanced ways in which teachers developed pedagogical empathy during debriefs. Just as teachers seek to learn how to respond to emergent student thinking, the teachers in this study actively sought to develop ways of responding to emergent student emotions. The development of pedagogical empathy thus coincides with and acts in support of the development of adaptive expertise.

References

Baldinger, E. E., & Munson, J. (2020). Developing adaptive expertise in the wake of rehearsals: An emergent model of the debrief discussions of non-rehearsing teachers. *Teaching and Teacher Education*, *95*, 103125. https://doi.org/10.1016/j.tate.2020.103125

Debellis, V. A., & Goldin, G. A. (2006). Affect and meta-affect in mathematical problem solving: A representational perspective. *Educational Studies in Mathematics*, *63*(2), 131–147. https://doi.org/10.1007/-s10649-006-9026-4

Hascher, T. (2010). Learning and emotion: Perspectives for theory and research. *European Educational Research Journal*, *9*(1), 13–28. https://doi.org/10.2304/eerj.2010.9.1.13

Hatano, G., & Inagaki, K. (1986). Two courses of expertise. In H. W. Stevenson, J. Azuma, & K. Hakuta (Eds.), *Child development and education in Japan* (pp. 262–272). W. H. Freeman & Co.

Kavanagh, S. S., Metz, M., Hauser, M., Fogo, B., Taylor, M. W., & Carlson, J. (2020). Practicing responsiveness: Using approximations of teaching to develop teachers' responsiveness to students' ideas. *Journal of Teacher Education*, *71*(1), 94–107. https://doi.org/10.1177/0022487119841884

Lampert, M., Beasley, H., Ghousseini, H. N., Kazemi, E., & Franke, M. L. (2010). Using designed instructional activities to enable novices to manage ambitious mathematics teaching. In M. K. Stein & L. Kucan (Eds.), *Instructional explanations in the disciplines* (pp. 129–141). Springer US. https://doi.org/10.1007/978-1-4419-0594-9

Sherin, M. G., Jacobs, V. R., & Philipp, R. A. (2011). Situating the study of teacher noticing. In M. G. Sherin, V. R. Jacobs, & R. A. Philipp (Eds.), *Mathematics teacher noticing: Seeing through teachers' eyes* (pp. 3–13). Taylor & Francis.

Uhing, K. (2020). *Exploring pedagogical empathy of mathematics graduate student instructors* [Unpublished doctoral dissertation]. University of Nebraska-Lincoln.

Discourse Patterns and Collective Cognitive Responsibility in Collaborative Problem-Solving

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Abstract: In knowledge building, learners achieve collective cognitive responsibility (CCR) by exerting their shared epistemic agency. Although CCR has been discussed as a critical part of the learning process, few studies have established analytical frameworks to examine how learners develop CCR through collaborative discourse. This study analyzed the collaborative discourse of seven groups of three university students each, who were tasked with solving a Jasper Woodbury problem to determine how CCR took shape. It used a mixed-method approach. Its results indicated that there are three distinct discourse patterns related to CCR: (1) collective CCR, in which each group member engaged in discourse, (2) rotating leadership CCR, in which pairs of members flexibly engaged in discourse, and (3) fixed leadership CCR, in which a specific pair of group members led discursive activity. The study concludes by discussing which of these discourse patterns might help students develop and sustain CCR in collaborative problem-solving.

Background and research purpose

In knowledge building, learners are encouraged to collectively advance their knowledge and continuously improve their ideas through collaborative inquiry (Bereiter, 2002; Paavola & Hakkarainen, 2005). Scardamalia (2002) described individual learners' intention to contribute to collective knowledge advancement as their epistemic agency and described collective intentions to do so as collective cognitive responsibility (CCR). As discussed in other studies (e.g., Chen et al., 2015; Damşa et al., 2010; Zhang et al., 2009), learners' epistemic agency should be exerted through their responsibility to construct collective ideas by making a judgment of the promisingness of their ideas and further improving them for solving their authentic problems.

Because knowledge building is a collaborative activity, it is challenging to evaluate knowledge building practices and processes. Several researchers have suggested that we must analyze how learners represent their collective knowledge and how these representations change over time in order to appropriately evaluate its advancement (Oshima et al., 2012; Scardamalia et al., 2012). Studies have attempted to develop methods of evaluating these representations. For instance, Zhang et al. (2019) suggested using idea thread mapping diagrams, which allow learners and instructors alike to assess learners' contributions to collective knowledge building over time in a network graph. Oshima et al. (2012) suggested using Knowledge Building Discourse Explorer (KBDeX) which provides learners with a vocabulary network and helps them ascertain which of their ideas are or are not connected. Other tools, such as Feng et al.'s (2019) idea-friend map (which was developed from KBDeX) helps students determine how their ideas are connected and how they can further integrate or elaborate upon their ideas.

Although previous studies have examined how collaboration between or within communities helps improve ideas, few studies have examined how individual learners contribute to collective knowledge advancement in CCR. Gutiérrez-Braojos et al. (2019) used scientometric analysis to assess the relationship between individual contributions and CCR. In their study, university students evaluated how the notes of their peers contributed to collective knowledge advancement. Each student's contribution value was calculated as the proportion of their notes which their peers recognized as helpful. While this approach allows us to represent CCR within a community and identify different types or values of contributions, it does not analyze how this process helps students improve their ideas. This study, therefore, aims to propose another analytical framework of CCR by extending socio-semantic network analyses (SSNA) of idea improvement so that both the idea improvement process and the degree of CCR exerted during this process can be evaluated. Below, we propose a new algorithm to represent CCR and demonstrate their analytical framework by examining discourse datasets from seven groups of three university students each.

Method

Participants and setting

The study's participants were 21 university students (seven groups of three). Groups of three participants were asked to solve a Jasper Woodbury problem called "Rescue at Boones Meadow (CTGV, 1992)." In the problem, a protagonist named Emily must bring a wounded bald eagle back to an animal hospital using a small airplane. Participants were asked to find the fastest route from the meadow to the hospital. The problem was presented in a 15-minute video and they were given 45 minutes to engage in collaborative problem-solving. They were also provided with an iPad (to watch the video) and a whiteboard (to write/draw their ideas). Their conversations and actions were recorded on video.

Analysis

The participants' conversations were transcribed verbatim and then subjected to two analyses. First, we modified and extended the original SSNA algorithm of KBDeX in order to analyze study participants' idea improvement and CCR. The original algorithm represents idea improvement as the aggregate change in the total degree-centrality (DC) of words in a given network, taking each turn in conversation as a unit of analysis. In the modified algorithm, we used the moving stanza-window method (Siebert-Evenstone et al., 2017) to conduct further analysis. Because every conversational turn is influenced by the previous turn and influences the next turn (Wells, 1999), we set a stanza-window of three conversation turns as a unit of analysis and then calculated the cooccurrences of words in all transcribed interactions. By modifying the algorithm, we made it possible to detect which conversational turns elicited ideas represented in other conversational turns, and thus made it possible to detect the origins and trajectory of idea improvement.

Second, we calculated each participant's idea improvement process by analyzing a discourse subset from each participant. We then compared each participant's contribution with their group idea improvement as well as all other students' contributions in order to evaluate how each participant contributed to idea improvement. After identifying various types of CCR, we conducted a discourse analysis of segments which SSNA identified as critical for examining discourse patterns.

Results

Idea improvement and CCR

For evaluating group idea improvement as well as individual contribution to it, our modified algorithm visualized the improvement processes as seen in Figure 1. The vertical axis represents the total value of the degree centralities in the word network. The steep increase in the graph means a pivotal point in discourse for improving ideas. In each group, we visualized four different lines representing the group as whole and three individual contributions. Through visual inspection, three types of CCR were identified: (1) *collective* CCR (two of the seven groups), (2) *rotating leadership* CCR (one group), and (3) *fixed leadership* (four groups). In the *collective* CCR groups, all three participants contributed equally to idea improvement at the group level (see the left graph in Figure 1). Participants' patterns of change in the total DC were similar to one another as well as the group improvement. In the *rotating leadership* CCR group, pairs of participants led CCR and the configurations of these pairs changed over time – i.e., each participant contributed to the group's idea improvement at different points in time (see the shaded areas on the right side of Figure 1). By contrast, a specific pair of students led discourse in the *fixed leadership* CCR groups.

Discourse patterns and CCR

Here, we examine segments of a collective and a rotating leadership group's discourse in order to identify patterns of discourse by which students held their CCR. These segments were selected because the collective CCR group displayed a remarkable increase in total DC and because different pairs of students were responsible for the rotating leadership CCR group's increase in DC.

S, J, and I's collaborative discourse is presented as an example of a collective CCR group. The following is a segment of their conversation turns 562–567:

562: S: OK, I got it. [Larry and Emily are in the same town.]

563: J: It doesn't matter if we go to the gas station and come back to the town by car, does it?

564: S: Well, see...

565: I: You mean that Larry will drive a car [to the gas station] while Emily flies [to the wounded eagle's location]?

566: J: Yeah, Larry drives a car!

567: I: On the highway.

This discourse pattern reveals that I and J built on S's understanding that two characters Larry and Emily were in the same town. S's understanding helped the other participants consider a new solution to the problem. By taking turns in conversation, they shifted leadership around to different configurations of pairs (S–J, S–I, and I–J).

Y, K, and M's collaborative discourse is presented as an example of a rotating leadership group. The following is a segment from their conversation:

390: Y: We consume 40 gallons [of gas] from here [the town] to there [the wounded eagle's location].
391: K: And, we can only use the road from the gas station to the town.
392: K: Our problem is – how can we bring the eagle back to Boones Meadow... No, from Boones Meadow back to the town.
393: Y: We have to go back to here [pointing to the town on their whiteboard map].
394: K: We have to think of the route to bring the eagle back from Boones Meadow to the town.
395: Y: No, no. We have to start from the town then go back to the town.
396: K: Oh, we have to think of the round trip!

In the other selected segment (633–638), another pair, Y and M, engaged in discourse in the similar way. Thus, the rotating leadership group distributed their collaborative leadership in different configurations of pairs over time to advance their collective knowledge.

633: M: As a different idea, we can say, Emily flies to Boones Meadow [the place of the wounded eagle] then takes another flight to the gas station. But, she does not have enough [gas], so she must walk to the station after landing on the way [to the gas station]. After Emily gets to the station, Larry brings the eagle back to the hospital in his car.

634: Y: What did you say after Emily gets the gas station?

635: M: Well, Emily flies from here [pointing the town on their map on the whiteboard] to here [pointing Boones Meadow on their map on the whiteboard], right? She still needs to move five miles [from Boones Meadow to the gas station].

636: M: While Emily flies to Boones Meadow, Larry can drive to the gas station. He waits for Emily's coming with the eagle from Boones Meadow. He then brings the eagle back to the town in his car. Isn't it the fastest route?

637: Y: But, we are not quite sure if she [Emily] can land on the way from Boones Meadow to the gas station, are we?

638: M: Yeah, you're right. Not sure about it.

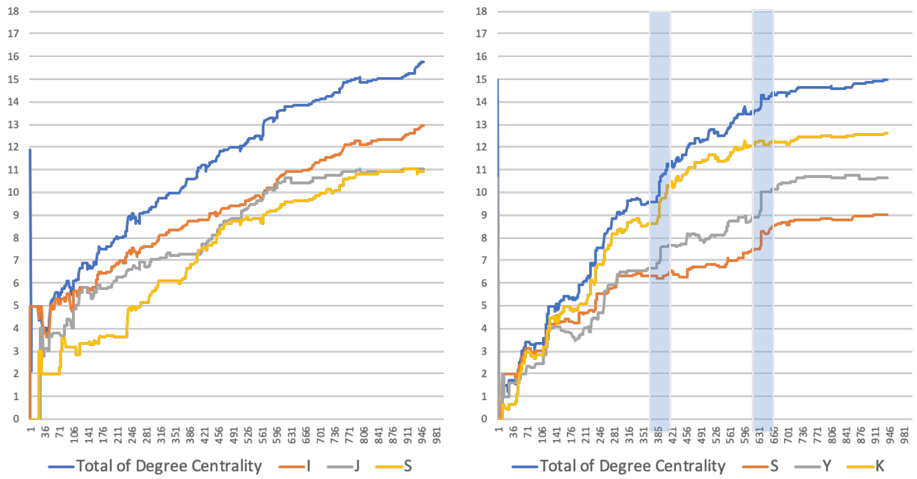

Figure 1. Temporal change in the total degree-centralities over conversation turns in a collective CCR group (left) and a rotating leadership CCR group (right).

Discussion

First, our study's modified SSNA algorithm articulated how students in a group engaged in CCR through collaborative discourse by identifying three modes of CCR. We expected that most participants would exhibit collective CCR. However, only two groups exhibited this pattern. The majority of groups exhibited a fixed leadership mode of CCR. All study participants were engaged in CCR throughout the idea improvement process. Although Ma et al. (2016) reported a similar finding at the individual level, this study expands their findings to collective knowledge advancement.

Second, this study revealed critical differences in the discourse patterns of each of the three modes of groups identified above. In the collective CCR group, different pairs took conversational turns smoothly within the same sequence of conversation turns and performed as a whole. Such smooth changes did not occur over a single sequence but over multiple sequences in the rotating leadership CCR group. Both discourse patterns helped the participants attain CCR as a group. Of course, different discourse patterns are appropriate for different contexts and group cultures.

Conclusion

This study examined CCR in collaborative problem-solving through a mixed-method approach. It identified different patterns of CCR and examined how study participants engaged in CCR through collaborative discourse. It found that that students attained CCR by sharing or rotating leadership of small groups. Future studies should examine individual-level factors which influence CCR or which discourse patterns should be encouraged to help fixed leadership groups transcend their current practices.

References

Cognition and Technology Group at Vanderbilt. (1992). The Jasper series as an example of anchored instruction: Theory, program description, and assessment data. *Educational Psychologist*, *27*(3), 291–315.

Feng, X., van Aalst, J., Chan, C., & Yang, Y. (2019). Fostering collective knowledge advancement through idea-friend maps in a large knowledge building community. In Lund, K., Niccolai, G., Lavoué, E., Hmelo-Silver, C., Gweon, G., and Baker, M. (Eds.), A Wide Lens: Combining Embodied, Enactive, Extended, and Embedded Learning in Collaborative Settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019, Volume 1 (pp. 288–295).

Gutiérrez-Braojos, C., Montejo-Gámez, J., Ma, L., Chen, B., de Escalona-Fernández, M. M., Scardamalia, M., & Bereiter, C. (2019). Exploring collective cognitive responsibility through the emergence and flow of forms of engagement in a knowledge building community. In *Didactics of smart pedagogy* (pp. 213–232). Springer, Cham.

Ma, L., Matsuzawa, Y., & Scardamalia, M. (2016). Rotating leadership and collective responsibility in a grade 4 Knowledge Building classroom. *International Journal of Organisational Design and Engineering*, *4*(1-2), 54–84.

Oshima, J., Oshima, R., & Matsuzawa, Y. (2012). Knowledge Building Discourse Explorer: A social network analysis application for knowledge building discourse. *Educational Technology Research & Development*, 60, 903–921.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. *Liberal education in a knowledge society*, *97*, 67–98.

Scardamalia, M., Bransford, J., Kozma, B., & Quellmalz, E. (2012). New assessments and environments for knowledge building. In P. Griffin, B. McGraw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 231–300). New York, NY: Springer Science+Business Media.

Siebert-Evenstone, A. L., Irgens, G. A., Collier, W., Swiecki, Z., Ruis, A. R., & Shaffer, D. W. (2017). In Search of Conversational Grain Size: Modelling Semantic Structure Using Moving Stanza Windows. *Journal of Learning Analytics*, *4*(3), 123–139.

Wells, G. (1999). *Dialogic inquiry: Towards a sociocultural practice and theory of education*. Cambridge, UK: Cambridge University Press.

Zhang, J., Scardamalia, M., Reeve, R., & Messina, R. (2009). Designs for collective cognitive responsibility in knowledge-building communities. *The Journal of the learning sciences*, *18*(1), 7–44.

Zhang, J., Tao, D., Chen, M. H., Sun, Y., Judson, D., & Naqvi, S. (2018). Co-organizing the collective journey of inquiry with idea thread mapper. *Journal of the Learning Sciences*, *27*(3), 390–430.

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Instructional Design, Situational Interest, and User Experience: Applications of Learning Experience Design to Promote Children's Online Engagement

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Abstract: Historically, learning for young students has occurred in formal, in-person classroom environments. But in just a matter of weeks, children were mandated to transition to a completely new mode of learning, facing new learning challenges with heightened anxieties. To this end, we aim to better understand how our learning experience design (LXD) efforts support or hinder children's engagement while participating in an online, video-based math course. This study operationalized LXD through the integration of e-learning instructional design (ID) as a lever for promoting students' situational interest (SI), emphasis on human-centered design to support students' user experience (UX), and the combination of SI and UX to foster student engagement in an online environment. Results provide practical implications for how we can intentionally iterate our designs to sustain children's online engagement as we prepare for future instances of traditional, online and even hybrid models of instruction.

Introduction and theoretical approach towards learning experience design

Currently, one major concern with distance learning is how to best engage and sustain young students' participation throughout the learning experience, given the contextual challenges such as the heightened anxieties caused by the COVID-19 pandemic and the often relatively unsupervised home educational settings (Agarwal & Kaushik, 2020). In this paper, we define engagement as the attention, curiosity, and interest students exhibit during an online video-based math lesson. We then explore how our design choices as researchers, designers and practitioners might support young students' engagement by applying principles of learning experience design (LXD). LXD is the process of creating learning environments to foster learning in a human-centered, goal-orientated method (Floor, 2018; Correia, 2018). In the context of our study, we operationalized LXD by grounding our course in e-learning instructional design (ID) frameworks and ensuring quality user experience (UX) design. We also explored the connection of a third facet: students' situational interest (SI) within a learning environment, as a motivator for sustaining their online engagement. Through this process, we leverage quality ID to support students' SI, strong UX to alleviate technical difficulties related to distance learning, and the combination of the two to facilitate increased engagement. These results provide practical implications for how we can intentionally iterate our designs to sustain young students' online math engagement.

Research in online learning attributes increased student engagement to quality ID (Pappas, 2015), student UX with the interface (Hu, 2008), and student motivational factors (e.g. interest, self-efficacy) that can emerge as a result of the learning environment (Chen et al; Sun et al, 2012). Centered around the notion that "learning" is inseparable from "doing," we adopted the Situated Cognition Theory (SCT) framework so that learners could grasp the concepts and skills that are taught in the context in which they will be utilized (Brown et al., 1989). In practice, SCT emphasizes immersive learning environments, where new information is taught to learners in a way that simulates real-life settings. We operationalized this by using pre-recorded videos of a real-world math lesson being taught by a teacher to students in a real classroom, and embedding interactive opportunities for modeling, coaching, scaffolding, articulation, reflection, and exploration (Pappas, 2015). Leveraging the SCT framework for e-learning course design, we assess students' SI as a result of our ID efforts. Situational interest refers "to the interest activated by the immediate learning environment" or the interest given the novelty aspect of a learning task (Schraw & Lehman, 2001). Past research indicates that SI is a powerful motivator in areas of math, reading, and history, when learner participation and interaction throughout the entire learning process is sustained (Chen et al, 2001). Thus, this study allows us to better understand how our intentional design choices within the online learning environment influence young students' SI to foster online engagement. Lastly, we explore students' UX, as it is considered a key contributor to students' success in online learning environments and has been shown to increase student engagement (Pellas, 2014). A common approach to assess UX in online courses is to measure course usability (Hu, 2008). In an online course, usability refers to the effectiveness of the learning interface and whether or not a student can successfully interact with the course platform to accomplish an intended task. As such, course usability aims to create a positive student UX through content accessibility, a significant predictor of student engagement in online learning environments (Thomson & Lynch, 2003).

To this end, we aim to better understand how our LXD efforts support or hinder young students' engagement while participating in an online, video-based math lesson. This study is guided by the following research questions: (RQ 1) *To what extent do students' SI within an online course influence students' perceived learning engagement (PLE) in math while learning remotely during a worldwide pandemic?* (RQ 2) *To what extent do students' course usability within an online course influence students' PLE in math while learning remotely?* (RQ 3) *Did the ID and course usability support students' online learning experience?*

Methodology

Course design context

The online course modules were hosted on a researcher-designed e-learning platform that was integrated with the teachers' preferred learning management system (LMS) to minimize course flow disruption. Cognizant of the research behind effective UX and ID in self-paced courses, intentional design choices were made to maximize digital interactivity and learner engagement. More specifically, an hour-long video lesson was segmented into ten parts instead of one long continuous stream to reduce fatigue, cognitive load, and opportunities for students to mind-wander (Mayer, 2019). Scaffolded problem sets (worked examples) were placed in between video segments for students to practice problems immediately. These types of problems scaffold novice learners by drawing attention to the structural similarities in the lesson to ensure students attend to the key ideas, concepts, and relationships in practice (Begolli & Richland, 2018). For example, students were first asked to recall strategies they learned from watching the videos. Next, students plugged in the procedural steps to solve the math question. Then, students were asked to compare their procedural steps with model example strategy solutions. After making comparisons across problem types and strategies, students would solve the math problem by assessing their conceptual understanding. Lastly, solution reflections were embedded within each problem scaffold for students to explain, in their own words, how they solved each math problem with their chosen solution strategies. This design choice enabled students to actively engage in their own productive metacognitive judgments and reflect on "how and why" they arrived at their solutions, which has been found to foster learner responsibility, increased test preparation, and review and practice (Tullis & Benjamin, 2011). Careful considerations were made to ensure that the course interface facilitated quality UX design. For example, course roadmaps, course goals, and navigational instructions were clearly "highlighted" and "boxed in" to promote learner ease of use and findability. Additionally, standardized vector icons were utilized before every instructional type, allowing students to differentiate between interface instructions as opposed to lesson-specific instructions. Each video also had instructions clearly stating how to pause, play, and re-watch. These UX design choices were made to mitigate visual complexities, technical difficulties, and allow users to focus on the content most relevant for the task at hand. The ability to click backwards in the course enabled students to freely navigate the course space with more autonomy. Through these iterations, an array of design decisions grounded in LXD principles were implemented to co-develop this online video math course, with the goal of integrating elements of a real classroom and interactive features of an online learning environment in order to maximize students' online engagement.

Data collection and analysis

We recruited 5th and 6th grade teachers from two districts in Orange County. A total of three 5th grade teachers, six 6th grade teachers, and one 5th/6th grade combo-class teacher agreed to be a part of the study. There were a total of 12 classes, each with 26-33 students. Of the (N = 195) students who participated, 55.8% identified as female and 44.2% identified as male. Student ages ranged from 10 to 13 years old, with a majority being age 11 (46%) and age 12 (44.9%). This sample consisted of children from a variety of racial/ethnic backgrounds (31.9% White, 2.7% Black, 22.1% Asian, 21.2% Latinx, 22.1% other). The online math lesson was administered to all students during Part 1 of the study. Two days later, four questionnaires were administered to students during Part 2 of the study. This included adapted versions of the Situational Interest Scale (Chen et al., 2001) and the Standardized User Experience Percentile Rank Questionnaire (SUPR-Q; Sauro, 2015). Both measures were 5-point Likert Scales ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Students' PLE was also measured using an adapted 5-point Likert scale (Rossing et al., 2012). Lastly, we used an adapted version of the Children's Impact of Events Scale (CRIES) developed by the Children and War Foundation (2005), which was a 4-point Likert scale, ranging from 1 (*not at all*) to 4 (*often*). Quantitative data were analyzed using SPSS. Pearson correlations tested the associations between the key variables in our study. Multiple regression analyses were conducted to examine how students' online usability, as well as students' SI, would influence their PLE in math while learning remotely. The SUPR-Q and SI scores were used as predictors on the outcome variable (PLE) to examine research questions one and two, respectively. Students' CRIES score was included in the regression model as the control variable. Qualitative analysis of student evaluation responses were analyzed in Qualtrics

Core XM, which was deductively coded. A codebook was defined and systematically applied. Inclusive and exclusive statements were clearly written to differentiate code applications.

Findings

Descriptive statistics were measured (PLE, SI, CRIES, and SUPR-Q scores). All of the measures were reliable based on the widely accepted recommendation of a Cronbach's alpha of .70 (Nunnally, 1978). Pearson correlations indicated that there was a significant positive moderate correlation between SI and students' PLE ($r = .67$, $p < .001$). Similar significantly positive moderate associations were observed between SI and students' online course usability ($r = .63$, $p < .001$), as well as between students' PLE and students' online course usability ($r = .59$, $p < .001$). However, there was a significantly low and negative association between students' levels of anxiety during the pandemic (CRIES) and their PLE ($r = -.22$, $p < .01$). A similar association between students' levels of anxiety and students' course usability was observed ($r = -.16$, $p < .05$). To estimate the effect of students' SI on their PLE in online math during the pandemic, multiple regressions were conducted with the PLE score as the outcome variable (see Table 1). Results indicate that there is a significant main effect of students' SI score ($\beta = .59$, $p < .001$). In addition, results indicate that there is a significant main effect of students' online course usability score ($\beta = .34$, $p < .001$). On average, students' online course usability and SI explained 51.5% of the variance in the model $F(3, 191) = 67.7$, $p < .001$.

Table 1: Multiple regression with SI and SUPR-Q as predictors for PLE, with CRIES as a control variable.

	Perceived Engagement	
Predictors	β	*SE*
SI	.589***	.078
SUPR-Q	.342***	.086
CRIES	-.108***	-.141
(Constant)	.056	.292
R^2	.515	
N	195	
Note: *** $p < .001$; ** $p < .01$; * $p < .05$ (Two-tailed test).		

There were two main themes identified that were related to the effectiveness of our ID and course usability. The first theme was "instructional design enhanced students' engagement," and the second theme was "the usability of the online course influenced students' learning experience."

Theme 1: Instructional design enhanced students' engagement

Students' engagement was defined as the amount of active participation, motivation, effort, interest, and attention while interacting with the online course. Through our analysis, we noticed emerging patterns specifically related to the implementation of the SCT instructional design model. This model used pre-recorded video to situate students in a real-life classroom context to support students' online engagement. For example, many students expressed that the design of the video lesson made them more motivated and willing to spend more time and effort learning online.

Student A: "…I like the interactive ways that I'm able to learn on this [online course] activity as "…it [online course] makes me feel like the real classroom…"

Student B: "I liked how this [online course] activity had videos and felt like you were really learning in class. It was easy and useful. This [online course] activity was also very easy to understand and helped me to understand there are many ways to solve a problem."

Student C: "…it [online course] made me want to learn even more… also I like how they [online course] use videos to explain the lesson and that help me a lot."

Theme 2: The usability of the online course influenced students' learning experience

Students' online course evaluations provided evidence on how our course's usability supported students' UX within the online learning environment. These excerpts provide evidence on how our conscious efforts to a more human-centered design affected students' learning experience. Self-paced learning was defined as references to autonomy, on your own time, and time frames with regards to pacing while participating in the online course. For example, they could easily navigate using the back button within the course interface. Additionally, students were able to re-watch, pause, and play a video if they did not grasp the concepts or explanations the first time.

Student D: "What I liked about this learning activity [online course] is that its a video and if I don't understand something I can go back to the point I don't understand"

Student E: "I liked that I could go back and see what I either did wrong or right."

Student F: **"**I like how I can go on my own pace and replay the lesson if I need to."

Conclusion and implications

This study operationalized LXD through the combination of e-learning ID as a lever for promoting students' SI, emphasis on human-centered design to support students' UX, and the combination of SI and UX to foster student engagement. Interestingly, our analyses indicate that students' SI and UX while interacting with the online learning interface were significant predictors of students' online engagement, even after controlling for students' heightened anxieties due to the global pandemic. Snippets of student responses reveal that the use of video situated in the real classroom context may be motivating students. We deduce that students' SIs are increased as a direct result of implementing the SCT instructional design framework. When participating in the online course, students felt like they were in a real classroom and mentioned how watching real students and teachers increased their motivation to learn even more. By preserving the ecological validity of the classroom environment, students were able to follow along with the teacher and immediately practice the math concepts. Gleaning student commentaries also revealed that careful attention to the course usability promoted quality UX design by facilitating ease of use, findability, and navigability (Simunich et al., 2015). These UX design decisions afforded students the opportunity to recognize their initial understandings of the math concepts and allow students to review and practice by navigating backwards or replaying a video. As such, students were able to take control of their learning pace and adapt their learning behaviors to stay engaged in the course content. Thus, the simultaneous integration of ID and UX design may be consequential in supporting students' engagement in an online learning environment. While more research is certainly warranted, we also conjecture that the underlying mechanism linking LXD and engagement is likely to be the resulting effect of increasing student's self-efficacy, task-value, and self-regulation. In conclusion, this study supports the literature on student online engagement and students' learning experiences through empathy, informing LX designers and practitioners on how we might effectively co-design and iteratively improve teaching and learning for future instances of traditional, online and even hybrid models of instruction.

References

Agarwal, S., & Kaushik, J. S. (2020). Student's perception of online learning during COVID pandemic. *Indian Journal of Pediatrics*, 1.

Ahn, J. (2019). Drawing Inspiration for Learning Experience Design (LX) from Diverse Perspectives. *The Emerging Learning Design Journal*, *6*(1), 1.

Begolli, K.N. & Richland, L.E. (2018). Bridging Cognitive Science and Real Classrooms: A Video Methodology for Experimental Research. *The Journal of Experimental Education*, *86*(4), 671-689.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher*, *18*(1), 32-42.

Chen, A., Darst, P. W., & Pangrazi, R. P. (2001). An examination of situational interest and its sources. *British Journal of Educational Psychology*, *71*(3), 383-400.

Correia, A. P. "ID 2 LXD" From Instructional Design to Learning Experience Design: The Rise of Design Thinking. *Driving Educational Change: Innovations in Action*.

Floor, N. (2018b). What is Experience Design? http://www.learningexperiencedesign.com/learn-1.html

Hu, S., & Kuh, G. D. (2002). Being (dis) engaged in educationally purposeful activities: The influences of student and institutional characteristics. *Research in Higher Education*, *43*(5), 555-575.

Pappas, C. (2015). Instructional design models and theories: The situated cognition theory and the cognitive apprenticeship model.

Schraw, G., & Lehman, S. (2001). Situational interest: A review of the literature and directions for future research. *Educational psychology review*, *13*(1), 23-52.

Simunich, B., Robins, D. B., & Kelly, V. (2015). The impact of findability on student motivation, self-efficacy, and perceptions of online course quality. *American Journal of Distance Education*, *29*(3), 174-185.

Sorensen, C., & Donovan, J. (2017). An examination of factors that impact the retention of online students at a for-profit university. *Online Learning*, *21*(3), 206-221.

Sun, J. C. Y., & Rueda, R. (2012). Situational interest, computer self-efficacy and self-regulation: impact on student engagement in distance education. *British Journal of Educational Technology*, *43*(2), 191-204.

Thompson, L. F., & Lynch, B. J. (2003). Web-based instruction: Who is inclined to resist it and why?. *Journal of Educational Computing Research*, *29*(3), 375-385.

Feedback in the Wild: Discrepancies between Academics' and Students' Views on the Intended Purpose and Desired Type of Feedback

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Abstract: Getting feedback on assignments is as ubiquitous of an educational experience as anything. The goal of feedback is to move students from where their skills and knowledge currently lie to some end criteria identified by the instructor. The present study highlights the gap between theory and practice by comparing undergraduate students' views on the purposes and idealized content of feedback to those of academics. The results suggest a shared understanding of the purpose of feedback. However, students do not necessarily *want* feedback that reflects those purposes. The relationship between students' views on feedback and their actual experiences with feedback are briefly discussed, as are the implications of the findings.

Keywords: Feedback, Motivation, Learning Outcomes, Teaching

Introduction

Throughout our time in school, we receive feedback on almost everything we do. But do we really have a universally accepted idea of what feedback and its purpose is? The primary goal of academic feedback, as generally understood by researchers, is to move students from where their skills and knowledge currently lie to some end criteria identified by the instructor (Hattie & Timperley, 2007). In their systematic review of the literature, Hattie and Timperley (2007) identified four main types of feedback students can receive: *Task Feedback, Process Feedback, Self-Regulation Feedback, and Praise/Self Feedback* (See Table 1 for representative examples of each of these four types of feedback).

Task Feedback is surface-level feedback that provides students with task specific feedback about whether their work is correct or incorrect. *Process Feedback* directs students to general strategies that may be applied to both the current task and future tasks. Because process feedback is more generalizable and encourages deeper learning, it is more beneficial and longer term than task feedback. Arguably, the most beneficial type of feedback is *Self-Regulation Feedback.* This type of feedback instructs students on how to self-assess their work and develop the skills necessary to become better self-regulators. *Praise/Self Feedback* is vague and more focused on the student than the task. Praise alone can have ironic consequences for future motivation because it does not encourage students to invest further effort. Thus, it tends to be the least effective at improving academic performance.

Contemporary feedback research has made important progress in illuminating factors that may impact an individual's response and, consequently, their uptake and use of academic feedback. Pekrun and colleagues (2014) observed the way feedback is formatted will impact a person's emotional reaction to that feedback (e.g., self-referential versus norm-referenced). Additionally, an individual's personality traits are likely to influence how they respond to feedback; although, generally all personality types tend to lose motivation when faced with negative feedback compared to positive feedback (Swift & Peterson, 2018). Finally, negative feedback can undermine our memory (Reeve et al., 2014) and consequently, our ability to put into action a plan to use that feedback may be impeded.

While we have an ever-growing understanding of the factors that impact our uptake and use of feedback, we know very little about feedback in naturalistic learning environments. Understanding feedback "in the wild," or how students think about and use feedback in a classroom setting, is critical for understanding the generalizability of past research. As an important first step in highlighting the gap between theory and practice, *the present study examines undergraduate students' definitions of academic feedback and their preferred content/type of feedback to receive.*

Methods

Participants

The present study was conducted in a first-year introductory applied psychology college course. The class had an enrollment of 102 students, 80 of whom consented to participate in the study (M_{age}=18.98, SD=1.36). The data presented came from a larger, IRB approved study that examined students' memory for feedback in a naturalistic classroom setting. For the purposes of the present study, we present student responses from two open-ended questions from the survey portion of the study: *What is the purpose of academic feedback?* and *Describe the content/focus of your desired feedback upon completing an assignment.*

Materials

Codebook

Students' responses to the open-ended questions were broken into thought units. Thought units were defined by a comment that contained one unique idea (see Table 1 for examples of what we classified as one feedback unit). Student thought units were coded into the four feedback categories presented by Hattie and Timperley (2007).

In instances where the thought units could not be placed into one of the four categories, it was assigned as "Other." These were then examined for similarities. No patterns within the "Other" category emerged and therefore remained as one category. The codebook was created and refined by all authors on this paper. The first author of this paper coded the students' responses to both questions.

Results

To best understand how students define the purpose of feedback using the criteria defined by Hattie and Timperley (2007), Table 1 shows the frequency of students' responses to the two open-ended questions. Students overwhelmingly (87.5%) identified *Process Feedback* as the primary purpose of feedback. Thirty-five students (43.75%) noted the importance of *Task Feedback*. Interestingly, no students discussed the Self-Regulatory or Praise/Self nature of feedback in their responses about purpose.

Even though students in their identification of the purpose of feedback neglected a critical component of feedback (i.e. Self-Regulation), most students noted the need for feedback that helps them improve in the learning process (Process Feedback). Hattie and Timperley (2007) noted that *Process Feedback* and *Self-Regulation Feedback* are key to deeper learning and subsequent subject mastery. Students stated that one of the purposes of feedback is to provide details about whether or not their work is correct, suggestive of the *Task Feedback* category. While task feedback is not as adaptive and generalizable as process feedback, it still has benefits of helping students understand the expectations of the current task. Taken together, we see that students can cite the importance of error-detection and awareness of strategies for producing better work (*Task Feedback* + *Process Feedback*).

While it is important to know that students and academics define the purpose of academic feedback in similar ways, it is also important to understand *whether there is congruence between what the students know is important to be included in feedback (the purpose) and what types of feedback they would actually like to receive.* Although students knew the purpose of feedback is to provide process related information, more students identified that they would want *Task Feedback* on an assignment (see Table 1) than any other type of feedback. This suggests that students may not be thinking about feedback as generalizable outside of the scope of a particular assignment (or its longer-term utility). Even though students knew that the purpose of feedback is not to receive *praise*, 16.25% of the students stated that they would like this sort of information in their feedback. This is important because there is little information about the task in *Praise/Self Feedback*. However, students felt that praise/self feedback would make them feel better about their work and may make the accompanying constructive criticism more palatable.

Notably, students' response to the survey suggests that students and academics discuss and understand the goals *and purpose of academic feedback in the same way. However, students do not necessarily want to receive feedback that reflects those purposes.* Prior research has identified both process and self-regulation focused feedback as key to enhancing students' future success. Students' responses mirrored this, at least for the process feedback, indicating both that they saw process feedback as important and desired this type of feedback on their work. Only one student noted wanting self-regulatory feedback. This is important because it may be a sign that students do not have the language to articulate the desire for more support in learning how to self-assess/regulate, or that they do not see themselves as a key player in revising/improving their own work.

Table 1: Number of instances of feedback type for both open-ended questions and example student responses

	Purpose of Feedback		**Desired Content of Feedback**	
	Number of instances	**Example student response**	**Number of instances**	**Example student response**
Task Feedback	35	"I think that the purpose of academic feedback is to help let you know what is wrong and what is done right. It can let you see your errors."	56	"I want to know what I did correct and what I did wrong"
Process Feedback	70	"I think that the purpose of academic feedback is to grow academically as well as a person. It helps me know what areas I can improve which I think are important for academic success."	49	"I would like to hear what I need to improve on for future assignments but also what I did well to keep that for future assignments too"
Self-Regulation Feedback	0		1	" I would also like to get a rubric grade as provided in the course as it helps make changes"
Praise/Self Feedback	0		13	1. "I expected to receive some motivational comments, for example: good work or excellent." 2. "My ideal feedback would be both positive and negative feedback. Receiving compliments on portions I worked hard on would ease the criticism on portions that the professor did not like."
Other (O)	0		8	"I would much rather have feedback that is direct than sugar coated."
Blank	0		2	

Discussion

Even though most students stated that the purpose of feedback was to provide process feedback, when reflecting on what their ideal feedback would contain, students most frequently endorsed task-focused feedback. This discrepancy highlights a gap between what students know to be important at a conceptual level, what they see as important in the "real world," and what types of feedback they actually want to receive and experience. Future research should examine the utility of training students on how to use feedback and rubrics to see if this will help students recognize and benefit from the more impactful process and self-regulation feedback.

While students did not see praise as a main goal/purpose of feedback, aligning solidly with the research, that did not mean students did not want to receive it. A small, but meaningful (16.25%) group of students expressed a desire for praise. Many of these students suggested that praise may motivate their uptake and use of the more constructive feedback by buffering the negative affect that accompanies this critique of their work. This presents an interesting discrepancy. While praise/self feedback does not have immediate academic implications on the assignment at hand, students still want to receive praise to facilitate/support their motivation. Future research should examine whether or not there is truth to this.

A potential limitation of this study is that students responded to the questions about their beliefs surrounding the purpose of feedback and their desired content/type of feedback after completing a free recall of the feedback they received on a class project one week earlier. It is possible that their recall of feedback biased their response to the relevant purpose and content questions. Students' responses may have been constrained by the type of feedback received on the assignment. For example, if students' feedback was limited to praise and task feedback, would it be possible for them to generate examples of other types of feedback? We can address this limitation directly. As previously mentioned, the data presented was part of a larger study examining students' memory for feedback. Our preliminary investigation into the feedback given to the students illustrates that students received a wealth of feedback, spanning all feedback types (see Table 2, from Weisen et al., 2021).

Table 2: Average number of feedback units given by the teaching assistant per student (preliminary analysis)

	Average Number of Feedback Units	***SD***
Task Feedback	10.29	3.30
Process Feedback	10.71	3.99
Self- Regulation Feedback	1.14	1.07
Praise/Self Feedback	0.57	0.53
Other (O)	1.86	0.69

Overall, the present study demonstrates a somewhat shared view of the purpose of feedback by researchers and students. However, students do not necessarily *want* to receive the type of feedback they know to be important/impactful. From a practical standpoint, if both learners and educators understand the types, importance, and function of feedback in the same way, then everyone involved in the educational experience stands to benefit by being more effective users and providers of feedback. It is important that researchers move beyond simply *highlighting* the gap between theory and practice, as is the case in this paper, towards actually closing this gap. Future research should explore whether teaching students how to better locate, as well as recognize the generalizable nature of self-regulatory and process feedback, have positive impacts on their use of these types of feedback and ultimately their learning.

References

Hattie, J., & Timperley, H. (2007). The power of feedback. *Review of Educational Research*, *77*(1), 81–112.

Pekrun, R., Cusack, A., Murayama, K., Elliot, A. J., & Thomas, K. (2014). The power of anticipated feedback: Effects on students' achievement goals and achievement emotions. *Learning and Instruction*, *29*, 115–124.

Reeve, C. L., Bonaccio, S., & Winford, E. C. (2014). Cognitive ability, exam-related emotions and exam performance: A field study in a college setting. *Contemporary Educational Psychology*, *39*(2), 124–133.

Swift, V., & Peterson, J. B. (2018). Improving the effectiveness of performance feedback by considering personality traits and task demands. *PLOS ONE*, *13*(5), e0197810.

Weisen, S., Hufnagle, A., & Van Boekel, M. (2021, April). *Investigating students' memory for feedback in a naturalistic classroom: A preliminary examination of qualitative data*. To be presented at the American Educational Research Association Conference, Orlando, FL, United States.

International Society of the Learning Sciences

Representational Fluency of Angle during an Educational Robotics Task

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Abstract: In this study, we examined how a small group of fourth grade students used representational fluency during an educational robotic task situated within a makerspace environment. Specifically, we considered how representational fluency played a role in their mathematical understanding of angle, a concept that is difficult for many students to understand. Results from video data revealed that various representations (e.g., language, gesture, concrete) within the task afforded students the opportunity to communicate more fluently about the concept of *angle*. We argue that attendance to multimodal representations, and the communication that occurs around and between those representations, better supports and reveals mathematical learning in non-formal contexts.

Introduction

Making contexts are increasing worldwide, with the general goal of providing an environment for youth to pursue interest-driven learning. Some of those makerspace efforts focus on supporting mathematical thinking, with an emphasis on providing an opportunity for youth to engage in the doing of and thinking about mathematics in authentic and non-formal ways (e.g., Doorman et al., 2019). However, the shift from formal learning to non-formal learning leads us to both a challenge and an opportunity: how do we identify, support, and evaluate the different forms of learning that take place in makerspaces? Our approach to this question parallels this year's ISLS theme of reflecting on the past and embracing the future, as we use insights gleaned from previous research on formal learning contexts to develop a lens that recognizes and embraces the different forms of mathematical learning that take place in informal makerspaces. In particular, we build upon Moore and colleagues (2013) translation model, Bieda and Nathan's (2009) investigation into representational fluency, and Alibali and Nathan's (2012) emphasis on gesture, to identify how youth engaged in an informal makerspace robotics activity use representational fluency to move between different modalities in their mathematical thinking and communication. In this paper, we investigated the following: What role does representational fluency play in fourth grade students' mathematical thinking of angle during an educational robotics task? This short paper is a mixture of empirical and methodological work, as we share the complex details of our analysis in order to illustrate how our research emerged from both past research and new visions of the future of mathematical learning.

Theoretical grounding

Scholars have argued that bringing computational tools into learning activities can provide multiple pathways for expressing and solving problems (e.g., Papert, 1980). Student's engagement with technology and computational devices is highly valued in STEM activities, and scholars have argued that in such interdisciplinary contexts, representations can support and deepen students' knowledge of STEM content (Korzma, 2003; Nathan et al, 2013; Nathan et al., 2017). Given the multimodal nature of robotics and programming environments, students developing such procedural knowledge require translation across different representations including symbolic, concrete, gesture and speech representations in order to solve problems (e.g., Alibali et al., 2012). However, one challenge students have to overcome as they complete such tasks is to fluently translate between representations. For this work we will use the framework for *building cohesion* across representations in STEM integration activities to understand how students used language, gestures and other forms of representations to ground their mathematical understanding of angles in a multimodal learning environment.

Methods and analysis

The data for this study was collected from the TinkerLab, a makerspace within an intermediate school (i.e., grades 3-5, ages 9-11) located in New York state. We focus here on one group of fourth-grade students (2 females, 3 males) who had experience with making activities as part of their weekly curriculum in the TinkerLab. The making activity was designed specifically to engage youth in the integration of digital tools, computational practices, and mathematical concepts during a free period during the school day. The activity consisted of two unstructured and student-driven phases. Phase 1 required the group to make a path for Dash (a programmable robot) by placing the tape on the floor from one side of the room to the other. This path was to be traversed by another group. Phase 2 required the group to program Dash using Blockly app on iPad to travel on the path that was placed by the other group. Youth were also provided with other tools - a pencil and measuring tape to measure the path. The activity lasted for approximately 22 minutes. Data collected from this group included a standalone camera that captured the group as a whole and two GoPro cameras were worn on the chest of two of the students that captured the point-of-view perspective of those students.

Our data analysis process consists of four phases. First, to sensitize ourselves, research team members silently watched a video in two-minute increments, followed by a discussion on what we observed in that increment (Jordan & Henderson, 1995). Our observations were grounded in evidence from the language, gestures, and actions captured on video. Second, each team member individually wrote descriptive and analytical memos for video data within ~15 sec increments. The flexible nature of the memoing process provided us with a "space and place for exploration and discovery" (Charmaz, 2006, p.81–82) and allowed us to take risks through articulating, exploring, and challenging our interpretations of the data. Third, our individual memos were then placed in a shared excel sheet, along with evidence of what was observed, allowing each member to look within and across memos. Regardless of how inconsequential these thoughts, feelings and impressions may initially seem, creation of a record in the form of memos ensured the preservation of such ideas that may later prove significant (Polit & Beck, 2006). Fourth, these individual memos were then analyzed for how students used representational fluency along six categories (see Table 1), as well as how their mathematical thinking about *angle* evolved and shifted while engaged in an educational robotics task.

Table 1: An Updated Translation Model-Definitions and Study Example

Category	Definitions and Study example
Concrete (CR)	Representation with Concrete Models, such as hands-on models and concrete physical models. Phase 1: *Almond used the tape to illustrate "here"- indicated to be somewhat of transversal to piece laid and "to here" is parallel to piece tape [continuation of zig-zag]*
Pictorial (PT)	Pictorial Representation, such as graphs, 2-D representations of physical models, and diagrams. Phase 2: *Students are using virtual protractor to determine the angle.*
Gesture (G)	Representational Gesture, iconic and metaphoric gestures, such as shows angle via handshape or motion. Phase 1: *Almond used his hand to illustrate "here to here"*
Language (LG)	Language Representation including both spoken and written communication. Phase 1: when designing a section Almond says, *"Are you saying it's like here to here?"*
Realistic (RL)	Representation through realistic, real-world, experienced contexts, or metaphors. Phase 1: *Red: "It is like one of the crazy roads that you see in movies."*

Note: The foundation of the table comes from Moore, Miller, Lesh, Stohlmann, & Kim (2013). We removed the "Symbolic (SB)" category because such a representation was not used in this context, and we added a new category - Gesture (G) – built upon Alibali & Nathan (2012). The given examples are directly from this study.

Insights

In Phase 1, students often used concrete, gesture, and language representations to express their mathematical thinking of angle, but also to negotiate the goal of laying a path from one side of the room to the other. For example, at the beginning, we observed Red lay a strip a tape to form an acute angle with another piece of tape (see Figure 1-A). Red stated, "Maybe like a ten degree angle." Red provided two forms of representations, concrete and language, which indicated why he formed an acute angle. However, the group was uncertain about Dash's mobility to make such a tight angle, and led to various group members' illustrating and negotiating how *angle* was being shaped by their knowledge of Dash. This was initiated through a language representation by Almond: "Can we do a ten degree angle? I don't think Dash can do ten degree angles." The teacher confirmed, again through language, "Dash cannot do like really tight angles." Green suggested they make the angle wider through both verbal (i.e., "a little wider") and gesture (i.e., moved her hands wider; see Figure 1-B) representations. Almond adopted the language of the teacher, "Yeah, really tight angles." As such, Almond's language representation of angle shifted from ten-degree angles to tight angles.

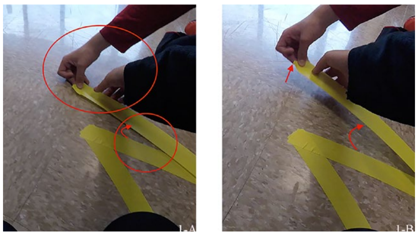

Figure 1-A. “ten-degree angle”

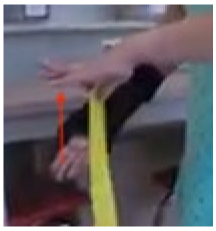

Figure 1-B. “a little wider”

As another example, we observed Pine and Almond communicating through concrete and language representations in regard to adding a piece of tape at a 45-degree angle. Almond was hovering a piece of tape above the floor that would form at a wide angle with the piece of tape already on the floor. Pine stated from a distance, “Make it more complex right there. Make it like a…” Almond rotated the tape with his left arm to form a smaller angle with the piece of tape, providing a response through a concrete representation. Pine confirmed this change in the angle through verbal representation: “Yeah, like a 45-degree angle like that.” This group of fourth graders also illustrated their thinking of angle through “seeing” a zig-zag path through realistic representations. For example, Green noted, "This is starting to look like some crazy shape." “It’s like a machine. It’s like a wire,” stated Almond. Red added, “It is like one of the crazy roads that you see in movies…yeah, there’s like all these different roads.” Students used real-world metaphors (e.g., wire, crazy roads) to express their understanding of zig-zag as alternating left and right turns in the path.

In the shift to Phase 2, with the introduction of Dash and the iPad, we observed a shift in their mathematical language to include the direction Dash would rotate on the path (e.g., “90 degree turn right”). This is likely due to the two kinds of representations afforded by the app as they were required to indicate whether Dash should turn left or turn right to a specific angle by moving an arrow on a virtual protractor (pictorial; see Figure 2).

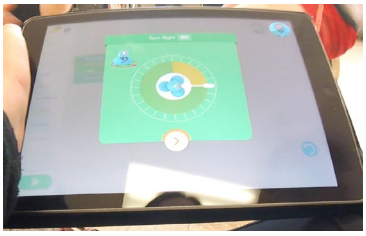

Figure 2. Virtual Protractor

The movement of Dash along the path also provided a space to represent angles through multimodalities both when Dash was not programmed successfully or in planning Dash’s next move along the path. For example, Pine and Almond discussed the angle size and direction in which Dash should be programmed when Almond created a border of the path with his hands (gesture representation; see Figure 3-A), then next placed his body/head over Dash as if he trying to get the perspective of Dash in relation to Dash’s body position on the path (another gesture).

Figure 3-A. Border of the path.

Figure 3-B. “tiny turn”

From his perspective and estimation, Almond stated through language, “So let’s do like 35, 35.” Dash also served as a concrete representation as students were observed manipulating Dash to express their thinking. For example, at the end of a test run, Almond moved Dash as he stated, “We only have to do like a tiny turn” to indicate that Dash was positioned appropriately along the path and a tiny turn was the next line in the code (see Figure 3-B).

Discussion and conclusion

Research on students' understanding of angle has shown their difficulties in coordinating different aspects of the angle concept (e.g., Keiser, 2004; Mitchelmore & White, 2000). The results of this study highlighted how this non-formal learning environment allowed for both everyday and formal mathematical language and mathematical thinking around angle. We recognize that such everyday language (e.g., zig-zag) and ways of representing mathematical thinking (e.g., gestures) may not be as acceptable to the field of mathematics as language-based communication, but we contend that it is evidence of an understanding of quantities and relationships that can be built up into more formal mathematical thinking. We also observed concrete representations afforded by the tools available (e.g., roll of tape, Dash), which are often not tools common to formal learning environments. As a thoughtful reviewer pointed out, further investigation into the role of *perspectives* – particularly as students can take on the perspective of Dash – and how it contributes to their embodied experience is crucial to this work. Further, this group of students seemed to have a shared understanding when using the different angle representations as we did not observe a sense of confusion or misunderstanding through repeated questions or clarifying gestures. Importantly, the addition of gestures as a component of the Moore et al. (2013) model highlight how crucial gesture is to representational fluency as it afforded us additional insights into students thinking of angle than could have been gleaned from any one representation. By adding gesture into their model, we have begun synthesizing their work on representation types with the conceptualization of representational fluency described in Nathan and colleagues' work (Bieda & Nathan, 2009; Nathan et al., 2013, 2017), as well as contributing to the literature on mathematical learning in non-formal makerspaces. Additional research can build upon this empirical and methodological work as the activity and available tools within any non-formal makerspace environment will afford a range of opportunities for students to represent their mathematical thinking and sense-making of other concepts (e.g., linear measurement) across representation types.

References

Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the Learning Sciences, 21*(2), 247-286.

Bieda, K. N., & Nathan, M. J. (2009). Representational disfluency in algebra: Evidence from student gestures and speech. *ZDM, 41*(5), 637-650.

Charmaz, K. (2006). *Constructing grounded theory: A practical guide through qualitative analysis.* London: Sage.

Doorman, M., Bos, R., de Haan, D., Jonker, V., Mol, A., & Wijers, M. (2019). Making and implementing a mathematics day challenge as a makerspace for teams of students. *International Journal of Science and Mathematics Education*, *17*(1), 149-165.

Jordan, B. and Henderson, A. 1995. Interaction analysis: Foundations and practice. *The journal of the learning sciences*. 4, 1 (1995), 39–103.

Keiser, J. M. (2004). Struggles with developing the concept of angle: Comparing sixth-grade students' discourse to the history of the angle concept. *Mathematical Thinking and Learning*, *6*(3), 285-306.

Kozma, R. (2003). The material features of multiple representations and their cognitive and social affordances for science understanding. *Learning and Instruction*, *13*(2), 205–226.

Mitchelmore, M. C., & White, P. (2000). Development of angle concepts by progressive abstraction and generalisation. *Educational Studies in Mathematics*, *41*(3), 209-238.

Moore, T. J., Miller, R. L., Lesh, R. A., Stohlmann, M. S., & Kim, Y. R. (2013). Modeling in engineering: The role of representational fluency in students' conceptual understanding. *Journal of Engineering Education, 102*(1), 141-178.

Nathan, M. J., Srisurichan, R., Walkington, C., Wolfgram, M., Williams, C., & Alibali, M. W. (2013). Building Cohesion Across Representations: A Mechanism for STEM Integration. *Journal of Engineering Education*, *102*(1), 77–116. https://doi.org/10.1002/jee.20000

Nathan, M. J., Wolfgram, M., Srisurichan, R., Walkington, C., & Alibali, M. W. (2017). Threading mathematics through symbols, sketches, software, silicon, and wood: Teachers produce and maintain cohesion to support STEM integration. *Journal of Educational Research*, *110*(3), 272–293.

Papert, S. (1980). *Mindstorms: Computers, children, and powerful ideas*. New York, NY*:* Basic Books.

Polit, D. F., & Beck, C. T. (2006). *Essentials of nursing research: Methods, appraisal, and utilisation* (6th Ed.). Philadelphia: Lippincott Williams & Wilkins.

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Toward a Conceptual Framework for Practical Measurement as Organizational Structure

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Abstract: A growing number of educational improvement efforts are incorporating the development of practical measures of learning into their work. This paper extends previous work on practical measurement by focusing attention on the organizational dynamics of measurement practice. In addition to their role in providing windows to certain kinds of information, measures also function as both carriers and drivers of new and existing assumptions, categories and values. We present the outlines of a conceptual framework of practical measurement situated within processes of organizational persistence and change, and we illustrate key facets of the framework with examples drawn from a DBIR project focused on co-developing practical measures of teacher learning in a university-district partnership.

Keywords: practical measurement, organizational structure, teacher learning

Introduction

Educational improvement efforts are increasingly incorporating the development of practical measures of learning into their work (Yeager et al., 2013), often in ways that situate such measures within ongoing inquiry or continuous improvement processes and position measures primarily as ways to assess whether designs are supporting desired outcomes (Bryk, Gomez, Grunow, & LeMahieu, 2015). Practical measures of learning are intended to be collected without excessive burden, to capture more ecologically valid forms of learning, and to be timely, such that data gleaned from them can be used for formative purposes. Practical measures have been employed extensively in approaches to educational reform drawing on improvement science methods, such as Networked Improvement Communities (e.g., Bryk et al., 2015). There is also growing interest in practical measures among RPPs (e.g., Penuel et al., 2018) and in measures of teacher practice and learning in addition to student learning.

In this paper, we extend previous work on practical measurement by focusing our attention on the organizational dynamics of measurement practice. In addition to their role in providing access to certain kinds of information, measures can also reflect, reify and/or disrupt the assumptions, categories and values at play in a given context (Espeland & Sauder, 2007). These functions of measures are especially relevant for educational leaders as they seek to build on, sustain, and improve professional learning opportunities as part of broader school improvement efforts. In what follows, we describe these varied functions as measurement metaphors and present the outlines of a conceptual framework of practical measurement situated within processes of organizational persistence and change. We illustrate key facets of the framework with examples drawn from a DBIR project focused on co-developing practical measures of teacher learning in a university-district partnership.

Measurement metaphors

Drawing on research in improvement science, sociology and learning sciences, we identity three key metaphors for the roles that measures can serve. We do not see these metaphors as incompatible, but rather as reflecting different aspects of ongoing processes of organizational persistence and change. The relationships between these three metaphors and the functions they represent is shown in Figure 1. We argue that recognizing this wider array of functions is critical for strategizing effectively around school improvement.

Measures as windows

Most discussion of the value of measures of learning—including practical measures—has focused on the information that measurement provides. We refer to this as a window metaphor: Measures allow us to see what learners understand, how schools are functioning, etc. Research grounded in the measures as windows metaphor has shed light on how organizational contexts influence the use of data gleaned through measurement efforts. This includes the organizational routines around data use (Spillane, 2012) and connections between schools and districts in using data (Honig & Venkateswaran, 2012; Simmons, 2012). Yet measures can and do function in other ways as well.

Measures as carriers

Measures are developed within broader organizational and cultural contexts. Decisions about what will be measured and how are influenced by existing structures and norms. Thus, measures can also be understood as carriers: Measures hold the assumptions of particular perspectives within their design and bring those assumptions with them when they are used. For example, law school rankings that reward selectivity carry the assumption that schools that are harder to get into are better (as opposed to, for example, attracting applicants who best match the school's character and mission) (Espeland & Sauder, 2007).

Measures as drivers

Additionally, measures necessarily capture particular slices of the world, foregrounding some features and backgrounding others. As such they serve to focus attention—and action—in patterned ways (Colyvas, 2012; Espeland & Stevens, 2008). While the windows metaphor suggests more of a passive and neutral role, measures can also be seen as drivers: Measures activate the categories, assumptions and values they carry, thus reproducing or disrupting associated patterns of action (Anderson & Colyvas, Under Review). For example, measurement systems organized around maximizing the percentage of students meeting proficiency standards led to the category of "bubble kids," and a pattern of disproportionate attention to students whose improvement would most affect this metric (Booher-Jennings, 2005).

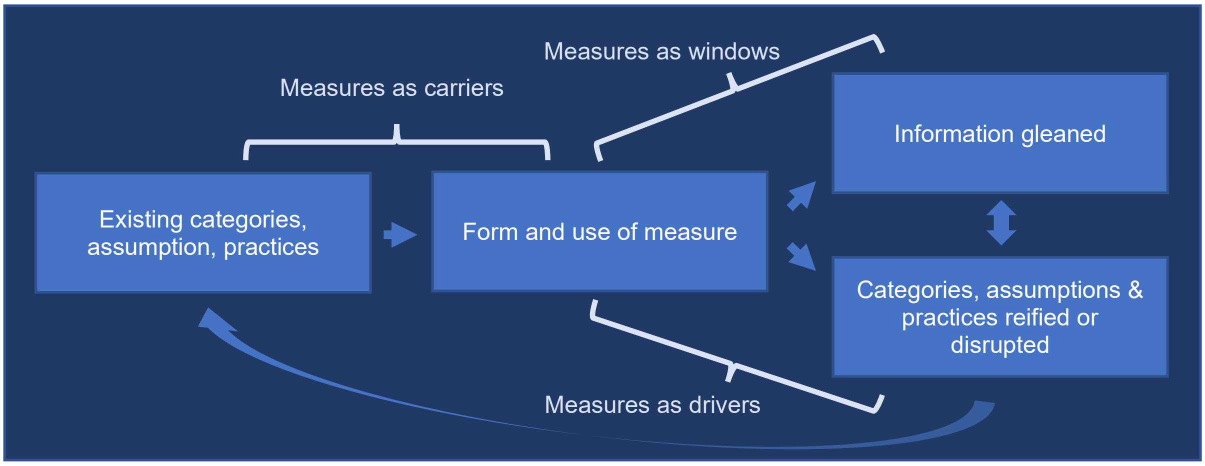

Figure 1. A developing conceptual framework for practical measurement as organizational structure.

In Figure 1, we illustrate how these different measurement metaphors reflect different aspects of the processes by which measures are created and used within their organizational contexts. Measures may *carry* assumptions and practices that shape their very form and how they are used; the form and use of measures in practice may in turn provide *windows* into desired information and may *drive* further reification or disruption of organizational perspectives and practices, which can then feed into further design and work with measures in an ongoing cycle. We argue that in order to understand and design for the use of practical measurement as part of a larger change process, educational leaders and researchers need not limit ourselves to treating—or conceiving of—measures solely as windows. Rather, we find it important to attend to the multiple ways that measures operate as elements of organizational structure. In our ongoing work, we are testing and refining this framework, partly in interaction with empirical examples of work with practical measures, described next.

Context and data

The current project is part of a design-based implementation research project (Penuel et al., 2011), in which university faculty and staff worked collaboratively with district STEM professional development (PD) leaders throughout the 2019-2020 school year to co-develop several practical measures of teacher learning.

Primary data sources for understanding how practical measures functioned as carriers, windows, and drivers in this context included the following: 1) initial interviews with four district PD leaders, focused on their own and their organization's goals for teacher learning and their experiences using varied sources of information to understand teacher learning, 2) recordings and artifacts from 27 co-design meetings involving iterative cycles of development and work with practical measures (in conjunction with PD sessions), and 3) iterations of the measures themselves. We treated interviews primarily as priming tools to understand the landscape and possible ideas and practices that might inform measure development and use. We then conducted content analyses triangulating across data sources related to two facets of the PD leaders' work: lenses on teacher learning (e.g., forms of instruction perceived to be easier or more challenging for teachers; valuing responsiveness to teachers' expressed needs), and approaches to measurement itself (e.g., quantitative vs. qualitative data; using questions consistently across PD series). We documented categories, assumptions, and practices related to both facets as expressed and enacted during co-design cycles. We also documented the sources of these ideas and practices as best we could and whether and how they were reified or disrupted as PD leaders used and refined measures.

Illustrative examples

While analysis of additional examples is ongoing, here we illustrate the conceptual framework in Figure 1 by comparing two distinct measures—one with origins in existing PD practice within the district, and one newly developed. Our brief vignettes are intended to highlight key parts of the framework, with particular emphasis on the less common metaphors of practical measures as *carriers* and *drivers* of organizational ideas and practices.

Measure 1: PD exit tickets

The first practical measure of teacher learning was an exit ticket, administered at the end of each PD session across series. It included several Likert-scale questions about teachers' perceptions of the quality of the session and how well it prepared them to understand and implement standards-aligned instruction, plus several open-ended questions asking what they found most valuable and areas of focus or improvement for the next PD.

The form of exit ticket reflected its function as a strong *carrier* of existing assumptions and practices, particularly around measurement. Indeed, the exit ticket's design pre-dated the project and carried existing questions and question types (specifically, the Likert-scale questions) intended to be kept consistent across departmental PDs. Multiple PD leaders expressed some challenges in gleaning useful information from the exit ticket as a *window*, describing how the questions elicited feedback from teachers' perspectives but were "not specific" (interview, 8/19/19) and did not often give "enough to know… how I need to shift my own instruction for teachers" in subsequent PDs (interview, 8/20/19). In a co-design meeting for a PD series focused on district curriculum (9/6/19), PD leaders noted that they would need to administer the exit ticket and briefly considered whether they wanted to add anything different to the measure, choosing not to do so prior to use. Nonetheless, in a debrief meeting following the PD, a PD leader quickly oriented to the exit ticket and specifically the Likert-scale items. They highlighted that the scores were largely positive ("higher than… last year" (9/30/19)) and used Excel to create averages across participants—a practice that had been used before with exit tickets, carried forward and further reified. In these ways, the form and use of the Likert scale exit ticket measures not only served as a *window* into teachers' perceptions of the PD, and *carrier* of prior measurement practices, but also a *driver*, reifying organizational valuing of teachers' perceptions of utility, practices of using average scores to interpret impact, and assumptions around comparability across PDs occurring in different years with different participants.

The exit ticket also seemed to function as an impactful *window* when PD leaders considered text-based responses to the question on areas of focus and improvement, which drove changes to leaders' thinking about teacher learning and corresponding changes to the sequencing of topics within the PD series. PD leaders interpreted this text by inductively generating two main categories of requests from teachers. Recognizing that one of those categories was not scheduled to be addressed until later in the year, leaders moved it up because of the "demand for it" (meeting, 9/30/19). Thus, the use of open-ended exit tickets as a *window* into teachers' priorities also facilitated their function as a *driver* of future PD design, including both the reproduction of existing session categories as well as the disruption of a prior assumption of how the sessions should flow to support teachers in learning to use the curriculum.

Measure 2: Problem of practice mapping

The second practical measure of teacher learning was a problem of practice mapping measure, which invited teachers in a professional learning community to articulate and explore a problem of practice they experienced in their classrooms. Given several topic areas to choose among (e.g., "discourse," "differentiation"), the measure included a series of open-ended questions—naming a specific problem within their selected topic area, what they currently saw in their classrooms, what they would like to see, why they thought the problem was occurring, and initial ideas of what they might try to address the problem.

In contrast to the exit ticket, the mapping measure was the subject of extensive co-design among partners. In developing the measure, PD leaders and partners built from a set of values shared amongst themselves and more broadly within the district—including working toward a shared vision of high-quality instruction (emphasized across interviews as a core district value), and naming and improving what's within your "locus of control" (co-design meeting, 9/18/19). They also worked to ensure that the measure was aligned with—or properly *carrying*—categories from district-level priorities. For instance, PD leaders grappled with whether common district foci should be named as the topic areas or be embedded across topic areas (ultimately choosing the latter, meeting, 9/9/19). They also brought in language from their own experiences with departmental strategic planning, framing what teachers would like to see as their "ideal state" (measure, 9/26/19).

In this example, the measure functioned as a *driver* for PD leaders' practice before it was even used with teachers. During a co-design meeting (9/18/19), leaders drew heavily on the measure's questions to plan for teachers' discussions during upcoming PD. Each question was allotted time for discussion, reifying the questions as key frames. Anticipating use also prompted negotiation of which questions teachers should come to consensus on; PD leaders decided that it would be important for teachers to agree on a desired ideal state, reproducing the value of working toward a shared vision in practice. This case illustrates how measures can *drive* the reification or disruption of existing assumptions and practices even without first being used in a traditional *window*-like manner.

Discussion

The posited conceptual framework brings two key lines of work into closer communication—work on practical measurement in improvement science, and work on measurement from an organizational theory perspective. Our examples illustrate clearly that measurement tools and practices do more than provide information, that is, they are not only *windows*. Rather, the very processes of designing and working with measures themselves can serve to reproduce and/or disrupt the categories, assumptions and practices operating in an organizational context. As such, the development of practical measures—intended to be interwoven with educational leaders' daily work—is also a process of developing organizational structures that *carry* and *drive* particular values and foci of attention and corresponding possibilities for organizational persistence and change. In some cases, these functions are interwoven with traditional *window*-like uses, while in other cases they operate somewhat independently. We hope that by attending more broadly to practical measures' multiple roles, we can likewise move forward with more holistic and effective approaches to educational improvement.

References

Anderson, E. R., & Colyvas, J. A. (Under Review). *What Sticks and Why? A MoRe Institutional Framework for Education Research*.

Booher-Jennings, J. (2005). Below the Bubble: "Educational Triage" and the Texas Accountability System. *American Educational Research Journal*, *42*(2), 231–268.

Burch, P. (2010). The Bigger Picture: Institutional Perspectives on Interim Assessment Technologies. *Peabody Journal of Education*, *85*(2), 147–162.

Colyvas, J. A. (2012). Performance Metrics as Formal Structures and through the Lens of Social Mechanisms: When Do They Work and How Do They Influence? *American Journal of Education*, *118*(2), 167–197.

Espeland, W. N., & Sauder, M. (2007). Rankings and Reactivity: How Public Measures Recreate Social Worlds. *AJS*, *113*(1), 1–40.

Espeland, W. N., & Stevens, M. L. (2008). A Sociology of Quantification*. *European Journal of Sociology / Archives Européennes de Sociologie*, *49*(3), 401–436.

Honig, M. I., & Venkateswaran, N. (2012). School–Central Office Relationships in Evidence Use: Understanding Evidence Use as a Systems Problem. *American Journal of Education*, *118*(2), 199–222.

Mehta, J. (2013). The penetration of technocratic logic into the educational field: Rationalizing schooling from the progressives to the present. *Teachers College Record*, *115*(5).

Penuel, W. R., Fishman, B. J., Haugan Cheng, B., & Sabelli, N. (2011). Organizing research and development at the intersection of learning, implementation, and design. *Educational Researcher*, *40*(7), 331–337.

Penuel, W. R., van Horne, K., Jacobs, J., & Turner, M. (2018). *Validity Argument for Practical Measures of Student Experience in Project*. 30.

Simmons, W. (2012). Data as a lever for improving instruction and student achievement. *Teachers College Record*, *114*(11), n11.

Spillane, J. P. (2012). Data in Practice: Conceptualizing the Data-Based Decision-Making Phenomena. *American Journal of Education*, *118*(2), 113–141.

Yeager, D., Bryk, A., Muhich, J., Hausman, H., & Morales, L. (2013). *Practical Measurement*. Carnegie Foundation for the Advancement of Teaching.

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Knowledge Creation Analytics for Jigsaw Instruction: Temporal Socio-Semantic Network Analysis

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Abstract: This study aims to gain insight into how to design lesson plans with jigsaw instruction to promote knowledge creation. Collaborative learning has been discussed as a method for improving students' learning. However, little research on jigsaw instruction analyzed from the knowledge creation perspective has been conducted. Previous research has resulted in the development of the new temporal socio-semantic network analytics (SSNA) to emphasize the visualization of ideas changing during the knowledge creation process. Therefore, we conducted temporal analysis on students' learning of a more complex problem through jigsaw instruction than previous studies to examine the differences between high- and low-learning-outcome groups. The results of three investigations suggest that designing lessons such that they prompt students to engage in generative tasks can contribute to learning as knowledge creation.

Theoretical background and research purpose

In the learning sciences, collaborative learning has been discussed as a method for facilitating learners' deeper disciplinary knowledge. Among the many types of collaborative learning, jigsaw instruction is a method that has been examined in many studies (Miyake & Kirschner, 2014). Jigsaw instruction is comprised of two participatory structures of collaborative learning: expert group activity and jigsaw group activity. In expert group activities, learners in a group are given the same material to study collaboratively. Conversely, in jigsaw group activities, each learner provides others with new information and knowledge obtained during the expert group activity.

While most studies on jigsaw instruction have analyzed collaborative learning as knowledge integration in the belief mode (Bereiter & Scardamalia, 2003), few studies have examined how learners' attempts to improve their ideas as collaborative knowledge objects in the design mode from the knowledge creation perspective. In the knowledge creation metaphor of learning (Paavola & Hakkarainen, 2005), learners are assumed to practice knowledge creation by collaboratively constructing knowledge objects (Scardamalia & Bereiter, 2014). In previous research on the jigsaw instruction method from the aspect of knowledge creation, the results have suggested that students should engage in creating knowledge objects, and educators should design embodied learning in class through design-based research (Oshima et al., 2017). However, no studies have tried to discuss how to design elements of jigsaw instruction from the perspective of knowledge creation.

Evaluating learning as knowledge creation practice is challenging because it involves the collective nature of knowledge. The primary target in knowledge creation is the collective state of knowledge constructed by a community of learners, and to evaluate collective knowledge advancement in knowledge creation practices, it is necessary to develop analytics answering the following questions: (1) how is the collective nature of knowledge is represented, and (2) how is dynamic change represented over time (Scardamalia & Bereiter, 2014)? The socio-semantic network analysis (SSNA) of discourse has been discussed as a promising approach for answering these questions (Oshima et al., 2012). As an application of SSNA, KBDeX represents the collective nature of knowledge as clusters of words representing ideas used in discourse and visualizes how a word's network structure changes over time. KBDeX also calculates several metrics, such as degree centralities, for network structures. Previous studies (Oshima et al., 2017; 2018) have demonstrated how different high- and low-learning-outcome groups engage in their collaborative discourse in a jigsaw group activity to discuss future instructional interventions to support low-learning-outcome groups.

There have been critical developments in the SSNA algorithm since the first presentation of SSNA as a knowledge creation analytic for jigsaw instruction (Oshima et al., 2017). Recently, Ohsaki and Oshima (2021) developed a new algorithm by applying the lifetime connection between words in a network and the real-time scale in visualizing the trajectory of metrics over time based on studies in dialogism and network science. Their study revealed that temporal network analysis is more appropriate for finding critical points in the discourse for idea improvement than aggregative network analysis.

In this study, based on the developments in the SSNA algorithm in recent years, we examine how discourse in knowledge creation practice is related to learning outcomes to gain insights into how jigsaw instruction design can be improved with further instructional support. We approach the research purpose with the following research question: how does the engagement of students in the high-learning-outcome group in the discourse differ from that of students in the low-learning-outcome group?

Method

Data collection and study design

We used a dataset with undergraduate students' pre-tests, post-tests, and collaborative discourse in a jigsaw group activity collected during a lesson unit that was part of a course on science education. A group of primarily second-year students created presentations on an air conditioner's mechanism as a complex problem that integrated science, technology, and engineering knowledge. A total of 29 students from the biology and environment departments were divided into nine groups of three or four. The main challenge of the jigsaw activity was, "How does an air conditioner continue cooling a room?" In the expert group activity, each member studied the three different documents on (A) theory of heat, (B) phase change and thermal energy, and (C) pressure and temperature in a different group for about 20 min. Next, members from different groups created a new group for the jigsaw group activity. Then, groups took on the main challenge by creating a presentation over 24 min.

We designed this study based on previous research (Oshima et al., 2017). Before and after the lesson unit, a teacher conducted pre- and post-tests to evaluate individual learning outcomes by using a worksheet with the main challenge printed as a question. A total of 28 students completed both tests by writing or drawing their ideas. Moreover, students' conversations during expert and jigsaw group activities were video-recorded. We transcribed discourses in the jigsaw group activity to examine how students engaged in collaborative problem-solving techniques. There was an average of 260.22 (SD = 70.66) utterances.

Analysis

To examine the research question, we conducted three investigations based on Oshima et al. (2017; 2018). The first investigation defined the high-learning-outcome group as one in which all students integrated knowledge from learning resources. We analyzed students' writing and drawing on the pre- and post-tests by plotting their understanding of an air conditioner system based on the Structure-Behavior-Function (SBF) framework (Hmelo-Silver & Pfeffer, 2004). Students were divided into four categories from "no understanding" to "fully integrated understanding across three documents" using the same categories as Oshima et al. (2017). When students' explanations in pre- and post-tests considered the relationship among structures, behaviors, and functions described in learning resources, we concluded they successfully understood the document. The first author and a trained student belonging to the laboratory for learning sciences independently evaluated students' SBF frameworks based on their explanations in each pre- and post-test. In this evaluation, Cohen's Kappa coefficient for the agreement between the two raters was 0.97. Disagreements were resolved through discussion.

The second investigation analyzed students' collective knowledge advancement through discourse analysis using temporal SSNA (Ohsaki & Oshima, 2021) to visualize students' knowledge advancement transitions and define the pivotal points for in-depth dialogical analysis. We selected 28 terms to explain the main challenge by a teacher, keywords in the learning resources, and basic scientific terms. KBDeX calculated the transition in the total value of the degree centralities of terms as nodes in the network across discourse exchanges. Additionally, we divided the lesson into three phases to analyze this visualization in detail.

The third investigation was an in-depth dialogical analysis to assess how students acted with collaborative problem-solving mechanisms. We chose the results from the most active group from each category and analyzed their discourse data at the defined pivotal points in three phases of the lesson. This method was based on the hypothesis that a stage near the highest degree of centrality would display the characteristic activity.

Results

From the investigations, we confirmed that four groups had integrated SBF understanding. These four groups were the high-learning-outcome groups, and the other five groups were the low-learning-outcome groups. The individual analysis results showed that 10 students were fully integrated, 13 were partly integrated, five expressed a single understanding of the learning document, and none were in the no-understanding category. Chi-squared analysis of student frequencies across high- and low-outcome-groups (fully or partially integrated and the single document) showed significance ($\chi^2 = 31.36$, $df = 2$, $p < .01$).

In the second investigation, the transitions in the total values of the degree centralities in each group showed a striking difference between the high- and low-outcome groups regarding whether to maintain the word clusters' changes (Fig. 1). The images' vertical axes signify the degree centralities' absolute values, and the horizontal axes represent time. The lines for the high-outcome groups illustrate that students continually used keywords and tried to connect these keywords to various teams. This difference is especially evident in the late phase of the lesson. The low-5 group peaked at the end of the first phase and was slightly different from other low-outcome groups, but the change in the second phase is not shown in Fig. 1.

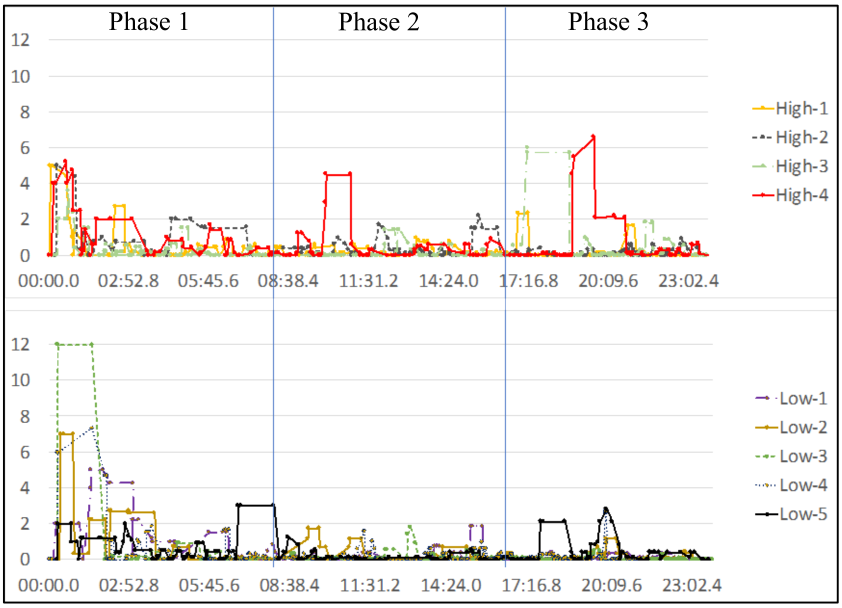

Figure 1. The transitions in the degree centralities of the high-learning-outcome groups (upper) and low-learning-outcome groups (bottom).

Dialogical analysis in the third investigation showed details in the differences between the high- and low-outcome groups. For this analysis, we chose groups high-4 and low-5. Next, we focused on pivotal points in each phase that were the highest for both groups because they show the group activities' characteristics. The first pivotal point for the high-outcome group confirmed that at 37 s, students shared knowledge from the documents. Then, they shared knowledge until the early timing (2 min 59 s) in phase 2, which is the second pivotal point. The pivotal point in phase 3 for the high-outcome group was at 19 min 38 s. By preparing the presentation, students checked their understanding. The original discourse data was in Japanese and was translated into English by the first author (keywords in SSNA are shown in italics). The discourse around the first pivotal point was as follows.

Student 4A (#5): In this document, *heat* moves from the high-temperature side to the low-temperature side, but it does not transfer from the low-temperature side to the high-temperature side. This is a physics explanation… *the second law of thermodynamics*. So, *thermal energy* moving with the material is called the *refrigerant*. It seems that a *refrigerant* carries *heat*.

Student 4C (#6): Hmm. *Refrigerant*….

Student 4A (#7): Right, so, yeah, at this… at this point, in the *condensation* and *evaporation* units, *thermal energy* moves between a *refrigerant* and the air.

Student 4C (#8): Hmm, hmm, hmm.

Student 4A (#9): This is the mechanism. Right. A *heat pump* mechanism transfers *thermal energy* from a cold space to a warmer one because of external *power*. It is similar to *an air conditioner*.

Even though, from Phase 1, the students in the low-outcome group started sharing the knowledge that they gained from the documents, the first highest point was marked when changing phases from 1 to 2 (around 6 min 52 s). At this point, they tried to learn the contents of document B because they had not engaged in sharing prior. Then, at the second pivotal point (8 min 34 s), dialogue data showed that students had tried to integrate knowledge collected from the documents. The low-outcome group's last pivotal point was shown at 19 min 58 s; it was close to the last high-outcome group's pivotal point. The students then discussed their understanding.

Discussion

This study's purpose is to improve the design of jigsaw instruction with further instructional support. Accordingly, this study raised the research question: how does the engagement of students in the high-learning-outcome group in the discourse differ from that of students in the low-learning-outcome group? The answer to this question can be discussed based on the shape of the graph in Fig. 1. The temporal SSNA delineated the high-outcome group's characteristic as a frequent shape consisting of a higher and lower score through all phases. Meanwhile, the transitions in the low-outcome groups' lines tended to both show the most dynamic changes at first and then relatively little change later. In addition, there were differences between the high- and low-outcome groups both in the value of the total degree centralities and the timing of change. Furthermore, it is suspected that the high-outcome group's members tried to create a common understanding based on other members' information from phase 1. This is because the line for high-4 in Fig. 1 delineates that they shared the documents' contents and mentioned many keywords during the first phase. The importance of creating a shared understanding has been discussed in previous studies (Oshima et al., 2017; Damşa et al., 2010). Additionally, moving to the stage of re-creating knowledge objects (namely, "generative collaborative actions") (Damşa et al., 2010) can also be attributed to the creation of shared objects from the early phase. Consequently, the present study suggests that epistemic goals and activity time are important in supporting low-outcome groups.

These findings suggest that when teachers support students to engage in a generative task, students may be more likely to engage in learning as knowledge creation. The low-outcome groups in the dataset could not engage in generative collaborative actions. Thus, redesigning the main challenge for smooth transitions to the generative task might prompt students to create a shared understanding and transition to generative collaborative actions. One possible main challenge may be to ask students "please explain why vending machines with heat pump systems are good for the earth." To solve this task, they need not only to integrate their knowledge but to generate their own idea based on knowledge from learning resources on an air conditioner as a heat pump system. This study contributed to the further development of jigsaw instruction as collaborative learning designs from the knowledge creation perspective, but it just analyzed a single case. In future studies, the hypothesis detected in this study should be examined by analyzing more data.

References

Bereiter, C., & Scardamalia, M. (2003). Learning to work creatively with knowledge. In de Corte, E. E., Verschaffel, L. E., Entwistle, N. E., & Van Merriënboer, J. E. (Eds.), *Powerful learning environments: Unravelling basic components and dimensions* (pp. 55-68). Pergamon/Elsevier Science Ltd.

Damşa, C. I., Kirschner, P. A., Andriessen, J. E. B., Erkens, G., & Sins P. H. M. (2010) Shared Epistemic Agency: An Empirical Study of an Emergent Construct, *The Journal of the Learning Sciences, 19*(2), 143-186.

Hmelo-Silver, C. E., & Pfeffer, M. G. (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions, *Cognitive Science*, *28*(1), 127-138.

Miyake, N., & Kirschner, P. A. (2014). The social and interactive dimensions of collaborative learning. In Sawyer, K. (Ed.), *The Cambridge handbook of the learning sciences*, 2nd ed. (pp. 418–438). NY: Cambridge University Press.

Ohsaki, A., & Oshima, J. (2021). Socio-semantic network analysis of knowledge creation discourse on a real-time scale. In Ruis, A. R., and Lee, S. B. (Eds.). *Advances in Quantitative Ethnography, ICQE 2021, Communications in Computer and Information Science*, *Vol 1312* (pp. 170-184). Cham: Springer.

Oshima, J., Oshima, R., & Matsuzawa, Y. (2012). Knowledge Building Discourse Explorer: A social network analysis application for knowledge building discourse. *Educational Technology Research and Development, 60*(5), 903-921.

Oshima, J., Ohsaki, A., Yamada, Y., & Oshima, R. (2017). Collective knowledge advancement and conceptual understanding of complex scientific concepts in the jigsaw instruction. In Smith, B. K., Borge, M., Mercier, E., & Lim, K. Y. (Eds.). *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on CSCL, Volume 1* (pp. 57–64). Philadelphia, PA: ISLS

Oshima, J., Oshima, R., & Fujita, W. (2018). A mixed-methods approach to analyze shared epistemic agency in jigsaw instruction at multiple scales of temporality. *Journal of Learning Analytics, 5*(1), 10–24.

Paavola, S., & Hakkarainen, K. (2005). The knowledge creation metaphor—An emergent epistemological approach to learning. *Science Education, 14*(6), 535-557.

Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In Sawyer, K. (Ed.), *Cambridge handbook of the learning sciences*, 2nd ed. (pp. 397–417). New York: Cambridge Univ. Press.

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Understanding Goals, Pedagogical Frameworks, and Relationships in Community-based Participatory Design

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Abstract: The extant literature suggests that human-centered approaches to design such as Participatory Design (PD) lend to more reusable and relevant design outputs, but often assumes this progression as an inevitable outcome of PD work. To investigate the factors contributing to this assumption, we document a comparative case analysis of the design processes of three studies centered on learning in communal spaces. All three studies shared the overarching objective of designing signage to promote playful learning opportunities in grocery stores, providing a rare opportunity to analyze different approaches to PD work in a controlled design area. We compare how three components interact throughout each design process: 1) researchers' goals 2) researchers' pedagogical frameworks and 3) community roles. We propose that future researchers consider the interplay of these three components as points of deliberation to formulate innovative and intentional PD practices. We offer a set of guidelines incorporating these components that researchers can reference when structuring their PD process.

Introduction

Within the learning sciences, human-centered methods such as Participatory Design (PD) have received increased attention to create more culturally-relevant and reusable learning artifacts *for, with, and by* those who will use them (DiSalvo, Clement, & Pipek, 2012). PD opens up opportunities to integrate input from users to design outputs centered around users' values and contexts (Ahn, Campos, Hays, & Digiacomo, 2019). Nonetheless, to optimize this process, researchers must interrogate their goals, assumptions of how learning occurs and how that relates to the outputs they develop, and the way they incorporate community participation in tandem (Ahn & Clegg, 2018).

Researchers' goals largely stem from their assumptions about learning. The pedagogical frameworks that researchers bring to the design process influence their conceptualization of how learning happens during interaction with design outputs (Ahn & Clegg, 2018). For the purposes of this paper, we conceptualize the three following high-level pedagogical schools of thought. Cognition and learning can be conceptualized as occurring individually (cognitive), situated in interactions with others (social), or extrinsically being linked to interactions within a cultural-historical context (sociocultural) (Greeno, 2011; Nasir & Hand, 2006). These pedagogical frameworks undergird how researchers approach and structure PD; therefore it is important to name and reflect on how their pedagogical frameworks influence their facilitation.

Within PD, community members can shape the design outputs by taking on different roles —*users* of artifacts, *testers* who provide feedback, *informants* who contribute insight at multiple stages of the design process, and *design partners* who are equal stakeholders throughout the design process (Druin, 2002). As such, it is important to consider the types of contributions researchers seek from community members—and the corresponding relationships and capacities to best incorporate them. In this paper, we demonstrate how the structure of PD projects leads to different design pathways, and contribute a framework for researchers to characterize and structure PD in education. We provide a unique case study that examines the design processes of three community-based research projects that aim to design grocery signage that promote learning. These three studies are variations of a study conducted by Ridge et al. (2015) that found an increase in parent-child conversations when signage was installed in grocery stores. We posed the following research question: **How do researcher goals, researchers' pedagogical frameworks and community participant roles influence PD processes and outputs?** We propose a set of guidelines based on our findings to highlight elements researchers should consider when structuring future PD work.

Methods

To reveal the different trajectories research teams took to design signage that facilitates learning in grocery spaces, we analyzed the design process and outputs of three projects building on the work by Ridge et al. (2015). Projects 1 and 2 already completed initial stages of their research and Project 3 is an ongoing PD project conducted by our research team. We provide more contextual details of each study in our findings.

We conducted and transcribed interviews with five researchers from Projects 1 and 2 to learn about their goals, design process, and experiences working with community partners. We also transcribed Project 3's co-design sessions and collected researchers' written reflections following the sessions and subsequent signage development meetings. The final data corpus included 61 pages of interview transcripts, 56 pages of co-design session transcripts, and 17 pages of reflections/field notes of co-design sessions.

We used an emergent thematic analysis in two phases to understand the design process of the different projects. In an open-coding phase, the research team examined sample interviews and co-design sessions to develop an initial codebook. The research team met to discuss codes, refine code definitions, and combine and reorganize codes that had overlapping conceptual definitions. Then we assigned codes across our research team so that each one was double coded for intercoder reliability. The research team wrote analytic memos to capture the structural components of the design process that surfaced across the three projects (Weston et al., 2001).

Findings

In this section, we use vignettes to illustrate the varying interplay between the goals, pedagogical frameworks, and relationship configurations in each design narrative. We emboldened sections of each vignette to demonstrate how these components are apparent in the structures of each research project.

Project 1: Signs promoting math talk in supermarkets

Project 1 researchers designed signs based on predetermined theoretical content and food groups, and examined their effectiveness in promoting increased children's math talk in supermarkets (Hanner, Braham, Elliott, & Libertus, 2019). Grounding their design in cognitive and social learning frameworks, researchers used directive language tailored to different developmental levels in their signs. One researcher recalled, "*We decided to have **one question that was low level targeted at the younger kids** in our age range and then **one that would be slightly more advanced** that would require some arithmetic operation or more complex reasoning process **to engage the slightly older kids**."* For example, one sign asked, "How many eggs are in a carton?" to encourage younger children to count; another prompted slightly older children to subtract by asking, "If we each ate an egg, how many would be left?"

Project 1 researchers were firm on the content and purposes of their signs, and positioned their partners as *users* and *testers*. To gain permission for implementation, researchers discussed with the local grocery store managers to gain *tester* feedback on specific design elements that are allowed for the signs (e.g. dimensions, content), and *user* feedback on where to institute them. A researcher reflected "*[Some stores required] that **they would have to create the signs**. And that kind of ruins the whole point of the study. So we couldn't do it with them. [...] **I couldn't make [the signs] super wide because [the grocery store staff] wanted everyone to be able to walk down the aisle easily**...and they also didn't **want something that would promote a specific product**."*

Researchers were ultimately able to accomplish their goals, but initiating permission-based relationships with partners to use predetermined signs seemed to set constraints on initiating and facilitating more substantial engagement with community partners. One researcher recalled, "*It seemed like **we couldn't convince grocery stores that this would be a meaningful engagement with the community or** [...] **making a more meaningful shopping experience for the families**.*" The signs were highly usable in the space to study math talk. However, researchers' firm stances on design and the corresponding roles their partners took may have resulted in less alignment with community values.

Project 2: Signs promoting elaborative talk in a food pantry

Project 2 researchers relied on social and cognitive theories to develop signage to examine whether guided prompts elicited more elaborative dialogue between caregivers and children compared to signs with learning pronouncements (i.e. "learning can happen anywhere!"). Researchers collaborated with a food pantry in a low-SES neighborhood and talked to patrons and staff to inform their signage development and placement.

Researchers had defined the theoretical content of their signs but still looked to learn about how to best situate them in topics relevant to their context. A researcher described their considerations when drafting signage prompts: "[We wanted] *sort of **open-ended, what, why, the W questions... So it was very easy for the parents to elaborate on the guided play kind of questions** [in the signs].*" To create signs relevant to their context, researchers incorporated community partners (food pantry staff and patrons) as *users* and *informants* to learn about the culture, routines, and layout of the food pantry. A researcher reflected: *"We went in [the food pantry] once just to start to volunteer [...] So we spent a bit of time in there [...] **getting to know the culture of the place. We talked to the people in charge to see what items they typically got**, what sort of products always came in, no matter what...things like that. And **based on the layout of the food pantry was how we decided where we'd be putting the signs up**."*

Researchers used this information to situate their signs in relevant foods and context to food pantry patrons and study the signs' influence on elaborative talk. Nonetheless, a logistically-based relationship resulted in constraints on facilitating value-informed participation with community partners. A researcher reflected, *"[Our partner organization]* ***really wanted an evaluator, not a scientist or researcher****, so* ***it was sort of one of those fundamental bad fit situations****."* Incorporating community partners' insight helped researchers optimize the signs' relevance and usability in the space, but ultimately did not abate several misalignments between researcher and community partner goals in the PD process.

Project 3: Signs promoting culturally situated STEM learning

In Project 3, we used cognitive, social, and cultural pedagogical frameworks to produce grocery store signage prompting conversations around STEM learning situated in local values and supermarket experiences. We conducted two co-design sessions with 20 participants—researchers, partners from a local health organization, and caregivers from a low-income predominantly Latinx community. In each session, participants recounted their grocery store experiences.

A researcher reflected on the goals of the project: "*This project looks for any underlying factors [...] within the family or in these participants' communities. It is important for us to find these factors so that we can* ***create posters relevant to this community's needs***." As such, we situated community partners as cultural *informants* with expertise in local cultural and lived experiences. Some of the values we heard were: familial connection, emotion, routines, and cross-cultural comparisons. For example, some parents (as immigrants to the United States) expressed frustration around changing from metric to imperial measurement systems: "***The children*** *[...]* ***they already know about pounds. But us as adults, in the butcher shop, [deciding between] a kilo and a pound*** *[...]* ***we're thinking it's a kilo, we get a pound****."* We drew upon cognitive skills involved in STEM learning that we heard in community members' stories—such as measurement unit conversion—to develop signs promoting interactions situated in local experiences, needs, and culture.

We defined content for our signs by conducting a thematic analysis on the data from our sessions. To translate the themes into signage ideas, we posed questions with the stem "How might we" coupled with the themes we saw arise in the data to try and prompt STEM learning interactions. One example question we posed was, *"How might we promote activities to convert different quantities, measurement systems or cultural ways that we measure?"* From this question, we developed a conversion table that families could use to convert between metric and imperial systems at the deli. However, at the current stage of our project we have not yet included community partners as *users* and *testers*, so we do not know whether families would engage with design output as desired.

Conclusion, limitations, and implications

This case study presents a unique opportunity to look across similar projects and examine how researchers' choices in each stage of the design process lead to different design directions. Our analyses shed light on the interplay of three critical components—researcher goals, pedagogical frameworks, and community roles—in PD processes. We found that researchers' pedagogical frameworks and goals across each project influenced how they structured the design process and conceptualized community roles.

Based on how community members are situated in partnerships, the constant incorporation and negotiation of researcher and participant input into design can result in a process of mutual learning (Yip et al., 2016). However, we acknowledge as a core limitation that none of the teams referenced in this paper has yet developed mutual learning opportunities in their PD. Work involving communities is inherently more complex due to the increased number of constituents; executing PD to its full potential therefore demands heightened intentionality and reflection in how to best incorporate these constituents. To support this process, we propose a set of **G**oals, **P**edagogical frameworks, **P**artner relationships (GPP) Guidelines (Figure 1) future researchers can use to highlight considerations around three key components when structuring their PD. By reflecting on these guidelines in the planning phase, researchers can harness PD approaches more effectively in complex community-based work and abate any foreseeable misalignments. Future researchers who aspire to maximize PD can use these guidelines to yield more usable design artifacts and sustainable interventions that incorporate community voices and promote mutual learning.

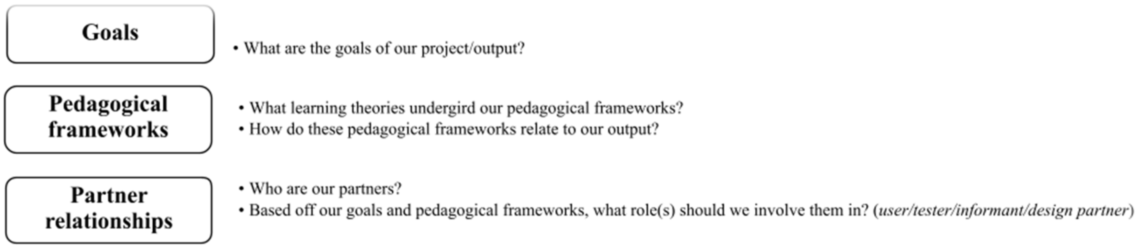

Figure 1. GPP guidelines for structuring community participation design

References

Ahn, J., Campos, F., Hays, M., & Digiacomo, D. (2019). Designing in context: Reaching beyond usability in learning analytics dashboard design. Journal of Learning Analytics, 6(2), 70–85. doi:10.18608/jla.2019.62.5

Ahn, J., & Clegg, T. (2018). Human-computer interaction and education: Designing for technology-enhanced learning experiences. The Wiley Handbook of Human Computer Interaction, 2, 821-830. doi:10.1002/9781118976005.ch38

DiSalvo, C., Clement, A., & Pipek, V. (2012). Communities: Participatory Design for, with and by communities. In J. Simonsen & T. Robertson (Eds.), Routledge International Handbook of Participatory Design (pp. 202-230). New York: Routledge.

Druin, A. (2002). The role of children in the design of new technology. Behaviour and Information Technology, 21(1), 1-25.

Greeno, J. G. (2011). A situative perspective on cognition and learning in interaction. In T. Koschmann (Ed.), Theories of Learning and Studies of Instructional Practice (pp. 41-71). New York: Springer.

Hanner, E., Braham, E. J., Elliott, L., & Libertus, M. E. (2019). Promoting math talk in adult-child interactions through grocery store signs. Mind, Brain, and Education, 13(2), 110-118. doi:10.1111/mbe.12195

Nasir, N. S., & Hand, V. M. (2006). Exploring sociocultural perspectives on race, culture, and learning. Review of Educational Research, 76(4), 449–475. doi:10.3102/00346543076004449

Ridge, K. E., Weisberg, D. S., Ilgaz, H., Hirsh-Pasek, K. A., & Golinkoff, R. M. (2015). Supermarket speak: Increasing talk among low-socioeconomic status families. Mind, Brain, and Education, 9(3), 127-135. doi:10.1111/mbe.12081

Weston, C., Gandell, T., Beauchamp, J., McAlpine, L., Wiseman, C., & Beauchamp, C. (2001). Analyzing interview data: The development and evolution of a coding system. Qualitative Sociology, 24(3), 381-400.

Yip, J. C., Clegg, T., Ahn, J., Uchidiuno, J. O., Bonsignore, E., Beck, A., & Mills, K. (2016). The evolution of engagements and social bonds during child-parent co-design. Proceedings of the CHI Conference on Human Factors in Computing Systems, USA, 3607-3619. doi:10.1145/2858036.2858380

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Identifying Research-Practice Tensions and Belief Shifts through Co-Design Processes

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Abstract: In this paper, we examine an experience of using co-design methods with Palestinian Arab educators and Learning Sciences researchers. In this research-practice partnership, we used a participatory methodology to generate new ideas for transdisciplinary STEM activities. This approach allowed researchers and educators to build trust, facilitated a better understanding of the local context, and enabled new educational possibilities to emerge through speculative design. We describe the collaborative process to create STEM learning environments for non-dominant learners in a settler-colonial context and highlight tensions we observed between research aspirations and practical constraints.

Introduction

This paper is part of a larger project that aims to study the engagement and participation of a non-dominant population of Palestinian Arab learners in transdisciplinary science activities. This is a collaboration between learning science researchers at Arizona State University and educators at Al-Rowad for Science and Technology, a community-based organization led by Palestinian Arab educators in the Haifa District in Israel. The organization is engaged in STEM education through science hands-on activities, after-school programs, and public science outreach events with Palestinian Arab youth and children in Israel. Through this collaboration, we drew on multiple design methods to strengthen the partnership and speculate about possibilities for designing equity-oriented STEM education environments in their context (Bang & Vossoughi, 2016; Dunne & Raby, 2013; Freire, 1973; Vossoughi & Gutiérrez, 2016). Through this work, we hope to expand on how participatory research with local communities can "disrupt historically shaped inequities and cultivate transformative agency from within communities" (Bang et al., 2016, p.29), position community members as experts, and strengthen research-practice partnership through critical pedagogy and dialogue. These efforts have the potential to shift power and authority away from researchers and toward collaborating with members of the local community, who have a deep understanding of the social and historical complexities at play, and the challenges and constraints underlying pedagogical decisions. As such, this work has implications for researchers who conduct research with non-dominant and historically oppressed populations.

In this paper, we describe the methodological choices we had when conducting co-design workshops to create educational experiences that consider equity, collaborative and interactive engagement, and learning with technology. In this work, we build upon participatory methods to involve participants in thinking about educational possibilities for their work (Bang & Vossoughi, 2016; Frerie, 1973). In this process, we used design fiction prompts to speculate such possibilities and engage practitioners to think about expansive possible futures of their work (Dunne & Raby, 2013). We frame this work as co-design to emphasize the role practitioners can play in research-practice partnerships. We use data from notes and transcripts from three sessions (6 hours total) to examine how co-design can be used as a methodological tool that positions collaborators as experts and enable productive dialogue within research-practice partnership. In addition, we examine if and how participants, including the researchers, experience shifts in thinking about learning, equity, and pedagogy through this process.

Positionality

As our identities as researchers and practitioners are a critical component of this research, we begin with a description of our positionalities.

Areej Mawasi, Researcher: I am an insider researcher in the broader context of the fieldwork. Both my undergraduate education in Israel and graduate studies in the United States were Western and Eurocentric. My fluid learning trajectories across contexts, geographies, languages, cultures, and methods enabled me to engage in scholarship across disciplines, paradigms, and geographies (Said, 2000). Within this partnership with the organization, my role was dynamic, initially I was an outsider and viewed as a researcher who was there to observe and make recommendations. Gradually, as our communication and trust increased, my role shifted and our collaboration grew stronger. In this project, I co-designed and facilitated the workshops, conducted and shared observations, analyzed and interpreted the data, and I was the lead author on this paper.

Ruth Wylie, Researcher: I am a white woman who was born and raised in the southwest United States. I have attended public and private universities in the United States and have training in Cognitive Science, Computer Science, and the Learning Sciences. My research focuses on supporting interdisciplinary and diverse teams to tackle global issues. For this project, I advised Areej on the design and execution of the workshops, participated in interpreting the data, and drafting the manuscript.

Wisal Ganaiem: I am the pedagogy and education counselor at Al-Rowad. I have a Master's in Educational Counseling. For this study, I shared with Areej insights on areas of interest of Al-Rowad in social change and science education, overview of practices we do with instructors (e.g., professional development, STEM pedagogy), and populations we work with. I also shared feedback on the structure and topics of the co-design sessions in alignment with instructors needs, and I fully participated in the co-design sessions.

Masaood Ganaiem: I am a scientist and team leader in research and development innovation. I grew up in Baqa Al-Gharbia and studied at a private school in Haifa. I hold a Ph.D. in immunology from Ben Gurion University in Israel. During my research career, I noticed a low number of Arab scientists in Israel. In 2013, with my wife Wisal and Arab academic fellows, I co-founded a non-profit organization called Al-Rowad for Science and Technology, with a vision to overcome the socioeconomic and geographic challenges and disadvantages in science education facing the Arab community in Israel. When we met Areej, we noticed commonalities in education perspectives and pedagogical practices; this encouraged us to collaborate on this project. Our collaboration helped us understand the potential impact of Al-Rowad's framework beyond our local community.

Participatory co-design research

For this study, we drew upon participatory approaches. Our goals were to create partnerships in which we co-construct knowledge with educators through co-design activities, challenge deficit-focused views of local communities' efforts in changing their realities and understand pedagogical practices in the learning environment from the educators' perspectives, not only through the researchers' lens. The organization volunteered to collaborate on this project because they were interested in expanding their impact through academic research beyond the local community. This work is conducted within a community-based organization, with Palestinian Arab educators. To better understand the existing practices and learning within this context, we conducted three co-design sessions over two days (6 hours total) with educators from the organization, to learn with them about the pedagogy and design of equity-oriented STEM environments for non-dominant Palestinian learners. Data for this paper includes video transcription of the sessions, design artifacts created during the sessions, and field notes.

Our partnership follows the characteristics of traditional co-design work. For example, (1) the work follows a non-linear process to implement innovations in real-world learning environments (e.g., Barab, 2014); (2) the work values interdisciplinary partnerships between researchers and stakeholders such as teachers, learners, parents, and administrators (Penuel & Spillane, 2014; Zuiker et al., 2017); (3) the work views learners and teachers as co-designers through participatory design processes that aim at thinking about educational possibilities (Bang & Vossoughi, 2016; Freire, 1973); (4) the work attends explicitly to the social, cultural, and political context in which these design activities take place (Bang et al., 2016; Bang & Vossoughi, 2016); and (5) the work uses design approaches to engage educators with thinking about possible futures within their pedagogy and learning environments design (Bang & Vossoughi, 2016; Dunne & Raby, 2013; Freire, 1973).

The co-design participants were 6 educators from the organization (2 lead instructors, 2 assistant instructors, Wisal (Third Author) as the pedagogy and education counselor, and the STEM pedagogy director and co-founder) and the first author. The sessions focused on the following themes: equity in STEM; collaborative learning; and learning with technology. During the sessions, participants engaged in discussion and presented their ideas. The sessions were followed by three design challenges to identify educational possibilities.

Preliminary findings

The findings suggest that co-design fiction can serve as a method to envision possible educational designs within an existing context. These findings highlight (1) tensions between research and practice, (2) shifts in the perceived role of researchers within the environment, and (3) shifts in what counts as learning.

Tensions-between research and practice

Educators made generative design suggestions such as integrating collaborative activities, proposing ways to add digital media tools, and suggesting modified activity flows to incorporate these activities within their existing practices. While these ideas aligned with the goals of each co-design session, we see this as an initial step. We had hoped our conversations about social and political issues within this context (e.g., diverse ways of knowing, marginalization, corruption, violence, hegemony in science) would lead to participants generating more transformative educational ideas. One possible explanation is that the educators were designing educational possibilities constrained by the existing status quo of the context of their work and mediated by the prompts that the researchers designed (e.g., the ICAP framework (Chi & Wylie, 2014)—Interactive, Constructive, Active, Passive—for use in the design of collaborative activities). It is clear that the organization is committed to social change through their education work, but they must navigate their existing social, cultural, and political contexts in a pragmatic way to provide an entry point to science education for a large number of Arab students across many towns and cities, including unrecognized Bedouin villages.

Perceived role of researchers within the environment

As mentioned above, Areej is from the local community where the organization functions. Areej had not previously been involved in work with the organization. Because of her status as a researcher and her training in the United States, the educators originally viewed her role as an expert, consultant, or evaluator. When asked their expectations for the co-design sessions, educators initially expressed that "they want[ed] to learn from [her] so they can improve," but also, "they know that [she is] here to do research." This shifted when Areej emphasized that she was there to learn *from* them and *with* them through a co-design process that aims to co-construct knowledge. For example, when Areej shared a slide with observations and emerging themes from previously observed practices, participants were surprised and questioned if Areej had been analyzing them as they completed the workshop activities. While the conversation was humorous in tone, it suggests that participants perceived the research process as something that is done "on people" rather than "with people." Throughout the co-design process, it became clear that the researcher was interested in working with the educators and to co-construct knowledge and expectations. Areej frequently sought feedback on her interpretations and perceptions. Through this process, trust was built and conversations became more open to constructive critique. One participant reflected, "the source of critique and how it is done makes a difference… if Areej shares suggestions, it is clear to me from the talk that it is for improvement." Session transcriptions suggest that the educators were able to shift their perceptions of the Areej's role and began to view the co-design sessions as a collaborative experience, while also increasing their level of trust. At the end of one session, Areej shared her preliminary observations and encouraged the members of the organization to continue exploring these themes in order to share principles with other organization or in other learning environments. In response, two participants said, "around the world," referring to conversations about using their expertise working with non-dominant learners to benefit other contexts. This shift in discourse changes the view from that of a researcher studying the educators to that of the researcher collaborating with and learning from them. Despite the initial power dynamics between researchers and practitioners in the context, the co-design process built trust and helped educators from the organization position themselves as active collaborators rather than simply passive participants.

What counts as learning

The educators' sense of what counts as learning also shifted throughout the co-design process. In our discussions, we talked about learning-by-doing in an out-of-school context (e.g., knowledge of a peasant farming their land, a woman organizing her spices in patterns). One participant disagreed about whether or not these examples constituted learning. The participant argued that these examples were people "robotically" doing things without thinking, while another described how his Palestinian illiterate grandmother, who is from an ethnically cleansed village of Al-Damun (see Zochrot - Al-Damon, 2014), creates mathematical geometry and patterns through sewing and embroidery that "a Doctor in Math cannot do." This example demonstrates that the educator's grandmother was not simply engaged in passive apprenticeship; she was creatively making and constructing new ideas and art using mathematical knowledge that she was able to transfer to others to maintain her village's history, culture, and knowledge. This example provided a possibility for the first participant to think about diverse ways of knowing, and this change in perspective was reflected in his descriptions later in the sessions, where he noted that he sees such examples as creating new things beyond what was taught. We believe such an exchange was possible because of the examples Areej shared with the practitioners in an attempt to engage them in decolonial discourses about science education in this context.

Conclusions and implications

The design research process is often described as iterative, interventionist, and involving retrospective analyses (Barab, 2014; Bannan-Ritland, 2003; diSessa and Cobb, 2004; Collins et al., 2004). While researchers have different views about the appropriate level of participant involvement in decision-making, these perspectives are informed by researchers' epistemologies, observations, participant feedback, and data collected across design cycles. We view iterative, interventionist, and researcher-centric approaches as problematic for work with non-dominant populations and community-based educators. Using a top-down colonial approach, centering researchers' voices or the priorities of funding institutions, and focusing on "research and scientific outcomes" minimizes participants' contributions and reproduces research and design that does not cultivate the knowledge and wisdom that local communities and educators already have. As we continue to engage in design research in the Learning Sciences, we argue for the following practices: (1) researchers' priorities should be shifted towards collaborative learning with educators. For instance, involving instructors in the co-design process, as a way to learn about their pedagogical practices, share with them about the theoretical and implications of such approaches, and co-design educational possibilities collaboratively (e.g., Bang & Vossoughi, 2016); (2) building trust by involving the leaders and members of organizations in decisions related to research activities (e.g., discussing with instructors, logistical decisions, involving parents in the study); (3) understanding the existing practices of the educators and community; and (4) engaging in designing learning environments where we dialogically exchange expertise with educators and community members.

Design research amplifies collaboration between multiple stakeholders (e.g., researchers, educators, instructional designers, policymakers, parents, students) (Zuiker et al., 2017). Such collaboration enables the design of tools and the implementation of studies that meet multiple goals (Bannan-Ritland, 2003). Education systems and learning are complex; therefore, designing and developing interventions to improve learning requires diverse research methods that involves perspectives of nondominant local communities and participants. Such perspectives are not always considered in the design process, particularly in contexts where education systems are oppressive, racist, and engaged in discrimination against non-dominant populations. Through our work, we attempted to create a research-practice partnership where we brought together learning scientists and practitioners. These diverse perspectives enable a deeper understanding of the local context and its social, cultural, and political aspects that shape the local community practices.

References

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making.

Bang, M., Faber, L., Gurneau, J., Marin, A., & Soto, C. (2016). Community-based design research: Learning across generations and strategic transformations of institutional relations toward axiological innovations. Mind, Culture, and Activity, 23(1), 28-41.

Bannan-Ritland, B. (2003). The role of design in research: The integrative learning design framework. Educational Researcher, 32(1), 21-24.

Barab, S. (2014). Design-based research: A methodological toolkit for engineering change. In The Cambridge Handbook of the Learning Sciences, Second Edition (pp. 151-170). Cambridge University Press.

Chi, M. T., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. Educational psychologist, 49(4), 219-243.

Collins, A., Joseph, D., & Bielaczyc, K. (2004). Design research: Theoretical and methodological issues. The Journal of the learning sciences, 13(1), 15-42.

DiSessa, A. A., & Cobb, P. (2004). Ontological innovation and the role of theory in design experiments. The journal of the learning sciences, 13(1), 77-103.

Dunne, A., & Raby, F. (2013). Speculative everything: design, fiction, and social dreaming. MIT press.

Freire, P. (1973). Education for critical consciousness (Vol. 1). Bloomsbury Publishing.

Penuel, W. R., & Spillane, J. P. (2014). Learning sciences and policy design and implementation: Key concepts and tools for collaborative engagement. In The Cambridge Handbook of the Learning Sciences, Second Edition (pp. 649-667). Cambridge University Press.

Said, E. W. (2000). Out of Place: A Memoir. Vintage.

Vossoughi, S., & Gutiérrez, K. D. (2016). Critical pedagogy and sociocultural theory. In Power and privilege in the learning sciences (pp. 157-179). Routledge.

Zochrot. (2014). Al-Damun. Retrieved November 12, 2020, from https://zochrot.org/en/village/49124

Zuiker, S. J., Piepgrass, N., & Evans, M. D. (2017). Expanding design research: From researcher ego-systems to stakeholder ecosystems. Learning, design, and technology: An international compendium of theory, research, practice, and policy, 1-28.

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Conceptualizing Critical Game Design as a Method to Engage Youth with Critical STEM

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Abstract: This conceptual paper examines the educational affordances of critical design as a pedagogical tool for youth engagement in critical STEM learning. We conceptualize a critical design approach for using game design as a medium for critical STEM learning. First, we define critical design for the purpose of the paper; second, we discuss why critical design is important for STEM learning, and third we address ways in which critical design approaches might be applied through critical game design. We propose that using critical game design to engage youth creates educational possibilities for thinking and communicating about the social, political, ethical, and historical dimensions of STEM.

Introduction

In this conceptual paper, we draw upon work in critical design, critical STEM learning, and game design to examine the educational affordances of critical game design to engage youth with fundamental STEM issues (e.g., ethics, ideologies, history, biases within STEM). Through these three lenses, we expand thinking about the potential of games as media to support design thinking and STEM literacies (e.g., Parekh et al., 2019) while attending explicitly to the social, cultural, ethical, and political dimensions of design. We view this approach as an opportunity to support transdisciplinary STEM learning (e.g., Sengupta-Irving & Vossoughi, 2019; Takeuchi et al., 2020), engage learners in communicating STEM issues through critical game design in a participatory manner (e.g., Literat et al , 2020), and position learners with greater agency through their design process.

We view design as a non-linear, dynamic, and complex process that involves decision making, thinking, and doing shaped by ideologies and values of designers, practitioners (e.g., teachers, stakeholders), researchers, and participants in the design process (Mawasi et al., 2020). Attending explicitly to social, cultural, ethical, and political ideologies embedded in design processes and outcomes (including artifacts, systems, and knowledge) is crucial for more equitable, inclusive, and transformative STEM learning experiences and practices (Barab et al., 2007; Bang & Vossoughi, 2016; Medin & Bang, 2014). This attention challenges the presumed social and political neutrality of design thinking models and prompts learners to explore the values, interests, and standpoints instantiated in and reinforced by designed objects and the larger practices or systems in which they are used (Barab et al., 2007; Mawasi et al., 2020). Such examination can engage learners in critical design efforts that question existing designs, enhance learners' experience of agency in design (e.g. Aguilera et al., 2020), and expand their critical interpretive and meaning-making capacities (The New London Group, 1996). Recently scholars have challenged the cultural, racial, and economic agenda of dominant forms of STEM education (Vossoughi & Vakil, 2018) and called for STEM education in which "liberatory politics and deep disciplinary learning co-exist and co-develop" (Vakil & Ayers, 2019, p. 455). In this paper, we join this conversation by providing speculative reconfigurings of how critical game design as a learning activity might engage learners in critical STEM.

Game design has multiple affordances for engaging learners in critical reflection on dominant design goals, processes, values, and assumptions (Flanagan & Nissenbaum, 2014). Among these affordances are the interactive and systemic nature of games; games engage players through goals and actions that comprise "figured worlds" reflecting culturally and socially contexts of meaning (Holland et al., 2001). Prompting learners to think about values reinforced by their own and others' design artifacts can help them identify and evaluate the ideologies these designs reflect (Thumlert et al., 2018). While Flanagan and Nissenbaum (2014) and other design educators offer strategies to prompt designers' reflection on values in games, such critical approaches have rarely been applied specifically to game design in STEM. Additionally, educational games that expose learners to societal and ethical issues within STEM fields typically are not designed by learners, rather, they are used as an educational tool to teach STEM related concepts and practices (e.g., Barab et al., 2010).

Building on such work, we first define "critical design," drawing on concepts and strategies from several different fields. Then we discuss critical game design as an opportunity to engage youth in STEM learning that enables them to actively engage with and challenge restrictive and inequitable ideologies and practices.

Critical design across disciplines

Various disciplines offer somewhat different conceptions of critical design that inform our approach to critical game design in STEM education. Here we briefly identify key ideas from industrial design, human-computer interaction, game design, and the learning sciences.

Critical design in industrial design

Within industrial design (also known as product design), critical design arose as a means to "challenge how people think about everyday life" (Dunne & Raby, 2013, p. 45), particularly about the nature and role of designed objects, and to encourage people to imagine different possibilities (Dunne & Raby, 2013). Malpass (2017) describes critical design practice within the industrial design field as an approach that aims to use design as a medium of inquiry for facilitating "ways of knowing, exploring, projecting, and understanding the relationship between users, objects, and the systems that they exist in" (p.43). The goal of critical design is not a new or more desirable product, but rather to prompt questions about the values a product reflects, the assumptions it operates within, and the ideologies embedded and enacted within design methods, tactics, and strategies (Dunne & Raby, 2013; Malpass, 2017). For instance, Malpass (2017) describes how critical designers employ satiric devices such as humor and irony to provoke trenchant critiques of hegemonic values associated with production and consumption. However, as Dunne and Raby state, critical design is not intended to be entertainment, nor a form of art, but a means of "making abstract issues tangible" particularly as these issues are instantiated in everyday objects.

Critical design in human computer interaction

Scholars such as Bardzell and Bardzell (2014) have extended the concept of critical design to the field of Human-Computer Interaction (HCI). Building on Dunne and Raby's view of critical design as means of changing perspectives and prompting new insights, Bardzell and Barzell define critical design as "a research through design methodology that foregrounds the ethics of design practice, reveals potentially hidden agendas and values, and explores alternative design values." (p. 3297). The authors provide a more detailed and multifaceted conception of criticality, drawing on ideas from critical theory as well as metacriticism. They also argue for a broader conceptualization of what "counts" as critical design, including some forms of art as well as designs that may not be intentionally subversive but ultimately raise awareness of underlying ideologies and biases in design processes and goals. Lastly, they critique Dunne and Ray's distinction between affirmative and critical design, noting that any given design can both affirm and critique various aspects of the status quo.

Critical design in games design

In his classic essay on toys, Roland Barthes (2012/1957) describes how children's toys, as representations of the adult world, reflect broader social and political ideologies and structures that communicate appropriate and desirable ways of being and knowing. Even the use of cheap plastic for many toys reinforces a disconnection between human designs and the natural world. Barthes' view is illustrative of the work of scholars who study the broader social and political dimensions of play. Scholars in the field of game studies have addressed the implications of play across different levels of modalities (systems, procedures, visuals, symbols etc.) through analysis of games, game mechanics, and game design (e.g., Bogost, 2010; Salen & Zimmerman, 2004). Games as a medium in this sense can take different forms, digital or analog. A particular emphasis has been on how game rules and processes - the "procedural rhetoric" of games (Aguilera et al., 2020; Bogost, 2010; Salen & Zimmerman, 2004) - reflect beliefs about how the world works.

Critical game design includes approaches that prompt game designers to reflect on and challenge the values and assumptions that may influence their own design processes (Flanagan & Nissenbaum, 2014) as well as the creation of games with the deliberate intent of provoking critical thinking among players about the values, perspectives, and ideologies a game reflects (e.g., Cassar, 2013). In this sense, game design becomes not the creation of entertainment but a form of activist critique and advocacy for a social issue (e.g., Games for Change Student Challenge). Critical game design can also engage players in critically examining game mechanics, narratives, and representations. This perspective illustrates how play and procedurality within games mediate meaning making that can reproduce or challenge ideological systems and values.

Critical participatory design in learning sciences

The growing attention in the learning sciences to social, political, and ethical dimensions of learning has contributed to interest in participatory design approaches (Bang & Vossoughi, 2016). This includes the use of participatory research methods that shift power dynamics between researchers and participants and leverage diverse ways of knowing (Mawasi et al., 2020; Vakil et al., 2016). These methods might be considered critical in the broad sense of challenging dominant assumptions about whose voice and knowledge "counts" in the research process. However, some researchers have adopted more overtly activist strategies that involve participants in identifying questions, designing research approaches and identifying their desired futures or educational possibilities (e.g., Bang & Vossoughi, 2016; Tzou, et al., 2019). For example, in their participatory design research approach Bang & Vossoughi (2016) account for critical historicity, power, and relational dynamics within design methods themselves, creating opportunities to transform existing practices towards transformative educational change, rather than reproducing inequities as an outcome of design processes. The authors invite us to consider what they call axiological innovation, that is, thinking about meaning-making mediated by aesthetics, theories, practices, values, and ethics in design processes (Bang & Vossoughi, 2016). Another example is critical design ethnography described by Barab et al. (2007) as an approach that explicitly addresses power issues and agendas within the design process and its outcomes.

Critical game design: An approach to engage learners with critical STEM

A commonality across previous work on critical design is explicit attention to how dominant design processes, artifacts, and consequences reflect and reinforce social, political, cultural, and historical agendas. Design is re-imagined as a means of calling into question these agendas. Engaging learners with such critical design approaches in STEM may contribute to broader efforts to recruit marginalized populations to STEM, develop more inclusive and ethical design practices, and challenge dominant ideological dimensions of STEM education.

STEM education continues to be dominated by Western ideologies of scientific knowledge, practices, and excellence (Medin & Bang, 2014). Critical STEM education has been proposed as a way to help students think critically about their own engagement with STEM in school and in daily life, understand the historical, political and ethical dimensions of STEM, and see the potential of STEM to contribute to a more just and equitable society (e.g., Sengupta-Irving & Vossoughi, 2019; Takeuchi et al., 2020). Building on Freirian notions of critical pedagogy, scholars propose that critical STEM education should explore how normative discourses in STEM shape the construction of STEM knowledge and strategies, and position learners to challenge biases and inequities by cultivating their ability to create and use new tools and methods for knowledge creation and representation (Vakil, 2014; Vossoughi & Gutiérrez, 2016). We propose that design approaches such as critical game design can play a central role in critical STEM education as a means of engaging learners not only in critique but in creating artifacts and experiences that offer new forms of engaging with STEM.

Our own interest in critical game design grew out of our previous experience with using game design to engage young people in design thinking. In this earlier work, we hoped to engage participants in designing games that addressed social issues of relevance to their communities and that were personally meaningful. We adopted a popular model of design thinking as a framework. In analyzing the participants' design process and game artifacts, we discovered instances of "spontaneous" critical reflection. For example, in creating a game about water pollution, participants argued over whether the game should be competitive or collaborative, and questioned assumptions that individual actions alone might be effective in addressing this problem. In another game focused on the problem of agricultural pollution, the youth designers rewarded certain game actions with food from Taco Bell, an ironic means of illustrating our often unconscious participation in the very systems that we critique. Such examples inspired us to seek ways to more deliberately support youth engagement in critical game design.

Our conception of critical game design is still evolving, but we offer some conjectures about this approach to critical STEM education. Critical game design as a pedagogical approach may and should encompass a variety of experiences, topics, and goals. In contrast to models of design thinking that offer simplified steps and toolkits, the process of critical game design can't be reduced to a recipe. Indeed, we anticipate that a critical approach will prompt participants to question some common design techniques. They might question popular strategies for "empathizing" with potential users, or observe how power relationships are implicitly reinforced in relationships between game designers and players. Critical game design does not have to consist of designing entire games; learners can be introduced to ideological aspects of games through playing and critiquing existing games with a STEM focus. Emphasis might be placed not only on how STEM is represented through narrative or visuals, but also how game play itself reinforces values such as competition or collaboration. Learners can redesign existing games as a means of challenging or re-imagining existing STEM practices, goals, and ideologies. They can design games intended to provoke critical reflection on STEM-related issues. There are a small but growing number of games created for social critique that may serve as inspiration. Even a game design challenge without an overtly "critical" purpose can be a starting point for critical reflection. At the same time, designing games should be integrated with other forms of STEM education to cultivate learners' understanding of fundamental STEM concepts and tools. Ideally we view this as a reciprocal process; as learners grapple with representing STEM issues through games, they may come to a deeper understanding of, for example, current theories about environmental systems, or the nature of scientific models. Game design offers considerable potential as a context for learning; we hope to provoke greater attention to its *critical* potential as well.

References

Aguilera, E., Stewart, O. G., Mawasi, A., & Cortés, L. E. P. (2020). Seeing beyond the screen: A multidimensional framework for understanding digital-age literacies. In Sullivan, P. M., Lantz, J. L., & Sullivan, B. (Eds). *Handbook of research on integrating digital technology with literacy pedagogies* (pp. 1-31). IGI Global.

Bang, M., & Vossoughi, S. (2016). Participatory design research and educational justice: Studying learning and relations within social change making. *Cognition and Instruction*, 34, 173-193.

Barab, S. A., Gresalfi, M., & Ingram-Goble, A. (2010). Transformational play: Using games to position person, content, and context. *Educational Researcher,* 39(7), 525-536.

Barab, S., Dodge, T., Thomas, M. K., Jackson, C., & Tuzun, H. (2007). Our designs and the social agendas they carry. *The Journal of the Learning Sciences*, 16(2), 263-305.

Bardzell, J., Bardzell, S., & Stolterman, E. (2014, April). Reading critical designs: supporting reasoned interpretations of critical design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1951-1960), ACM Digital Library.

Barthes, R. (2012). *Mythologies* (R. Howard, Trans.). Hill & Wang. (Original work published 1957).

Bogost, I. (2010). *Persuasive games: The expressive power of videogames*. MIT Press.

Cassar, R. (2013). Gramsci and games. *Games and Culture*, 8(5), 330-353.

Dunne, A., & Raby, F. (2013). *Speculative everything: design, fiction, and social dreaming*. MIT press.

Flanagan, M., & Nissenbaum, H. (2014). *Values at play in digital games*. MIT Press.

Holland, D. C., Lachicotte Jr, W., Skinner, D., & Cain, C. (2001). *Identity and agency in cultural worlds*. Harvard University Press.

Literat, I., Chang, Y. K., & Hsu, S. Y. (2020). Gamifying fake news: Engaging youth in the participatory design of news literacy games. *Convergence*, 26(3), 503-516.

Malpass, M. (2017). *Critical design in context: History, theory, and practices*. Bloomsbury Publishing.

Mawasi, A., Aguilera, E., Wylie, R., & Gee, E. (2020). Neutrality, "new" digital divide, and openness paradox: equity in learning environments mediated by educational technology. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020*, Volume 3 (pp. 1617-1620). Nashville, Tennessee: ISLS.

Medin, D. L., & Bang, M. (2014). *Who's asking?: Native science, western science, and science education*. MIT Press.

Parekh, P., Gee, E., Tran, K., Aguilera, E., Cortés, L. E. P., Kessner, T., & Siyahhan, S. (2019). Water, levels, and loops: Evidence of teens' emerging understanding of systems while designing games. In *Proceedings of FabLearn 2019* (pp. 73-80), ACM Digital Library.

Salen, K., Tekinbaş, K. S., & Zimmerman, E. (2004). *Rules of play: Game design fundamentals*. MIT press.

Sengupta-Irving, T., & Vossoughi, S. (2019). Not in their name: re-interpreting discourses of STEM learning through the subjective experiences of minoritized girls. *Race, Ethnicity and Education*, 22(4), 479-501.

Takeuchi, M. A., Sengupta, P., Shanahan, M. C., Adams, J. D., & Hachem, M. (2020). Transdisciplinarity in STEM education: a critical review. *Studies in Science Education*, 1-41.

The New London Group. (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review*, 66(1), 60-93.

Thumlert, K., de Castell, S., & Jenson, J. (2018, October). Learning through game design: A production pedagogy. In *Proceedings of the 12th European Conference on Game-Based Learning.* Academic Conferences Ltd

Tzou, C., Meixi, Suárez, E., Bell, P., LaBonte, D., Starks, E., & Bang, M. (2019). Storywork in STEM-Art: Making, materiality and robotics within everyday acts of indigenous presence and resurgence. *Cognition and Instruction*, 37(3), 306-326.

Vakil, S. (2014). A critical pedagogy approach for engaging urban youth in mobile app development in an after-school program. *Equity & Excellence in Education*, 47(1), 31-45.

Vakil, S., & Ayers, R. (2019) The racial politics of STEM education in the USA: Interrogations and explorations, *Race, Ethnicity and Education*, 22:4, 449-458, DOI: 10.1080/13613324.2019.1592831

Vakil, S., de Royston, M. M., & Kirshner, B. (2016). Rethinking race and power in design-based research: Reflections from the field. *Cognition and Instruction*, 34(3), 194-209.

Vossoughi, S., & Gutiérrez, K. D. (2016). Critical pedagogy and sociocultural theory. In Esmonde, I., & Booker, A. N. (Eds.), *Power and privilege in the learning sciences* (pp. 157-179). Routledge.

Vossoughi, S., & Vakil, S. (2018). Toward what ends? A critical analysis of militarism, equity, and STEM education. In Ali, A. I., & Buenavista, T. L. (Eds.) *Education at War: The fight for students of color in America's public schools* (pp. 117-140). Fordham University Press.

Community of Practice in a Physics Department: Double-Majored Students' Perspective

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Abstract: This paper explores undergraduate students' experiences in a physics department compared to the departments of their second majors (education and mathematics) in the light of the community of practice framework. We interviewed double-majored students at an urban US masters-granting institution to examine their sense of community in each department. We found that while the community of practice is strongly established within the physics department, students feel a weaker sense of community in their secondary departments, despite taking a similar quantity of classes in the other departments. The physics department has a strong community in part because of the activities of physics faculty: group work in classes, accessible research, and participation in scientific events. In this paper, we present narrated experiences of two case studies where we examine the nuances of their sense of community and the factors that strengthen the perceived physics community.

Introduction

The connection between students and related communities can have a long-term effect on professional development and persistence in a discipline (Hunter et al., 2007; Irving & Sayre, 2014). Understanding how students perceive the community that they belong to is an essential part of curriculum development aiming to increase students' sense of belonging and participation in the community. As a part of such projects carried out in an urban institution, this work attempts to understand how students perceive their communities through their learning and working experiences.

We investigate students' sense of community using communities of practice (CoP). A CoP is formed by a group of people who share similar interests and foster those interests through shared activities (Wenger, 1998). An authentic community where learners share goals, skills, values, and other knowledge can increase achievements through interaction between members (Davidson & Kroll, 1991). Physics education literature has used the CoP framework in both formal and informal learning contexts to analyze the process by which learning assistants develop their physics identity (Close et al., 2016), examine identity development of upper-division physics students (Irving & Sayre, 2014), or study physics identity development outside of academic setting through informal physics programs (Fracchiolla et al., 2020).

Through two case studies of students with two majors at one institution, we claim that they perceive their primary department (physics) as a stronger community than their secondary departments (mathematics and education). The main factor that makes physics a strong departmental CoP is the faculty's pedagogical choices. They intentionally design courses which focus on collaborative group work, and encourage students to be a part of the community through interactive events and activities, especially through research. We support our claim with narrated analysis in the light of the CoP framework. Implications of this study include identifications and better understandings of factors that support students' sense of belonging to the community, which can lead to better future design for curriculum development.

Theoretical framework

Wenger defines CoP as groups of people who share the same interest in a topic through which they will learn and do things together to make their interest grow. According to Lave and Wenger (Lave & Wenger, 1991), the three main characteristics of CoP are: joint enterprise, mutual engagement, and shared repertoire. (i) Joint enterprise is a set of shared interests, goals, and passions that members of the community collectively engage in and hold each other accountable to. The topics of interests can be renegotiated by members as long as the commitment to sharing them remains. (ii) Mutual engagement refers to the set of interactions that members do together such as discussions, resource sharing, and relationships building which enable them to learn from each other. (iii) Shared repertoire refers to routines, tools, ways of doing things, etc. developed through mutual engagement. A group must have these three core characteristics to be considered a CoP. While all CoP have the same characteristics, they can hold a variety of forms: some are large and broad such as the community of physicists in the United States, while some are small and local such as a research group at a university. An individual can participate in several CoP concurrently. For example, a female physics student can be an active member of a cosmology research group and an active member of a women in physics group. Active participants in different CoP have opportunities to learn and develop their interests within each community. A CoP may involve many participants who can be either peripheral (newcomers) or central (old-timers). Through mutual engagement, over time peripheral participants may build up their own trajectory towards being central members through knowledge and skill development. Different communities might take different amounts of time in the trajectory to become central members (Irving & Sayre, 2014).

This paper focuses on examining a sense of community in the physics, education, and mathematics departments within one institution. For this purpose, we center the mutual engagement component of the CoP framework without deeply considering joint enterprise and shared repertoire. All students coming to each department share the goals of acquiring disciplinary knowledge and skills, and mapping their long-term career trajectories. In addition, in each community, there is a set of common norms within the community to communicate and construct knowledge. For example, students and faculty in the physics department share a similar interest in enhancing our understanding of how the universe works (joint enterprise). The physics community communicates through mathematics and computer programs to construct their knowledge (shared repertoire). With that joint enterprise and shared repertoire assumed across departments, the goal of this study is not to determine what set of activities constructs a CoP in all three characteristics of the framework. Instead, we highlight the mutual engagement component, and examine to what extent mutual engagement affects students' sense of belonging in their community. We present narrated analysis through the lens of CoP, mostly focusing on mutual engagement to show how students feel more connected to their primary department compared to their secondary departments.

Context and methodology

Participants in this study were recent alumni and current students from the same master-granting urban institution in the US. It provides a wide variety of programs with more than 130 undergraduate and 175 graduate programs. The physics, mathematics, and education departments each offer major, minor, and combined degree programs for undergraduate students. Beside courses, physics and mathematics faculty also actively engage in research in various subfields, and structure their research so that undergraduates can participate.

Our research conducted 20 interviews focusing on students' career planning, sense of purpose, and the resources and support provided by their institution that helped them plan their careers and explore their sense of purpose. For this paper, we focus on students' experiences in the physics department and how they perceive the departmental community. Because the influential characteristics of a particular community of practice can often be identified when contrasted with another, we examine the experiences of double majors in physics and other disciplines. While many of the participants are double majors, in this paper, we chose two case study subjects: Julia (physics and education) and David (physics and mathematics). Julia and David were chosen because they clearly articulated their contrastive experiences in their primary and secondary departments. Julia is satisfied in her career as a physics high school teacher three years after graduation. David is currently deciding what happens next after his upcoming graduation as he is interested in both teaching and research. Julia and David share a mutual passion for physics and teaching: they are both looking for ways to use their acquired knowledge and skills to help the younger generation develop their scientific and critical thinking skills.

Each 45-minute interview (conducted over Zoom) had two interviewers (one primary, one secondary) and one participant; the interviewers were unaffiliated with the urban institution. The analysis began by watching Julia and David's interviews to locate statements relating to their experiences in their primary and secondary majors. Then, we iteratively paid attention to nuances in discourse pertaining to mutual engagement such as doing research, building relationships with peers and faculty, attending conferences, etc. For example, statements such as "I feel connected, I have a good relationship with faculty" gave us evidence of a strong sense of belonging to the community. In contrast, "I don't really talk to advisors, we don't have great relationships" conveyed a weaker sense of belonging to the community. Discourse analysis helped us identify what students and faculty do together in each department to grow their interest in each field, leading us to compare and contrast students' sense of community among their affiliated departments. The analysis was collaboratively discussed until consensus was reached among 4 researchers.

Analysis and discussion

Sense of mutual engagement in the primary department

A central part of students' sense of community is the mutual engagement they feel in the classroom. Classes, both lecture and lab, included strong group work components and students *"[worked] through almost every assignment together"* (Julia). Collaborations among lab partners were highly encouraged and students relied on each other to *"develop your answer or talk about what was wrong, how to fix this"* (Julia). These collaborations are not haphazard: the faculty do significant work to encourage and support students' mutual engagement. Faculty *"[initiated] the group work when we were struggling together"* (Julia), and helped *"[establish] the relationship throughout the lab groups"* (Julia). These intentional choices made by faculty foster people to "*give each other academic support, and there is an interconnectedness"* (David) in the department, which creates a supportive learning environment around coursework in the community.

These collaborations continue outside the classroom and specific class activities. The physics department offers students opportunities to do research, invites students to attend seminars, and encourages engaging beyond the scope of a departmental community by "*sending useful things like career programs, conferences, just little things but give [students] opportunities to have a wide thought"* (David). Being engaged in doing research with faculty can increase students' interest and motivate students to pursue physics in the long term as they "*enjoyed the type of research that [physics faculty] were doing. That's part of why [students] stay in the field"* (David). In addition to doing research, attending a national STEM conference (SACNAS) or national professional association (SPS) promotes joining a communicative environment to exchange information with other peers outside the class since these events "*put a lot of networking experiences, colloquia, or advice in grad school, how to effectively communicate in conferences"* (David). This sense of support for connections to the outside world helps students feel more connected within the local physics community.

Another defining factor of mutual engagement in the physics community is the close relationship between faculty and students, in which faculty become strong sources of support for students for both academic and career guidance. For instance, *"[Dr. D, a prof] set an example as a woman in physics", "had a big influence"* on what Julia is doing right now, and also "*helped [her] to figure out direction*" in her life. Similarly, David talks with both Dr. D and the department chair about his future and career path, noting that the chair is "*really supportive and helpful thinking about the career"*. Physics faculty's encouragement of interactions inside the classroom, outside the classroom and at wider scientific events makes students perceive faculty as approachable and supportive of students' current and future success, which fosters a sense of close-knit community among students and faculty.

The mutual engagement among students and faculty in the physics department has been strongly influential in fostering a sense of community. Not only do faculty teach physics courses, but they also immerse departmental culture into their instructional practice such as encouraging students to work in groups, encouraging participation in research, and sending useful information for scientific events. Based on that, both Julia and David have constructed a strong sense of community in the physics department. As David says, "*[we] all know what everybody else is doing, [all] know what faculty are doing, what graduates are doing, it's interconnectedness. [They] acknowledged about each other, and anybody in that"*.

Comparison with the secondary departments

It is important to note that Julia and David are both central participants in the physics departmental community. In contrast to their primary major, both Julia and David feel disconnected from the communities from their secondary majors. A lack of assigned group work outside of the education classroom makes students work more individually without relying on classmates to complete assignments. *"Outside of the class, there was no group work to do so [it'd] be writing papers, doing reading"* (Julia, education). Secondly, *"[her] academic advisor wasn't helpful"* (Julia) in helping students think about career choices. Julia *"didn't talk to [her advisor] much besides choosing classes"* and *"didn't have a great relationship with them as [she] did with [her] physics professor"* (Julia). In addition to this, while the physics department sent out many emails about job opportunities, graduate school application, writing effective CVs, etc., *[students] have never received the same emails about conferences or useful tips of things"* (David) in mathematics to support their understanding of what is happening in the field. The disconnect between department, faculty and students can result in a lack of essential support in growing students' interest, which leads to a reduced sense of belonging to the field. Lastly, research in the mathematics department feels less available to students. Contrasting with physics where "*[people] do research, talk about research, in math it doesn't really happen"* (David). Instead, *"the department looked more focusing on coursework"* (David). These three factors -- low group work outside of the classroom; the disconnect between department, faculty and students; and inaccessible research -- explain why students feel less sense of community in their secondary departments.

We don't want to claim that the secondary departments lack supportive community. From our data, it could be that those other departments don't have a strong sense of community among students; but it could also be true that these two students are peripheral to the communities of practice in their secondary departments, and therefore do not feel a strong sense of community and mutual engagement. From these two case studies, we cannot distinguish these two interpretations of their secondary departments.

Alternative explanations

There may be other explanations as to why students are more likely to feel a stronger sense of community in the physics department. We provide such explanations and then argue back to defend the physics department as a strong CoP based on mutual engagement between faculty and students. Firstly, it could be true that the unique nature of physics requires collaboration. Physics solves many complicated problems; therefore students need to work together collaboratively to develop solutions which lead to a stronger sense of community. However, it is worthwhile to mention that math and physics are similar in nature. Both are STEM disciplines that require a significant amount of problem solving, and math is the language through which physics is done. Hence, the content itself in each discipline is not a discerning attribute of the CoP development. Secondly, the small size of the classroom itself might be a factor why everyone knows each other. However, at this institution, physics and mathematics classes are similar in size, and physics and education also *"have about the same size hmm education cohort and physics cohort"* (Julia). Size of the classroom, therefore, does not directly affect the connection among members in the community. Overall we suggest that a strong sense of the physics community from Julia and David is not affected by the content of the field or the size of the classroom, but rather affected by pedagogical choice of physics faculty and how faculty merged departmental culture into instructional practice.

In this paper, Julia and David feel a stronger community connection in their primary department (physics) than their secondary departments (education and mathematics) because of the activities that faculty and students mutually do together. However, our claim is based on perspectives of two students only which may not fully reflect the whole culture of each department. Future work will need to expand data and look more into other components of the CoP framework in order to examine whether our claim still holds or not.

Conclusion

These double-majored students have a strong sense of community in the physics department, but not in their education and math departments. From our narrated analysis, we conclude that the content of each discipline or classroom size do not affect the establishment of CoP. The strong physics community mainly results from the pedagogical choices of physics faculties who merge the departmental culture into their instructional practice to support students' engagement in the community such as strongly encouraging group work, making research approachable, and encouraging students to attend scientific events. A strong perceived physics community enables students to engage in authentic practices of a physicist which can result in physics identity development (Close et al., 2016; Irving & Sayre, 2014). Our findings suggest that departmental culture should be structured to provide students with more opportunities to connect with classmates outside of the classroom, to work with faculty through research, and to broaden the relationships with people in the field by attending conferences. Future work will continue to examine the sense of community of other participants as well as explore how students prepare for future careers based on their sense of community in the physics department.

References

Close, E. W., Conn, J., & Close, H. G. (2016). Becoming physics people: Development of integrated physics identity through the Learning Assistant experience. *Physical Review Physics Education Research*, *12*(1), 010109. https://doi.org/10.1103/PhysRevPhysEducRes.12.010109

Davidson, N., & Kroll, D. L. (1991). An Overview of Research on Cooperative Learning Related to Mathematics. *Journal for Research in Mathematics Education*, *22*(5), 362–365. https://doi.org/10.2307/749185

Fracchiolla, C., Prefontaine, B., & Hinko, K. (2020). Community of practice approach for understanding identity development within informal physics programs. *Physical Review Physics Education Research*, *16*(2), 020115. https://doi.org/10.1103/PhysRevPhysEducRes.16.020115

Hunter, A.-B., Laursen, S. L., & Seymour, E. (2007). Becoming a scientist: The role of undergraduate research in students' cognitive, personal, and professional development. *Science Education*, *91*(1), 36–74. https://doi.org/10.1002/sce.20173

Irving, P. W., & Sayre, E. C. (2014). Conditions for building a community of practice in an advanced physics laboratory. *Physical Review Special Topics - Physics Education Research*, *10*(1), 010109. https://doi.org/10.1103/PhysRevSTPER.10.010109

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation* (p. 138). Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

Wenger, E. (1998). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press. https://doi.org/10.1017/CBO9780511803932

Reconciling Structuring Collaboration and Student Agency

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Abstract: Advancement in supporting knowledge construction creates deeper problems on how to reconcile structuring collaboration with promoting student agency. In order to provide a case study for these problems, we used an instructional method, the "Knowledge Constructive Jigsaw", as an external macro-script in a science lesson and analyzed pre-, post-lesson answers and a 15-minute discussion by three seventh graders. We captured knowledge sharing and individual construction by adapting a framework, a "function mechanism hierarchy", and a dual-unit analysis at a group and individual level. The results indicate the reconciliation, that is, the students shared knowledge pieces while constructing their own knowledge, for which a coupling between the coarse-grained script and well-organized materials appeared responsible.

Introduction

As the learning sciences advances its refinement in supporting collaborative knowledge construction, it poses deeper problems on how to reconcile *structuring collaboration* with *promoting student agency*. This paper provides a case study to show that structuring collaboration towards the teacher's expected outcome does not necessarily hinder but promotes student agency, or the self-organizing character of knowledge construction. Along with the conference theme of "reflecting the past and embracing the future," we reflect upon a discussion between two approaches of scripted collaboration and Knowledge Building (Bereiter et al., 2017), provide our case study wherein three junior high school students deepened their understanding in their own way and also successfully shared knowledge as a group in a science lesson, and examine which elements of lesson design are responsible for reconciling the two aspects of knowledge construction for future practices.

In the discussion above, experts in Knowledge Building welcomed a change in the views of *scripts* as *rigid, prescriptive cognitive structures* to *flexibly adaptive group supports* for facilitating the use of learners' internal scripts, while experts in script theory adopted more socio-cognitive views into classroom learning (Vogel, Wecker & Kollar, (2017). Thus, the notion of flexibility, which Dillenbourg & Tchounikine (2007) once analyzed conceptually, needs to be examined in actual socio-cognitive processes. For example, setting a common task and providing materials may constrain learners' interactions into a corridor towards expected outcomes, but in reality, each learner may construct her or his own knowledge through the interaction. In order to reveal such an intricate relationship between constraint and self-organization, we need to collect data from a lesson wherein learners are motivated to share knowledge to achieve a common goal and analyze learning processes by mapping their writings and utterances onto a knowledge framework and using both units of analysis of the individual and the group.

Instructional method: Knowledge Constructive Jigsaw

We take group learning in the lesson conducted by the "Knowledge Constructive Jigsaw" (hereafter "KCJ") method (Miyake, 2013) as an example. The KCJ consists of five learning activities: (1) writing an answer to the day's given problem, (2) an expert-group activity which allows each individual learner to accumulate pieces of knowledge relevant in solving the problem, (3) a jigsaw-type activity where learners from different expert groups get together to exchange and integrate the pieces of knowledge and form an answer, (4) a crosstalk activity where the learners exchange their ideas for solutions, involving the entire class, and (5) writing down an individual answer again to the same problem. This method distributes knowledge among the learning partners in Step 2 for integration in Step 3; however, it places greater emphasis on the role of a shared "problem" for knowledge construction by adding Steps 1 and 4, as well as that of the conceptual changes of each individual by adding Steps 1 and 5. The method is considered to be an *external macro-script* like the Jigsaw (Dillenbourg & Jermann 2007), and we do not predict how the script is enacted in a particular situation as it is coarse-grained enough to allow learners' self-organization of knowledge and discussion.

Analytical method: Function-mechanism hierarchy and dual-unit analysis

The series of activities above enables us to compare students' dialogues with writings: for example, the former in the jigsaw activity of Step 3 with improvements in the latter from Step 1 to Step 5. We bring in two analytical methods to take advantage of this feature: a "function-mechanism hierarchy (FMH)" (Miyake, 1986) and a dual-unit analysis. The FMH is a hierarchy that consists of two types of knowledge: function and mechanism, which is suitable in clarifying the detailed structure of the lesson and knowledge construction by the learners. The dual-unit analysis is to analyze the same data using two units of analysis: the individual and the group. Saito and Miyake (2011) demonstrated that, when analyzing a collaborative process sequentially, the selection of knowledge pieces, time of reference and order vary from learner to learner; however, when analyzing it in an aggregated way, most of the pieces are referred to by most learners while the rest are referred to by only a few learners.

Research questions

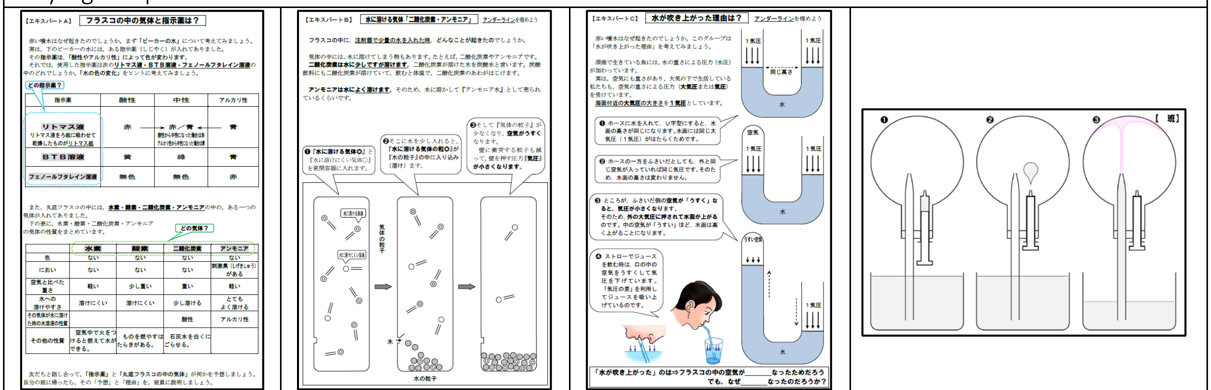
A combination of the instructional method and the two analytical methods enables us to capture a convergent, knowledge-sharing aspect constrained by the macro-script and a divergent, individualistic knowledge-construction aspect that goes beyond what is given in the situation. We predict that a set of the "problem (jigsaw task)" and "expert materials" strongly constrains students' knowledge sharing, especially when knowledge pieces are explicitly presented and hierarchically organized, while the students differ from each other in knowledge construction by connecting and weighing particular pieces, especially when fewer prompts for discussion or scaffolds for writing are presented, that is, *unscripted*. Thus, our first research question is, "Are the knowledge pieces of expert materials successfully shared among the three students through the jigsaw activity?" and the second one is, "Do the three students differ from each other in the number of references to knowledge pieces and relation-making among them both during the jigsaw conversation (Step 3) and post-lesson writings (Step 5)?"

Method

A veteran junior high school teacher, a partner teacher in the authors' project, conducted a KCJ lesson in Grade 7 science ("Generation and the nature of gas") for 19 students. The teacher demonstrated an experiment in which a transparent solution in a beaker was vigorously pumped up through a glass tube into an upside-down, sealed, round-bottom flask, which turned red when he injected a small amount of water into the flask with a syringe. He posed the day's problem and each student wrote his or her answer on an *unscripted* worksheet. Then, the students engaged in the activities of Step 2 through Step 4 in 50 minutes. The teacher prepared materials for the expert activity and a whiteboard for the jigsaw activity, from which he expected the answer below (Figure 1).

We handed out a headset microphone and IC-recorder to each student, collected voice data, and transcribed it by hand for the analysis. We also collected students' answers before and after the lesson to analyze whether they referred to the points shown in Figure 1. Out of six jigsaw groups we chose one group which consisted of Alpha, Bravo and Charlie (assumed names which mean Alpha was assigned expert material A, Bravo for B, and Charlie for C). We chose this group since they proposed high-quality explanations at the level of

Day's given problem "How did this red fountain occur? What is the mechanism?"



A: Gas and indicator | B: Solution in water | C: Solution blow-up | Whiteboard for the Jigsaw activity

An expected answer should include the four points below:

1. At the onset, "ammonia gas" was injected into the flask; "phenolphthalein solution" into the beaker (Material A).
2. When the water was injected into the flask with the syringe, the ammonia gas, being very soluble, melted into the "ammonia water" and the air pressure in the flask was reduced (B).
3. When the pressure in the flask was reduced, the water in the beaker pushed by the outside atmospheric pressure rose up the glass tube and a fountain occurred (C).
4. Since a phenolphthalein solution was in the water, entering the flask from the beaker, it reacted with the "alkali" of the ammonia water and the fountain became red (A).

Figure 1. Expert materials, worksheet for the jigsaw-type activity and expected answer for the targeted lesson.

molecular motion in Step 4 and all of them wrote the four points in the expected answer in Step 5.

Figure 2 shows the FMH for the lesson. The functions are shown in circles as F, indicating knowledge pieces of facts and phenomena. The mechanisms are indicated in rectangles as M, describing explanations of "how and why that happens" by connecting the functions with each other. The mechanism of the red fountain (F0-1) can be explained by the combination (M1) of the water injection (F1-1), ammonia gas (F1-2) and phenolphthalein solution (F1-3). Yet, if someone questions why the transparent materials turned red, the answer requires another level of explanation such as the chemical one at level 2. Likewise, the function at level n requires the mechanism at level n+1 in a repeated way. By mapping pieces of information contained in each expert material onto the hierarchy with bold alphabet letters A, B and C (when it was implied, they were indicated by letters in parentheses), you can see that most knowledge pieces were explicitly presented and hierarchically organized with each other.

We also analyzed the students' pre and post lesson answers and the 15-minute jigsaw dialogues using FMH: first, dividing each sentence into *content word* and *function word* (connectives, pronouns); and second, mapping the former on the framework as referring to the knowledge pieces and the latter as relation-making among the pieces. The total number of utterances of the group was 596.

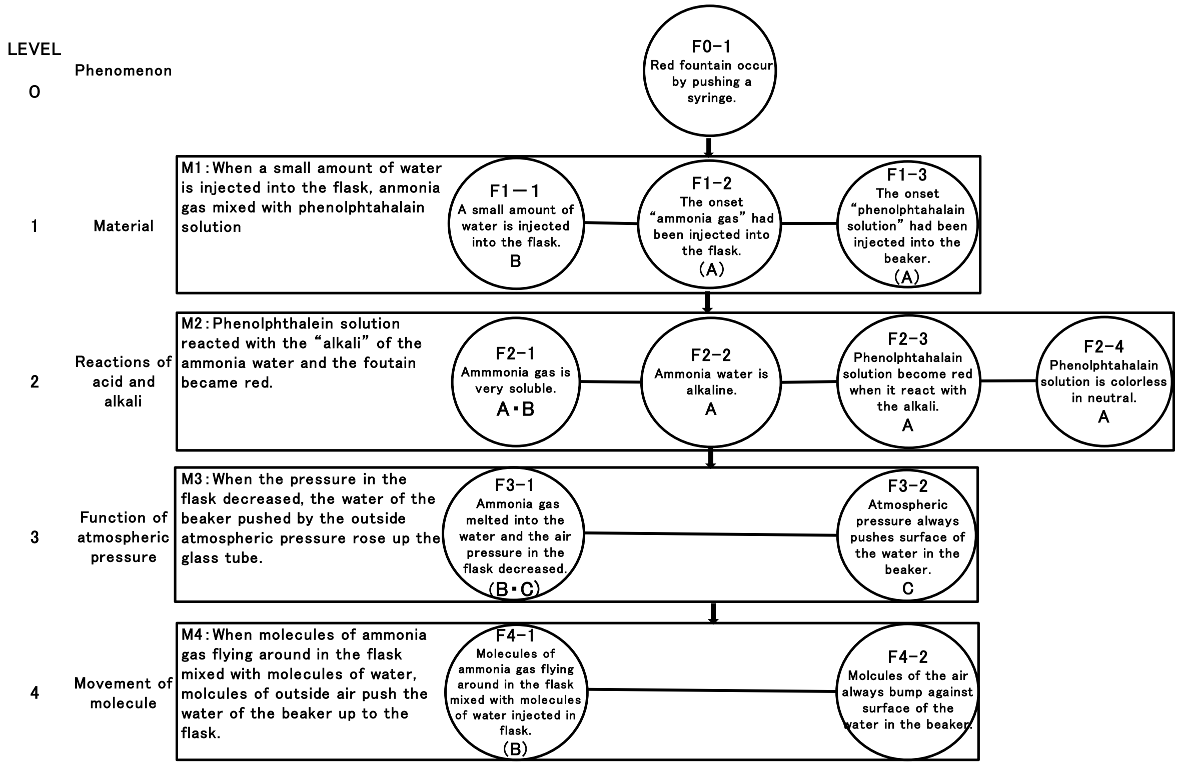


Figure 2. Function-mechanism hierarchy for the red fountain problem

Results and discussion

When we analyzed the pre- and post-lesson (Steps 1 and 5) answers of 12 students whose worksheets were collected, we found that their coverage rate of the four points in the expected answer improved from 3.2% in Step 1 to 87.5% in Step 5. Despite the fact that the lesson was conducted at the beginning of the unit and the students knew little about the content, the improvement was big enough to conclude that the class achieved the goal.

Table 1 shows the result of the detailed analysis of the target group. The column "Knowledge" indicates knowledge pieces shown in Figure 2, and the columns of the "Pre-lesson answer", "Jigsaw activity" and "Post-lesson answer" represent whether each student referred to, repeatedly referred to, or linked each piece with another. If we look at Table 1 in an aggregated way, eight out of 12 knowledge pieces were shared among the three students through the jigsaw activity, and seven out of the eight pieces referred to were utilized in the post-lesson answers. Considering the fact that they referred to only one knowledge piece in the pre-lesson answers, we can say that all the members improved their understanding towards a common goal by sharing the knowledge pieces. Taking a closer look at Table 1, however, individual differences are revealed in both the jigsaw activity and post-lesson answer. Alpha referred to nine knowledge pieces during the jigsaw activity and constructed her post-lesson answer by connecting the pieces about the gas and indicator (Levels 1 and 2); Bravo referred to nine pieces and constructed her explanation around two points such as the injection of water (F1-1) and the reduction of pressure (F3-1, F4-1); Charlie referred to ten pieces and broadened connections across all levels in his post-lesson answer.

The results indicate that while the knowledge pieces of the expert materials were successfully shared among the students through the jigsaw activity, they differ from each other in the number of references to knowledge pieces and relation-making among them from the jigsaw activity to post-lesson answers, as if they had walked down the corridor towards expected outcomes while constructing their own knowledge through interaction with others. It is implied that the constraint caused by the macro-script makes diversity and agency flourish in finer levels of knowledge construction. In this particular lesson, a coupling between well-organized materials and coarse-grained scripts without strict control or guidance appeared responsible for reconciling structuring collaboration with student agency. Yet, we do not intend to generalize this result from only one case, especially because another case under analysis suggests that a pattern of role exchange among member influences both the convergent and divergent knowledge construction process. Rather, we would like to claim that not only controlled experiments but also in-depth analyses of knowledge construction processes contribute to clarifying the intricate relations between constraint and self-organization and designing lessons for deeper learning.

Table 1: Reference and link of knowledge of three students in the lesson

Knowledge	Pre-lesson answer			Jigsaw-type activity			Post-lesson answer		
	Alpha	Bravo	Charlie	Alpha	Bravo	Charlie	Alpha	Bravo	Charlie
F1-1(B)	○	○	○	○+	◎+	○+	○	○+	◎+
F1-2(A)	—	—	—	◎+	◎+	◎+	◎+	○+	○
F1-3(A)	—	—	—	◎+	◎+	◎+	◎+	○+	○+
F2-1(A,B)	—	—	—	◎+	◎+	◎+	◎+	—	◎+
F2-2(A)	—	—	—	○+	◎+	◎+	◎+	○+	○+
F2-3(A)	—	—	—	◎+	◎+	◎+	○+	○+	○+
F3-1(B,C)	—	—	—	○+	◎+	◎+	○+	◎+	○+
F3-2(C)	—	—	—	○+	○+	◎+	○+	○+	◎+
F4-1(B)	—	—	—	—	◎+	○	—	◎+	◎+
F2-4	—	—	—	◎+	—	—	○+	○	○+
F0-1	—	—	—	—	—	—	—	—	—
F4-2	—	—	—	—	—	—	—	—	—

○ Reference, ◎ Repeated reference, — No reference, + Link

References

Bereiter, C., Cress, U., Fischer, F., Hakkarainen, K., Scardamalia, M., & Vogel, F. (2017). Scripted and unscripted aspects of creative work with knowledge. In B. K. Smith, M. Borge, E. Mercier & K. Y. Lim (Eds.), *Making a difference: Prioritizing equity and access in CSCL, 12th International Conference on Computer Supported Collaborative Learning (CSCL) 2017, Volume 2* (pp.751-757). Philadelphia, PA: International Society of the Learning Sciences.

Dillenbourg, P., & Jermann, P. (2007). Designing integrative scripts. In F. Fischer, I. Kollar, H. Mandl, & J. Haake (Eds.), *Scripting computer-supported collaborative learning. Cognitive, computational, and educational perspectives* (pp. 275–301). New York: Springer.

Dillenbourg, P., & Tchounikine, P. (2007). Flexibility in macro-scripts for computer supported collaborative learning. *Journal of Computer Assisted Learning, 23*(1), 1-13.

Miyake, N. (1986). Constructive interaction and the iterative process of understanding. *Cognitive Science, 10*, 151-177.

Miyake, N. (2013). Case report 5: Knowledge construction with technology in Japanese classrooms (CoREF). In P. Kampylis, N. Law & Y. Punie (Eds.), *ICT-enabled innovation for learning in Europe and Asia* (pp.78-90). European Commission, Joint Research Centre.

Saito, M., & Miyake, N. (2011). Socially constructive interaction for fostering conceptual change. In H. Spada, G. Stahl, N. Miyake & N. Law (Eds.), *Connecting Computer-Supported Collaborative Learning to Policy and Practice: CSCL2011 Conference Proceedings, Volume I* (pp.96-103). Philadelphia, PA: International Society of the Learning Sciences.

Vogel, F., Wecker, C., Kollar, I., & Fischer, F. (2017). Socio-cognitive scaffolding with computer-supported collaboration scripts: A meta-analysis. *Educational Psychology Review, 29*, 477-511.

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International Society of the Learning Sciences

Probing Biology Teachers' Disciplinary Literacy through their Adaptation of a Research Article

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Abstract: Disciplinary literacy framework is concerned with the unique skills and strategies of reading and writing in a specific discipline. Adapted primary literature (APL) refers to an educational genre specifically designed to enable the use of scientific research articles in high school. APL articles represent the structure, linguistic norms, epistemic standards and content found in research articles, and can therefore be used to promote disciplinary literacy. However, very little is known about how teachers adapt research articles, or how they justify decisions they make regarding these adaptations. In this study we analyzed in-service teachers' justifications for decisions they made when adapting a scientific research article for their students, in the context of a methods course. Our research provides a "window" into teachers' understanding of disciplinary literacy aspects, and provides critical insights that can be further used to develop better teacher professional development programs and teacher education.

Introduction

Reading scientific texts has become accepted as one of the major required practices to become literate in science (NRC, 2012). However, although current learning standards foreground advanced literacy learning in the subject areas (e.g., the United States *Common Core State Standards*), the majority of students do not progress much beyond basic reading skills (Goldman et al., 2016). Moreover, the vast majority of texts that students read in science classroom are from textbooks, popular research from the media or review articles from the internet. These texts often do not reflect the core attributes of scientific reasoning and are antithetical to the epistemology of authentic science (Ariely et al., 2019; Chinn & Malhotra, 2002).

Disciplinary literacy (Shanahan & Shanahan, 2008) emphasizes the way of thinking in a discipline, including what is important to pay attention to, what counts as evidence for an argumentation, what level of confidence the field has in the knowledge it produces, how texts are organized, constructed, etc. (Shanahan & Shanahan, 2020; Shanahan & Shanahan, 2008). These practices are inherently epistemic, based on ideas about what kinds of knowledge are valued (Duncan et al., 2018).

There are many challenges in integrating disciplinary literacy skills into science classrooms. For example, many science teachers know the content of their disciplines, but they may know only implicitly its literary processes (Hynd-Shanahan, 2013). As a result, many teachers lack the knowledge about the vital role that literacy plays in enhancing science learning, and they fail to mentor their students in the necessary literary practices that would help them read in science (Osborne, 2014). Teachers need a sophisticated understanding of the nature of scientific texts, as well as how they are used authentically by the scientific community. Therefore, effective professional development is needed to help teachers learn and refine the pedagogies required to teach these skills (Darling-Hammond et al., 2017).

Engaging with adapted primary literature (APL) to promote disciplinary literacy

Adapted Primary Literature (APL) refers to an educational genre specifically designed to enable the use of scientific research articles in high school (Falk et al., 2008). PSL articles are adapted to match students' knowledge, reading abilities and cognitive skills, while retaining the authentic characteristics of the PSL article (Yarden et al., 2015), and the scientific language (Ariely et al., 2019). Since APL articles represent the structure, linguistic norms, epistemic standards and content (arguments, claims and evidence) found in PSL articles (Ariely et al., 2019; Yarden et al., 2015), these articles can be used to promote important aspects of scientific literacy that are harder to achieve using other text genres such as textbooks or popular articles.

Standards in the US and elsewhere require that science teachers shift the ways in which they support their students in learning literacy practices to a more disciplinary approach (NRC, 2012). However, there is little research about secondary science teachers' understanding of disciplinary literacy, or how they interpret and make sense of the epistemic and linguistic features of PSL articles. Research on pedagogies aimed at promoting advanced literacy skills are scarce, and mostly focused on ways in which teachers integrate disciplinary approaches and activities in their classrooms (Koomen et al., 2016). Moreover, while research on APL with students is very promising, there is hardly any research on teachers' engagement with APL.

Research goals and questions

Understanding teachers' justifications for decisions they make in the adaptation process is important because it illuminates what teachers notice, value, see as important for students to learn. Teachers' justifications may therefore provide insights into teachers' understanding of disciplinary literacy, and may shed some light on the challenges they face when asked to implement disciplinary literacy practices in their instruction. This knowledge is crucial for developing interventions for teachers that can help them foster disciplinary literacy among their students. Therefore, in this study we asked: What kinds of justifications do in-service biology teachers make when adapting a scientific research article for their students?

Methods

Research context

The context of this study is a four-weeks unit (8 hours) that is part of a 26 hours university level course for in-service biology teachers entitled "Science Literacy". The course aims to promote teachers' pedagogical and disciplinary knowledge by interacting with, and learning about disciplinary texts. In the 8 hours unit teachers were asked to adapt a PSL article for their students.

The article selected for adaptation was a short research article, published in a medical scientific journal. The article deals with the effect of pomegranate juice on serum Angiotensin Converting Enzyme (ACE) activity, and on systolic blood pressure in human patients (Aviram & Dornfeld, 2001). We found this article suitable for the teachers to adapt because the concepts and processes discussed in the article are largely aligned with the current high school biology curriculum. In addition, the article is short and relatively simple, allowing the teachers to adapt it within the time limits of the course.

Data collection and analysis

Twenty-one in-service high school biology teachers (with 5-20 years teaching experience) adapted the PSL article. All the teachers taught at public schools from various locations in Israel, and had a B.Sc. degree in biology. The writing sessions were collaborative in groups of 2-3 teachers (9 groups in total). The teachers were encouraged to reflect on their justification for changes they made to the article (omissions, additions), but also on justifications for leaving certain elements of the article as they were.

We collected a total of 265 justifications of features of the PSL text that teachers chose to change or retain in the adaptation process in their written artifacts at the end of the course. We classified the justifications according to their type to four main categories using a grounded analysis approach. A subset of the data (~20%) was validated by two additional researchers. The agreement on the categorization at the beginning was ~82%, and after discussion reached ~93%. Further elaboration on the categories is given in the Results section.

Results

The teachers' justifications included considerations along four dimensions: pedagogical, epistemological, content-based, and structural. We provide definitions and proportions of the categories, and examples of teachers' actual justifications in Table 1.

We found that out of all justifications (n=265), the majority (64.1%) were pedagogical, about a quarter (24.2%) were epistemological, and a few were content based or structural (8.3% and 3.4%, respectively). Since pedagogical and epistemological justifications are focused on students' needs and abilities (and less on technical features as was the case of structural or content-based justifications), we focus our analysis on these justifications.

Interestingly, we found that the majority of pedagogical justifications were in support of a *change* in the article; adding, omitting or changing the ways in which the information is presented in the original article. However, the majority of epistemological justifications were in support of *retaining* the way information was presented in the original article. This reveals a potential tension between pedagogical and epistemological justifications; in a sense one may come at the expense of the other. This tension was often apparent during the adaptation process as shown in the following examples.

In some cases, the teachers were less attentive to important epistemological features. For instance, rebuttals have an important role in argumentation, and in the PSL article chosen for this study, the rebuttals provided alternative interpretations of the results, and pointed out some of the research limitations. However, many teachers chose to omit rebuttals that appeared in the original article, and to leave only conclusions and evidence that support the claims made in the article, in order not to confuse the students' or to reduce the cognitive load (a decision with pedagogical justifications). In other cases, the teachers saw the importance of transparency of methods or results (a decision with epistemological justifications), but were less concerned with accurate and nuanced reporting of the methods or results. For instance, they often chose to remove important information about the sample, or to remove error bars, standard deviations, or to completely omit "messy" results that were less conclusive, in order to make the data representation less complicated and more straightforward for their students to interpret (a decision with a pedagogical justification).

We also found different distributions of pedagogical and epistemological justifications in different article sections. Although there were high proportions of pedagogical justifications in all sections, in the *Discussion* and *Methods* sections there were relatively more *epistemological* justifications (44% and 30% respectively), compared to the Introduction and Results sections (16% and 12% respectively).

Table 1: Categories of teachers' justifications when adapting an article for students

Categories of justifications (n=265)		**Examples (justifications appear in italics) & proportions out of all justifications**	
Pedagogical	Justifications focus on students learning needs and abilities. This includes justifications for adapting the text to match cognitive and reading abilities, and prior knowledge, creating learning opportunities, and promoting students' interest and motivation.	We omitted any information about polyphenol concentrations, *because we want to reduce the cognitive load.* We added a question about the graph *so that students could practice graph analysis.*	64.1%
Epistemological	Justifications focus on using the article as a model for learning about the scientific epistemology and reasoning. This includes justifications for including reliable processes, transparency of information presented in the text and different aspects of the nature of science.	We kept the information that the effect of the pomegranate juice may be secondary [to the antioxidant properties of pomegranate juice]. *It is important that students will be exposed to the uncertainty presented in the article, and that they get to know articles in which not everything is proven and certain.*	24.2%
Content-based	Justifications focus on the content of the article to create coherence and continuity within the text.	We omitted any information about rampiril [ACE inhibitor] *because it doesn't connect directly to the experiment presented in the [APL] article.*	8.3%
Structural	Justifications focus on the texts' structure, for technical reasons.	We separated the results from the discussion, *because this is the acceptable structure of a scientific article.*	3.4%

Discussion

In this study we provide a novel analysis of teachers' justifications for decisions they made when creating an APL article for their students in the context of a course assignment focused on promoting teachers' disciplinary literacy and the use of disciplinary texts in biology classrooms.

Our analyses show that teachers had two main types of justifications when it came to their teaching goals in the context of engaging students with a disciplinary text. First, pedagogical justifications, the majority of the teachers' justifications were pedagogical, aimed at adapting the text to match the students' abilities and needs. Second, epistemological justifications, which were aimed at providing opportunities to learn and reflect on different epistemological aspects of science, including the nature of reasoning and reliable processes. It should be noted, that the teachers in this study were explicitly taught about the epistemology of science and about the communicative role of different scientific text genres, which allowed them to create an APL and take epistemological considerations into account.

The fact that the teachers had many pedagogical justifications may not be surprising. However, a quarter of their justifications were epistemological, and although they were much less frequent than pedagogical ones, we believe that teachers' awareness of and attention to epistemological considerations is important and encouraging. In addition, the fact that the *Discussion* and *Methods* sections in the adapted article had relatively more epistemological justifications suggests, that these sections that are usually under-represented in classroom texts, may provide the teachers opportunities for integrating more epistemic and disciplinary features that can be taught using the APL article.

The teachers' decisions and justifications throughout the adaptation process revealed a tension between pedagogical and epistemological justifications. On the one hand, teachers wanted the text to match their students' prior knowledge and abilities, therefore, they made numerous *changes* throughout the article. On the other hand, the teachers wanted the text to remain epistemologically authentic, so that it will reflect the scientific discourse and disciplinary norms. In this case the teachers *retained* different features in the article. This tension often resulted in teachers abandoning important epistemological features of research articles such as rebuttals for claims in the article, and data that are relevant to the argument and to the evaluation of evidence. This provides important insights about the role of different justifications when creating an APL article for students, and specifically pedagogical and epistemological ones. If all justifications were epistemological, we would end up with a PSL article, not suitable for high school students. If all justifications were pedagogical, the texts might end up resembling a textbook or a popular article. Therefore, the results from this study emphasize the importance of having *both justifications* when creating an APL article, and the need to help teachers develop useful heuristics for balancing them.

Implications

Although teachers were able to notice epistemic features that are essential for building the argument in the article, in some cases they were less attentive to these features, or to their epistemic role (for example, omitting rebuttals from the Discussion). In other cases, teachers valued some aspects of scientific epistemology more than others. These decisions that teachers make highlight the tension between pedagogical and epistemological justifications. Therefore, one implication for teacher education programs is to focus on helping teachers to understand the article's argumentative structure. This includes understanding the role of each section in building the argument, and the importance of epistemic considerations relevant to the scientific argument as they pertain to each section.

Another implication concerns the selection of text materials for science teaching. Shifting to a more disciplinary approach requires that teachers make disciplinary texts available to students, and provide guidance and interpretation of particular text features, and specific disciplinary reading strategies (Shanahan & Shanahan, 2020). Nevertheless, texts will only support disciplinary literacy to the extent that the texts are appropriate to the purpose and methods of the discipline. Thus, the content should meet the demands of the curriculum, but also include the specialized text features of the discipline (Shanahan & Shanahan, 2020). This calls for a careful consideration of texts and materials used for science education, which should include texts that reflect more authentically the scientific reasoning and communication.

References

Ariely, M., Livnat, Z., & Yarden, A. (2019). Analyzing the language of an adapted primary literature article. Towards a disciplinary approach of science teaching using texts. *Science & Education*, *28*(1–2), 63–85.

Aviram, M., & Dornfeld, L. (2001). Pomegranate juice consumption inhibits serum angiotensin converting enzyme activity and reduces systolic blood pressure. *Atherosclerosis*, *158*(1), 195–198.

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education*, *86*(2), 175–218.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development*. Palo Alto,CA.

Duncan, R. G., Chinn, C. A., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching*, *55*(7), 907–937.

Falk, H., Brill, G., & Yarden, A. (2008). Teaching a biotechnology curriculum based on adapted primary literature. *International Journal of Science Education*, *30*(14), 1841–1866.

Goldman, S. R., Britt, M. A., Brown, W., Cribb, G., George, M., Greenleaf, C., Lee, C. D., Shanahan, C., & Project READI. (2016). Disciplinary literacies and learning to read for understanding: A conceptual framework for disciplinary literacy. *Educational Psychologist*, *51*(2), 219–246.

Hynd-Shanahan, C. (2013). What Does It Take? The challenge of disciplinary literacy. *Journal of Adolescent & Adult Literacy*, *57*(2), 93–98.

Koomen, M. H., Weaver, S., Blair, R. B., & Oberhauser, K. S. (2016). Disciplinary literacy in the science classroom: Using adaptive primary literature. *Journal of Research in Science Teaching*, *53*(6), 847–894.

National Research Council (NRC). (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, D.C.; The National Academies Press.

Osborne, J. (2014). Teaching Scientific Practices: Meeting the Challenge of Change. *Journal of Science Teacher Education*, *25*(2), 177–196.

Shanahan, C., & Shanahan, T. (2020). Disciplinary literacy. In J. Patterson (Ed.), *The SATsuit and classroom practice: English language arts/literacy* (pp. 91–125). New York; College Board.

Shanahan, T., & Shanahan, C. (2008). Teaching disciplinary literacy to adolescents: Rethinking content area literacy. *Harvard Educational Review*, *78*(1), 40–59.

Yarden, A., Norris, S. P., & Phillips, L. M. (2015). *Adapted Primary Literature* (Vol. 22). Dordrecht; Springer Netherlands.

What Can Automated Analysis of Large-Scale Textual Data Teach Us about the Cultural Resources that Students Bring to Learning?

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Abstract: In this paper, we explore what the application of data science techniques to student-produced texts will reveal about the cultural resources that historically-othered learners bring to formal learning environments. We analyze 14,526 essays written by high school students in Brazil, present preliminary findings, and consider the ways this type of analysis might support teachers' design work in ways that are sensitive to variation in students' experiences.

Keywords: cultural resources, everyday practices, structural topic modeling, textual data

Introduction

Students bring many cultural resources to school with great potential to support participation in the cultural practices of academic disciplines (Nasir, Roseberry, Warren, & Lee, 2006). Exemplifying "cultural resources" are everyday bodies of knowledge, skills, and abilities (Moll, Amanti, Neff, & Gonzalez, 1992), ways of engaging in activities (Gutierrez & Rogoff, 2003), discourse practices (Lee, 1995), forms of reasoning (Nasir, 2005), values (Pea & Martin, 2010), and complex beliefs (Bang & Medin, 2010) developed in the richly generative cultural practices of the multiple communities in which students participate (Lee, Nasir, Pea, & de Royston, 2020). There is growing learning sciences consensus that educators should build upon their students' cultural knowledge, especially that of those historically marginalized for multiple facets of their identities. Building on cultural knowledge should prove to support academic learning (Nasir et al., 2006).

In an effort to counter deficit perspectives that other certain groups, a number of theoretical frameworks emerged in the 1990s, providing concepts and tools to support the design of robust learning environments that are responsive to variation in students' experiences. These include, for example, Culturally Responsive Teaching (Gay, 2018), Culturally Relevant Pedagogy (Ladson-Billings, 1995), Funds of Knowledge (FoK: Moll et al., 1992), and Culturally Sustaining Pedagogy (Paris, 2012). Despite differences in critical commitments and emphases, these frameworks share a consequential common assumption: that by recruiting the cultural resources that students have developed through everyday experiences, teachers will be better able to engage those students in learning in ways more immediately relevant to students' lives. A growing body of empirical research documents the connection between classroom practices that capitalize on historically-marginalized students' lived experiences and their engagement and learning across disciplines (Aronson & Laughter, 2016).

One of the most lasting frameworks, the FoK approach, pays special attention to families' social histories and labor activities, and provides a pragmatic toolkit for teachers to build knowledge of students' cultural resources and to then use that knowledge to support students' formal learning. The original approach suggests that teachers visit students and families and document in ethnographic observations and interviews the knowledge and skills available to students via households' everyday practices (González et al., 2005). Broader conceptualizations of FoK (Hogg, 2011), along with related frameworks like Third Space (Moje et al., 2004) and Funds of Identity (Esteban-Guitart & Moll, 2014) have sought to address some of the FoK approach's limitations, such as the exclusion from analysis of other communities in which students themselves choose to participate and the reliance on ethnographic analysis. While acknowledging that the idea is not new, Funds of Identity researchers have proposed using student-produced artefacts as a way of obtaining empirical information about students and then crafting connections between curricula and students' contexts (Llopart & Esteban-Guitart, 2018). Such use has most often been proposed in the context of a single classroom, using artefacts collected by individual teachers.

Here we explore whether a similar idea might be leveraged on a broader scale. Specifically, we examine what the application of data science techniques to student-produced texts reveals about the cultural resources that historically-othered learners bring to formal learning environments. While teacher-initiated qualitative-only approaches are an excellent option when feasible, it could serve the field well to complement such approaches with big-data-backed approaches so as to allow for investigation that is both broad and deep. As data collection technology evolves, there are increasingly many data sources available to researchers, and the insights drawn from such data can and should be used to support teachers in building knowledge about their students.

Taking up that project, we use Structural Topic Modeling (STM) to identify the topics (and extract essays associated with them) that students who have historically been marginalized in Brazilian society choose to write about. Following cultural-historical activity theory (Cole & Engestrom, 1993), we accept the premise that all acts of writing are situated, and that writers always recruit cultural resources that are made available to them to appropriate and internalize through their participation in the cultural communities to which they belong. While other pressures, such as the political, historical, and cultural context might partially shape students' choice of topic, those choices are still in large part driven by their interests, knowledge, and experiences. We then examine whether and how those topics differ geographically (state by state, urban vs. rural) and/or by year written. We chose those particular lines of comparison due to constraints on available demographic data, yet they are by no means the only potentially revealing ways of delimiting micro- and macro-communities. Variations in cultural resources are rooted in the practices of the multiple communities in which students participate – practices that are layered and vary over time. Ultimately, we ask: What insights about students' cultural resources can we gain from large-scale textual analysis?

Background

Brazil's education system is (unofficially) segregated along both racial and class lines. Public school students account for roughly 90% of high school students in Brazil (BRASIL, Inep, 2019). High quality private schools remain largely the purview of white and relatively affluent students, while most non-white, low-income students attend public schools. As such, research on public school students in Brazil can provide insights into the education of students who have historically been marginalized in Brazilian society.

The Portuguese Language Olympics (PLO) is a biannual writing contest for public school students across Brazil. The competition invites 5th to 12th graders nationwide to produce poems, literary memoirs, chronicles, opinion articles, or short documentaries about the places they live. The contest has a very broad reach. In 2016, for example, 4,874 of Brazil's 5,564 municipalities participated. Further, the reach is not skewed geographically; both the urban/rural makeup and the regional distribution are fairly similar to Brazil's wider demographics. Given the PLO's reach, student submissions to the PLO serve as an excellent source of large-scale textual data that could inform educational practices. The current project capitalizes on this potential. Specifically, the dataset used in this study consists of the collection of all opinion articles written by PLO participants between 2012 and 2016 who advanced to at least the municipal level. This includes a total of 14,526 essays, for each of which a student was asked to write a persuasive essay articulating their view on a polemic topic in the place they live.

Data analysis

The data were analyzed using Structural Topic Modeling (STM), an unsupervised machine learning algorithm (Roberts, Stewart, & Tingley, 2014) that takes in a set of textual data to (1) identify latent topics within each text, and (2) estimate the relationship between those topics and information about each text (topical prevalence covariates). A topic is defined as a mixture over words where each word has a probability of belonging to a topic, and the sum of word probabilities for a given topic is one. Each text is defined as a mixture over topics, and the proportions of all the topics across any given text always sum to one. In the present study, STM is useful for discovering what students write about and for estimating the relationship between students' characteristics and how much attention they give to particular topics.

After estimating a structural topic model with 14 topics (STM requires users to specify the number of topics), we labeled each topic based on the words most highly associated with it as well as the actual essays associated with each: "Challenges Schools and Students Face," "Public and Private Investment," "Economy and Unemployment," "Tourism and Natural Attractions," "Life in the Countryside," "Violence, Crime, and Drug Abuse in Youths' Lives," "Mobility Issues," "Land Rights Issues," "Politics and Elections," "Water Scarcity and Pollution," "Public Health Services," "Agriculture," "Cultural Heritage and Festivities," and "Local Community." We selected students' states, school locations (urban or rural), and essay years as topical prevalence covariates to be studied and then estimated expected proportions of essays belonging to each of the 14 topics as a function of these covariates. Preliminary results are discussed below.

Preliminary findings

What do students write about in their essays?

Of the 14 topics, some were more prevalent than others. "Economy and Unemployment" was the most prominent topic, represented in 11% of the corpus. The least prevalent topic, "Land Rights Issues," was represented in 3% of the corpus.

What is the relationship between covariates and the expected proportion of an essay that belongs to a topic?

State

For 10 of the 14 topics, the proportion dedicated to a given topic appears to vary by state. Further, with few exceptions, the percentage of essays dedicated to each of the 14 topics appears more similar within regions than between them. Initial comparison with the reference category revealed statistically significant differences (*ps* < .05) in topic proportion in student essays between states.

Urban vs. Rural

Certain topics (e.g., "Agriculture," "Environmental Issues," and "Local Community"), were more prominent in rural students' essays, while others (e.g., "Public and Private Investment" and "Cultural Heritage and Festivities"), were more prominent in urban students' essays. Other topics were observed across both urban and rural samples but still leaned either urban (e.g., "Violence, Crime, and Drug Abuse in Youths' Lives") or rural (e.g., "Land Rights Issues"). Still other topics, such as "Challenges Schools and Students Face," and "Life in the Countryside," were more evenly represented in both urban and rural students' essays. Excepting three topics ("Challenges Schools and Students Face," "Life in the Countryside," and "Land Rights Issues"), further analysis confirmed statistically significant differences (*ps* < .05) in topic proportion in student essays between rural and urban areas.

Year

Finally, with respect to year, 10 topics were found to vary statistically significantly by year (*ps* < .05). Five topics' prevalence increased from 2012 to 2014 and/or 2016: "Challenges Schools and Students Face," "Public and Private Investment," "Violence, Crime, and Drug Abuse among Youth," "Mobility Issues," and "Cultural Heritage." Conversely, five topics' prevalence decreased from 2012 to 2014 and/or 2016: "Economy and Unemployment," "Tourism," "Life in the Countryside," "Politics," and "Agriculture."

Discussion and directions for further research

Our results reveal that students encompass a wide range of topics in their essays, which reflect a collective body of shared and unique experiences and knowledge resources that teachers could learn from and tap into when designing culturally-adaptive learning experiences. The states and areas where students live appear to influence how much students write about each of the topics identified in the corpus. Some topics show little state-based variation, suggesting that they are widely-shared concerns across Brazilian youth. By contrast, topics that seem to reflect more locally-salient experiences exhibited wider state-based variation. The same patterns were observed along urban vs. rural lines. Finally, the year in which students wrote their essays also played a role in how much they discussed certain topics. Through the topics they write about, we can gain insight into some of students' economic, social, political, and environmental *concerns*. Students demonstrate *knowledge* of issues and priorities in their communities. They convey *difficult knowledge* (Zipin, 2009) that reflects challenging existential conditions in which they find themselves as members of young and often marginalized populations in Brazil. Further, in choosing a topic, a student *positions* him-/herself as someone who cares about that specific issue.

A closer look at the essays helps us understand what kinds of insights can be gained that could aid teachers in understanding the communities students participate in, the practices they engage in, and the cultural resources they thereby develop. For example, in one essay with an estimated 50% dedicated to "Challenges Schools and Students Face" and 35% to "Agriculture," the author describes the difficulties of balancing school obligations with work on bean plantations. She asserts that data show that "50% of high school students drop out of school to harvest beans," highlights the economic importance of bean crops to students' families, and details the struggles faced by students who work the bean harvest, arguing that schools should consider "students who are unable to reconcile study with work" and create initiatives that make it possible for them to study while also assisting their families with the harvest. From this essay, we can glean information about several communities the author participates in (students who work, bean harvesters) and activities he/she engages in (growing, harvesting).

We believe that such insights about students' topics constitute a valuable resource that cries out to be leveraged to improve learning in formal instruction. This could be the raw material for teachers to design learning environments that build on students' cultural resources. Further, teachers could use such insights and the essays themselves to spark student learning dialogues (Wells, 1999), prompting them to think critically about the communities to which they do or do not belong, as well as about why students from their region might write about a given topic more often than students from another. Such conversations have generative potentials for helping teachers elicit a multitude of cultural resources, not only those related to knowledge contents.

The findings presented thus far are only the beginning. Moving forward, our goal is to work with science, math, and language arts teachers in Brazil to study how they might utilize the topics uncovered by data science in conjunction with an exemplary corpus of essays in designing culturally-informed learning experiences.

References

Aronson, B., & Laughter, J. (2016). The theory and practice of culturally relevant education: A synthesis of research across content areas. *Review of Educational Research*, *86*(1), 163-206.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education*, 94(6), 1008–1026.

BRASIL. Instituto Nacional de Estudos e Pesquisas Educacionais Anísio Teixeira (Inep). (2019). Censo da Educação Básica 2019: Resumo Técnico. Brasília.

Cole, M., & Engestrom, Y. (1993). A cultural-historical approach to distributed cognition. In G. Salomon (Ed.), *Distributed cognitions: Psychological and educational considerations* (pp. 1–46). New York: Cambridge University Press.

Esteban-Guitart, M., & Moll, L. C. (2014). Funds of identity: A new concept based on the funds of knowledge approach. *Culture & Psychology*, *20*(1), 31-48.

Gay, G. (2018). *Culturally responsive teaching: Theory, research, and practice*. NY: Teachers College Press.

González, N., Moll, L., & Amanti, C. (Eds.). (2005). *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. Mahwah, NJ: Lawrence Erlbaum.

Gutiérrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. *Educational Researcher,* 32(5), 19-25.

Hogg, L. (2011). Funds of knowledge: An investigation of coherence within the literature. *Teaching and Teacher Education*, *27*(3), 666-677.

Ladson-Billings, G. (1995). Toward a theory of culturally relevant pedagogy. *American Educational Research Journal*, *32*, 465–491.

Lee, C. D. (1995). A culturally based cognitive apprenticeship: Teaching African American high school students skills in literary interpretation. *Reading Research Quarterly*, 30(4), 608–630.

Lee, C. D., Nasir, N. S., Pea, R., & de Royston, M. M. (2020). Introduction. Reconceptualizing learning: A critical task for knowledge-building and teaching. In Lee, C. D., Nasir, N. S., Pea, R., & de Royston, M. M (Eds.), *Handbook of the cultural foundations of learning* (pp. xvii-xxxv). NY: Routledge.

Moje, E., McIntosh Ciechanowski, K., Kramer, K., Ellis, L., Carrillo, R., & Collazo, T. (2004). Working toward third space in content area literacy: An examination of everyday funds of knowledge and discourse. *Reading Research Quarterly*, 39(1), 38–70.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory into practice*, *31*(2), 132-141.

Nasir, N. S. (2005). Individual cognitive structuring and the sociocultural context: Strategy shifts in the game of dominoes. *Journal of the Learning Sciences*, 14(1), 5–34.

Nasir, N. S., Rosebery,A. S.,Warren, B., & Lee, C. D. (2006). Learning as a cultural process: Achieving equity through diversity. In R.K.Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 489–504). NY: Cambridge University Press.

Paris, D. (2012). Culturally sustaining pedagogy: A needed change in stance, terminology, and practice. *Educational researcher*, *41*(3), 93-97.

Pea, R., & Martin, L. (2010). Values that occasion and guide mathematics in the family. *Research on Learning as a Human Science.* New York: Teachers College.

Roberts, M. E., Stewart, B. M., & Tingley, D. (2014). stm: R package for structural topic models. *Journal of Statistical Software*, *10*(2), 1-40.

Wells, G. (1999). *Dialogic inquiry: Towards a socio-cultural practice and theory of education*. Cambridge University Press.

Zipin, L. (2009). Dark funds of knowledge, deep funds of pedagogy: Exploring boundaries between lifeworlds and schools. *Discourse: Studies in the Cultural Politics of Education*, 30, 317–331.

The Inseparability of Identity and Knowledge Construction in Humanistic Knowledge Building Communities

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Abstract: This research builds on the idea that learners' identities and the knowledge they advance are inseparable. Our aim is to examine how fostering learners' identities can shape the way they view knowledge, suggesting that instructional environments should attend to identity development as they should to epistemic goals. In this paper, we first explicate the theoretical grounds underlying the inseparability argument. Next, we describe the special design of a learning environment, called a humanistic knowledge building community, to explain how the interconnectedness of identities and knowledge can be supported to become an intentional facet of the knowledge building endeavor. Our findings and the resultant conceptualization extend broad views of learning that consider ways-of-knowing and being as intertwined, to show how the actual ideas that learners advance are also deeply entrenched with their ways-of-knowing and being. Such accounts have been described in learning sciences literature, but have not been empirically documented.

Focusing on identity to advance ideas

Inquiry-based learning environments focus on advancing the ideas of their participants based on their genuine questions and interests. Scholarship, particularly the sociocultural perspectives we draw from, maintain that people's knowledge and identities are intertwined and inseparable (Herrenkohl & Mertl, 2010; Lave & Wenger, 1991). In practice, identities are often relegated to the background. For example, out of the twelve design principles that guide implementation of knowledge building communities (KBCs), not one of them focuses centrally on the participants' growth (Scardamalia, 2002). Empirical studies should be carried out to better understand the intricate relations between ideas and identities. The aim of this research is to examine how students' identities and knowledge are co-constituted in a specially designed learning environment, called a humanistic knowledge building community (HKBC: Hod & Ben-Zvi, 2018). HKBCs are designed to encourage their participants' freedom to express and explore both their identities as learners as well as the knowledge they choose to advance. By recognizing that identities and ideas are intertwined, it makes sense to design inquiry-based learning environments where participants can express, reflect on, and get feedback on their identities and knowledge, as well as the connections between them. Our analysis is therefore focused on showing the different ways that people's identities and their knowledge are co-constituted.

Background

Socioculturally-minded research has suggested that broad views of learning are necessary to conceptualize the advancement of knowledge (Herrenkohl & Mertl, 2010). Sociocultural approaches view the mind as inherently situated (Lave & Wenger, 1991) and therefore co-mediated across personal, interpersonal, and community planes (Rogoff, 1995). From a personal stand-point, learning involves transforming one's participation—and therefore identity—in a community discourse (Rogoff, 1995), oftentimes from peripheral to more central (Lave & Wenger, 1991). One's transforming identity is guided interpersonally, such as through apprenticeship learning (Eberle, 2018). Transforming into a central participant in a discourse cannot be achieved without advancing the ideas that are valued by the community. Ideas, knowledge, or what is informational (Hand & Gresalfi, 2015) are therefore intertwined with the identities of its participants.

Research already shows that broad views of learning can account for the co-mediational relationship between ways-of-knowing and ways-of-being (Hand & Gresalfi, 2015; Herrenkohl & Mertl, 2010). Our research builds on this proposition in two ways. First, we contend that the connection between ways-of-knowing and ways-of-being can be intentionally supported through design. Second, we differentiate between ways-of-knowing and ways-of-being with knowledge and identities. That is, ways-of knowing refer to people's epistemic commitments and the ways they build knowledge. Ways-of-being deals with non-epistemic domains, such as how people are viewed in social interaction. Although ways-of-knowing and ways-of-being focus on different things, they are both linked by practices or ways-of-doing *something*. When any practice is repeated enough to become stable (and is thus likely to be reified in discourse), it can be considered as an identifying feature of a person, or their identity (Heyd-Metzuyanim & Sfard, 2012).

In our research, we are interested in the actual knowledge that a person advances in relation to their ways-of-knowing and ways-of-being. Is it possible that the actual knowledge that people produce is closely related to their identities? If so, how? For instance, Wortham (2004) identified a bi-directional analogy of social identifications and epistemic concepts that people use while participating in classes. He noticed that students used cognitive categories to identify each other socially and these identifications help them understand concepts in person-related disciplines. Additionally, they also use epistemic concepts to identify others' socially. As Wortham (2004) notes, "it turns out that the content represented by a participant example and the interactional patterns enacted through that example can sometimes run parallel" (p. 177). Taking this forward, it raises the question of what would happen when students are given the opportunity to freely explore their ideas and their own identities in parallel within the community? These are questions from a broad view of learning that do not, to our knowledge, have any empirical accounts in the learning sciences.

Based on the rationale that knowledge and identities are inseparable, Hod & Ben-Zvi (2018) conceptualized the humanistic knowledge building community (HKBCs) as a designed learning environment that brings together idea-based and identity discourses. Idea-centered discourse is based on the theory and practice of KBCs (Scardamalia, 2002), while identity discourse is based on person-centered theories of personal growth through process oriented groups that focus on the here-and-now (Yalom & Leczsz, 2005). Both of these approaches are principle-based, fundamentally putting their trust and respect into the participants so they can take ownership and have agency over the processes they engage in while addressing the emergent goals of the community. The design of HKBCs gives students freedom-of-ideas and freedom-of-identities through designed activities, with a focus on jointly advancing both of these as part of the community goals. This research set out to study the different ways that students' knowledge and identities are co-mediated when they are given freedom-of-ideas and freedom-of identities. Specifically, we asked: (a) in what ways are students' initial expressions about their ideas and their identities related? and (b) how do students' ideas and their identities change as they are shaped through their ongoing participation in the community and by its members?

Methodology

Our data corpus was drawn from a full 14-week semester (2018-2019) from a graduate course that was designed as an HKBC and which included an entire group of 18 students, an instructor (moderator), and a teacher's assistant (co-moderator). CATELT was structured as a blended course, where weekly 210 minute face-to-face meetings alternated with ongoing activities for the remainder of the week in a wiki environment. Activities were generally designed to promote knowledge advancement by letting people explore their interests in relation to the community (freedom-of-ideas) or focus on people's experiences, interpersonal relationships, and identities in the here-and-now (freedom-of-identities) in both the face-to-face and online environments. Throughout the semester, we collected audio and video recordings of every face-to-face meeting, collected online artifacts created on the wiki by the students; and conducted open interviews at opportune times, either during breaks, or on the phone, when something interesting occurred as related to the research questions. Specifically for this analysis, we focused on two students (one presented here) within the course who worked as a pair on the final project, examining: (a) group reflection sessions; (b) personal reflective diaries; (c) wiki entries; (d) final papers; and (e) interviews.

To examine the initial identities and ideas of the students, we focused our efforts on the beginning stages of the course, where students typically reveal their prior knowledge and practices in ways that have yet to be tainted by the ongoing developments in the community. The sharing of interests and experiences was purposefully facilitated in activities designed by the moderators during the first few weeks of the course, as well. Once students' initial identities and ideas were collected, we examined the intricate and situational ways that these students both advanced their knowledge and interests and the way the community shaped these through their feedback or modelling processes. Ultimately, we created a narrative account of the findings (Erstad & Sefton-Green, 2013). To ensure that the analysis process was reliable, we engaged in extensive interpretive meetings together with another researcher in the course (who was focused on a different set of questions), and with a research group (to whom we presented the evidence and later engaged in discussion around it).

Findings

In this section, we report on Ziv (pseudonyms). *Due to page restrictions here and the lengthy nature of narrative accounts, we can only provide quick descriptions of his expressions instead of detailed, first-hand accounts.*

Ziv, aged 40, was a modern orthodox man who was a high school physics teacher. Ziv's identity was expressed as a person who was a 'knower' with 'absolute answers', analytical instead of personable, and controlling of collaborative learning processes. For example, in reflecting on group work, he explained that by working with a group the product was "mediocre", where if he was the leader he could bring it to excellence (Wk 4).

Given the conditions of freedom-of-identity that were supported in the course, Ziv's practices within the community ran parallel to those in his everyday life and to the ideas that he initially showed interest in the HKBC. Specifically, Ziv focused on the ideas of expertise and the Zone of Proximal Development (ZPD) through the lens of the role that teachers play in supporting learners. Ziv's interest reflected his identity in advancing himself as an expert teacher and "knower". For example, he wrote that that learning about expertise "was very meaningful for me because… it helps me very much as a teacher understand the learning processes that I see in the classroom and how [I can] facilitate this." In his knowledge building efforts around this idea during Wk 2, he focused on the highest levels of expertise and how he could get there. He chose to explore the topic of "adaptive expertise", reflecting about himself and providing a specific list of ways he could become an expert. Ziv's interest in the ZPD was similarly meant to advance his own teaching practices, again positioning him as the knower who needs to provide others with answers. He explained that his choice of ZPD as the main topic of his final course project was about how to turn a novice to an expert in what he referred to as an asymmetrical relationship between the two.

As the community got to know Ziv and recognized his practices, they were able to provide him with a wide range of customized feedback that promoted his identity development. The feedback he received covered many of the salient facets of his identity and practices, which especially came through in a dramatic community discussion around Ziv during Wk 8. There, many members of the community sensitively shared their thoughts about Ziv to him in the here-and-now, providing him with a new level of self-understanding that allowed him to make intentional changes to his identity and practices, for example:

> *Mod:* You want to get full control. We [in this course] are talking about something else. Most of us read and do not understand everything, especially something so complicated. I understand something partially and that is okay. How does it feel compared to the beginning [of the course]? There were tables and charts [that you created] for those who worked with you...

> *Nurit:* During one of the first reflections when we talked about changing, you told someone not to change. And maybe this is what you want for yourself? Maybe you need to release 'Ziv the physics teacher'.

The comments touched on a tender area for Ziv, giving him many new ideas about himself to reflect on. In the immediacy of the discussion he responded impersonally, but still in a way that suggested that he understood that his practices and identity could transform:

> *Ziv:* We learned in a very absolutist [educational] system. Maybe change is needed.

Throughout the remainder of the semester, Ziv exhibited a number of personal changes along these lines, suggesting that he appropriated the feedback. For example, during a collaborative assignment (Wk 10), students were asked to advance their collective knowledge. Ziv posted a note that expressed his uncertainty, "I still do not understand how to work with it but this is an opportunity to learn", and showed a high degree of openness about the process of work by writing, "I suggest that we work here [in a particular page] to build knowledge… what do you think?". These changes were also echoed in Ziv's final course reflection, where he noted that "I could have only guessed rationally before the 'hug', but once I experienced it, I can say that I understood it differently from the way I understood it in the beginning."

The changes to Ziv's identity were reflected in his changing focus of inquiry. Ziv's understanding of novices and experts as well as the ZPD shifted from (a) how the concepts can help him as a teacher, to (b) concepts that had diverse processes and social orientations. For example, Ziv participated in a small group discussion about the concept of ZPDs during Wk 8, where he emphasized that "The process [of novice and expert relationships] is reciprocal. The teacher also learns from what they [the students] bring…"

Whereas at the start of the semester Ziv focused on the ZPD from an asymmetric position where he was the expert, Ziv later took great interest in symmetrical social relationships, or how peers can help one another advance. This was reflected strongly in his final course paper, where he wrote:

> *Ziv:* Vygotsky did not give us explicit didactics in this concept and did not interpret his explicit intention of the mediator's identity... it is impossible to understand otherwise that any meaningful development of the learner will be based on a pedagogy of social learning, and not merely individual.

Discussion and conclusions

The research questions in this study sought to elucidate (1) the relatedness of students' initial expressions about their ideas and their identities, and (2) how these ideas and identities change as they are shaped through their ongoing participation in the community. In relation to the first question, Ziv's inquiry interests when given the freedom to be himself was deeply connected to his identities and practices in his everyday life. The narrative account of Ziv shows that his initial identity as 'the knower' was tied to his interest in being an expert (teacher) and the teacher's role as mediator in the ZPD.

Our analysis of Ziv's narrative showed that the actual ideas and the perspective taken on them were closely related to important aspects of his identity. This was expressed both in the interpersonal relationships that he formed within the community as well as from experiences that he told about in his life outside of the community. A close look at his knowledge thus provided a window into his identity, showing how inseparable these two concepts really are. The consequential feedback that Ziv was given about his interpersonal relationships in the here-and-now of the community was highly potent, as the ahistorical focus touched on deeper themes that ran across his everyday life. Thus, the feedback helped him think deeply about his identity and this ultimately shaped the way he viewed the ideas he was advancing.

Clearly this could have gone in the reverse direction also in that his advancing ideas could have shaped his identity. However, it is more likely to work in the opposite direction because identities are much broader than knowledge, dealing with the totality of a person, including their interests, beliefs, culture, history, goals, etc. Ideas, in contrast, are more transient and can be changed more easily. This is why, for example, knowledge can be built relatively quickly and ideas can be changed through argumentation. Changing conceptions are obviously very important and a central purpose of education. The point we are trying to make is that by addressing people's identities, we can touch on much more deeply rooted aspects of people's knowledge and this can ultimately help foster deep and sustainable knowledge and perspectives on it.

More specific to the learning sciences, the answers to our research questions are consistent with holistic notions of learning following sociocultural traditions (Herrenkohl & Mertl, 2010). They emphasize the importance of ever-deepening interpersonal relationships, as these provide opportunities for students to see aspects of people's identities that are often hidden behind masks they put on in their cultural roles as students who are not truly "free" to be themselves. Getting to know a person facilitates a deeper understanding of their ideas, particularly in settings like ours where the process of learning and knowledge are intricately tied together. Exploring issues of identity also facilitates self-understanding, and as we saw with Ziv, allowing a person to make more intentional decisions both in relation to how to engage in the knowledge building process as well as what topics to pursue. Obviously, it would be of high interest to see how these issues play out in other HKBC contexts, like math or science with kids, and we hope that future research will take up these questions.

References

Eberle, J. (2018). Apprenticeship learning. In F. Fischer, S. R. Goldman, C. E. Hmelo-Silver, & P. Reimann (Eds.), *International Handbook of the Learning Sciences* (pp. 44-53). New York, NY: Routledge.

Erstad, O., & Sefton-Green, J. (Eds.). (2013). *Identity, community, and learning lives in the digital age.* Cambridge University Press.

Hand, V., & Gresalfi, M. (2015). The joint accomplishment of identity. *Ed. Psychologist*, *50*(3), 190-203.

Herrenkohl, L. R., & Mertl, V. (2010). *How students come to be, know, and do: A case for a broad view of learning.* Cambridge University Press.

Heyd-Metzuyanim, E., & Sfard, A. (2012). Identity struggles in the mathematics classroom: On learning mathematics as an interplay of mathematizing and identifying. *International Journal of Educational Research*, 51-52, 128-145.

Hod, Y. & Ben-Zvi, D. (2018). Co-development patterns of knowledge, experience, and self in humanistic knowledge building communities. *Instructional Science*, *46*(4), 593-619.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge, UK: Cambridge University Press.

Rogoff, B., & Chavajay, P. (1995). What's become of research on the cultural basis of cognitive development?. *American Psychologist*, *50*(10), 859.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. *Liberal education in a knowledge society*, 97, 67-98.

Wortham, S. (2004). From good student to outcast: The emergence of a classroom identity. *Ethos*, *32*(2), 164-187.

Yalom, I. D., & Leszcz, M. (2005). *The theory and practice of group psychotherapy*. NY: Basic Books.

"Let's Talk About Election 2020": Quantitative Civic Literacies of Solidarity and Critique in an Online Digital Network

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Abstract: This study investigates youth civic participation around the 2020 US presidential election. Drawing on theory from civic participation, quantitative literacy, mathematics, and science education, this study describes *quantitative civic literacies*--how youth use quantitative reasoning as they "read" the social-political world and "inscribe" their own participation. We analyze a large collection of youth video production on youth-identified civic issues, specifically focusing on engagement around the "dual pandemic" of structural racism and COVID-19. Employing qualitative methods, we identified two emergent trends that shed light on intersections of quantification and youth civic production: 1) the paired usage of quantification and a human story, and 2) critiques of overgeneralization and totalizing quantification. This engagement reflects sophistication and awareness about the role of quantification and risks of over-reliance on quantification without deep human context. We offer implications for educators across disciplines, speaking to a core purpose of public education--critical and informed participation in democratic communities.

Introduction

The relationship between quantitative literacy, democracy, and schooling has been posed as an imperative for equitable futures in education (Ball, Goffney & Bass, 2005), and as a key civil rights issue for this millennium (Moses & Cobb, 2001). In an increasingly technologically advanced society awash in data, concerns about the abilities of the public to participate in the world as informed citizens have led to shifting definitions and priorities for literacy itself. Quantitative literacy has been posited as "the new literacy" (Steen, 1997), fundamental for participation in a modern-day democracy (Quantitative Literacy Design Team, 2001). Recently, data literacy has been added to this call (Boaler & Levitt, 2019). Yet few math or science classrooms, spaces ripe for quantitative reasoning as applied to civic life, explicitly engage students in civic topics. In the small set of literature documenting math and science classrooms that do so, findings suggest that young people are engaged, motivated, and ready to connect their disciplinary content learning to their social and political lives (e.g. Calabrese Barton & Tan, 2010; Gutstein, 2006; Levine, Keifert, Marin & Enyedy, 2020).

Beyond the math or science classroom, youth engage in civic participation and production in myriad ways, using multiple modalities (digital, visual, etc.) to critique, construct, and imagine their worlds (Kahne, Middaugh, and Allen, 2015). In the months surrounding the most polarizing election experienced by the United States (US) in modern times, over 1000 youth from across the nation produced and posted digital media addressing an issue of importance to them through the educational web-based platform, *Let's Talk About Election 2020*. In addition to the election itself, the Black Lives Matter movement and the COVID-19 global pandemic, coined the "dual pandemic" for the intersecting impacts of systemic structural racism with the virus-induced global medical crisis, provided a backdrop for students' recordings.

It is at this unique time that we seek to understand how youth are bringing together forms of quantitative literacy with civic production to reimagine their turbulent worlds. Contributing to the fields of civic participation, quantitative literacy, mathematics, and science education, the study takes youth media production in *Let's Talk About Election 2020* as the landscape for beginning to map the terrain of quantitative civic literacies - how youth use quantitative forms of reasoning as they "read" the social-political world and "inscribe" their own participation through civic engagement (Freire & Macedo, 2005). Specifically, this ongoing study asks: 1) How does quantitative literacy intersect with and contribute to different forms of youth civic composing? 2) When youth write about urgent topics such as Black Lives Matter and COVID-19, what forms does quantitative literacy take across these distinct civic terrains?

Youth, civics education, and civic literacy

Traditional conceptions of civics and civic education in the US are built around "characteristics of citizenship" (Flanagan & Levine, 2010) that promote a vision of civics in which students develop an understanding of the functioning of the US government. We make use of a more expansive conception of civics that includes a focus on “participatory politics” (Cohen, Kahne, Bowyer, Middaugh, & Rogowski, 2012), positioning schools as places that can support “participatory readiness” (Allen, 2016) for engagement not only in political communities, but also in “intimate and communitarian relationships” (p.27). In addition to informed consumption and production of civic-related information, this conception of civics includes the learning of empathetic listening for solidarity and the development of tools for imagining and creating more just and inclusive communities (Dewey, 1923). It furthermore advances a global perspective rather than one that is centered narrowly around the US.

Literacy has long been understood as fundamental to a participatory democracy, including participation in both governmental politics and the development of a more just and inclusive society (Dewey, 1923). In approaching the *Let's Talk About Election 2020* student videos, we use the construct of civic literacies to indicate the multiple modalities and spaces in which youth critique and create social and political worlds (Kahne, Middaugh, and Allen, 2015). With this study we begin to illuminate when and how different forms of civic composing reflect crucial intersections between civic and quantitative literacies.

Quantitative literacy

Building from the joint constructs of civic literacies and civic composing, we put forth a conception of civic literacies that includes quantitative literacies - argued as essential to equitable futures in education. In defining quantitative literacy, we draw from the Organisation for Economic Cooperation and Development (OECD) definition of quantitative literacy as the use of reasoning around: (1) quantity, (2) relationships and change, and (3) uncertainty to address “real life” problems (de Lange, 2006).

Quantitative reasoning is often associated with mathematics, and currently a central tenet of US-based K-12 standards for mathematics processes (NCTM, 1989; 2000) and practice (Common Core Standards Initiative, 2011); likewise, it is integral to several science and engineering practices outlined by the Next Generation Science Standards (NGSS; Achieve, 2013), such as using mathematical and computational thinking. Yet, quantitative reasoning embedded in meaningful social and political contexts is rarely accounted for in state-based measures that drive curriculum and instructional decisions. Orrill (2001) explains that quantitative literacy, distinct from school-based mathematics curriculum, “does not so much lead upward in an ascending pursuit of abstraction as it moves outward toward an ever richer engagement with life's diverse contexts and situations” (Orrill, 2001, xvii).

Methods

To answer the research questions, we enacted a qualitative analysis of transcripts from video and audio made by youth surrounding the 2020 US Presidential Election. *Let's Talk About Election 2020* offered an online, digital space for youth to share perspectives nationally via audio and video, hosted through public radio station KQED. Students chose a topic of meaning to them and produced an audio or video segment of approximately two minutes in length to post on the publicly available platform along with up to five “tags” describing the issues discussed. Some of these segments were chosen for public radio or TV broadcast then broadcast publicly through the national public radio or public broadcasting networks KQED and PBS.

Filtering from the set of nearly 1000 student made media segments, using student-posted “tags,” as well as media titles, we identified and examined the 51 media segments that addressed Black Lives Matter (BLM) and the 47 media segments addressing the COVID-19 pandemic. We downloaded these videos and audio segments as well as their student-produced transcripts. Initial analysis reported in this paper was limited to transcripts uploaded and coded in AtlasTI, a qualitative data analysis software.

Coding of transcripts employed a combination of a priori and emergent codes. In the first phase of analysis we applied an a priori framework, drawing on the three forms of quantitative literacy outlined by de Lange (2006), with modified operationalized definitions.

- **Quantity and number** - having to do with size, numerical patterns, measurement, representation of number, the meaning of operations, magnitude, computation, and estimation
- **Relationship and change** - having to do with growth, cycles, fluctuations, functional relations, equations, inequalities, equivalence, divisibility, making use of varied representations including symbolic, algebraic, graphic, tabular, and geometric.
- **Uncertainty** - having to do with data and chance, statistics, probability, and inference, collecting data, data analysis, data display and visualization

Through emergent coding, distinctions were identified between quantification that used numbers or statistics and non-numerically specific forms of quantification, forming sub-categories for each of the above three quantitative forms of reasoning.

Through a process of coding, memoing, and constant comparison among researchers (e.g. Strauss & Corbin, 1994) we identified two trends that sit at the intersection of quantitative literacies and civic composing: 1) the pairing of quantification with a human story and 2) critique of quantitative superlatives. Preliminary findings elaborate on these two trends.

Preliminary findings

Across both sets of transcripts, students used all three forms of quantitative reasoning, drawing less frequently on uncertainty than on the other two. Students often used numbers to communicate about historical or current events, but more commonly used non-numeric quantitative qualifiers such as "many," "more," "growing," "unequal," or "high risk" to describe magnitude, relationships, change, and uncertainty in probabilities.

Shared across both sets of transcripts, two trends emerged that shed light on intersections of quantification and youth civic production: 1) the paired usage of quantification and a human story and 2) critiques of overgeneralization and totalizing quantification. These two trends are highlighted in Figure 1.

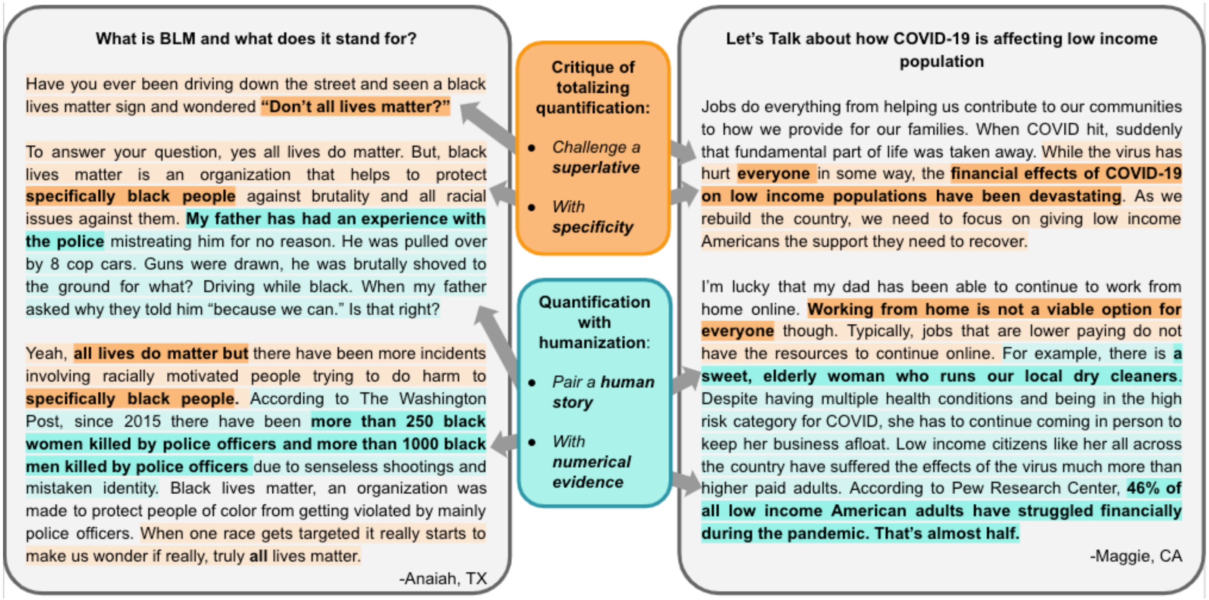

Figure 1. Coding from a Black Lives Matter and COVID-19 media transcript.

Quantification with humanization

Transcripts often evidenced a rhetorical move in which the author paired quantitative data with a human story to frame an argument. Using varied forms of reasoning with number, Anaiah from Texas tells the story of her father being pulled over by eight police cars and in doing so gives a face to the widespread anti-Black police violence that has led to fear, anger, and the deaths of "more than 250 black women" and "more than 1000 black men" in the US since 2015. Mixing together reasoning with number, relationships and change, and uncertainty, Maggie from California shares her concern about "a sweet, elderly woman who runs our local dry cleaners" who is "in the high risk category for COVID" but has had to continue working as an example of the ways that the coronavirus pandemic has disproportionately impacted lower income Americans, citing that "46% of low income American adults have struggled financially during the pandemic." With this rhetorical move, Anaiah, Maggie and others used the specificity of a personal story to humanize cold statistics that can abstract data from its lived significance. In subtle contrast to forms of civic composing that prioritize informing and treat quantitative data as the stamp of legitimacy, this rhetorical move appears to be one of solidarity in which quantitative data is treated as reliant on the legitimacy of the particulars of human experience.

Critique of totalizing quantification

While youth authors widely used non-numerically specific references to quantification, there were also many instances of critique of the usage of totalizing quantitative terms (superlatives) such as "all," "everybody" or "nobody." Youth media makers critiqued or rejected quantifications that were used to overgeneralize, arguing instead for the care and attention of specificity. In her video, Anaiah carefully confronts the question of "'Don't all lives matter?'," a common rebuttal to the claim that Black lives matter. As described above, she unpacks the specificity of violence against Black people including her own father, and the role of BLM as an organization and movement to challenge anti-Black violence. She highlights this challenge to the use of "all" in her closing line, "When one race gets targeted it starts to make us wonder, if really, truly, all lives matter." Maggie, like Anaiah, challenges the universality of experience; even when a pandemic is global, she argues, it does not affect everyone in the same way. For low income populations in particular, she writes, the effects "have been devastating."

Implications and next steps

These two ways of engaging with quantification in civic composing reflect a level of sophistication and awareness about the role of quantification in the world and the risks of over-reliance on quantification without deep human context and specificity. In the landscape of civic reasoning and argumentation, quantitative evidence is often understood to signal authority; instead youth media production on Black Lives Matter and the coronavirus pandemic suggests personalization and human experience as taking the legitimizing position.

Implications suggest that classroom-based instruction can build from youth awareness of the complexity of quantification. Youth quantitative civic literacies revealed in the two trends resonate with the call for deep contextualization of number and quantification in math and science classrooms (Calabrese Barton & Tan, 2010; Gutstein, 2006). Analysis identified the emergent findings described here from transcripts of audio from youth media. We will further pursue how youth communicate nuanced ideas about measuring and quantifying the stakes and impact of risks to human life within the dual pandemics of COVID-19 and Black Lives Matter.

References

Achieve, Inc. (2013). The next generation science standards, for states, by states. Retrieved September 22, 2020, from https://www.nextgenscience.org/

Allen, D. (2016). *Education and equality*. University of Chicago Press.

Ball, D. L., Goffney, I., & Bass, H. (2005). The role of mathematics instruction in building a socially just and diverse democracy. *The Mathematics Educator*, 15(1), 2–6.

Boaler, J. & Levitt, S. (2019). "Are we teaching the wrong mathematics to high school students?" Retrieved from https://www.youcubed.org/wp-content/uploads/2019/10/Are-we-teaching-the-wrong-math.pdf

Calabrese Barton, A., & Tan, E. (2010). We be burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences*, 19(2), 187–229. https://doi.org/10.1080/10508400903530044

Cohen, C. J., Kahne, J., Bowyer, B., Middaugh, E., & Rogowski, J. (2012). Participatory politics. New media and youth political action.

Common Core State Standards Initiative. (2011). Standards for Mathematical Practice. Retrieved from http://www.corestandards.org/Math/Practice/.

de Lange, J. (2006). Mathematical literacy for living from OECD-PISA perspective.

Dewey, J. (1923). *Democracy and education: An introduction to the philosophy of education*. Macmillan.

Flanagan, C., & Levine, P. (2010). Civic engagement and the transition to adulthood. The future of children, 159-179.

Freire, P., & Macedo, D. (2005). *Literacy: Reading the word and the world*. Routledge.

Gutstein, E. (2006). *Reading and writing the world with mathematics: Toward a pedagogy for social justice*. Taylor & Francis.

Kahne, J., Middaugh, E., & Allen, D. (2015). Youth, new media, and the rise of participatory politics. From voice to influence: Understanding citizenship in a digital age, 35.

Levine, S., Keifert, D., Marin, A., and Enyedy, N. (2020). Hybrid argumentation in literature and science for K-12 classrooms. In *Handbook of the cultural foundations of learning* (pp. 141-159). Routledge.

Moses, R. P., & Cobb, C. E. (2001). *Radical equations*. Boston: Beacon.

National Council of Teachers of Mathematics (NCTM). (2000). *Principles and standards for school mathematics*. Reston, VA.

Orrill, R. (2001). Mathematics, numeracy, and democracy. In Steen, L. S. (Ed.). *Mathematics and democracy: The case for quantitative literacy*. Preface (pp. xii-xx). NCED.

Quantitative Literacy Design Team. (2001). The case for quantitative literacy. In Steen, L. S. (Ed.). *Mathematics and democracy: The case for quantitative literacy*, (pp. 1-23). NCED.

Steen, L. A. (1997). *The new literacy. Why numbers count: Quantitative literacy for tomorrow's America*. Chicago.

Strauss, A., & Corbin, J. (1994). Grounded theory methodology. *Handbook of Qualitative Research*, 17(1), 273-285.

Encountering Uncertainty and Learning to "Try and Try and Try": The Development of Teachers' Perseverance within Science

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Abstract: Current efforts in science education emphasize the need for students to experience science in ways that mirror professional scientists' practices and dispositions. As uncertainty is inherent in science, one important disciplinary disposition is then learning how to wrestle with uncertainty and develop a stance of perseverance at the encounter of uncertainty in scientific work. We argue that in order to support students in developing a stance of uncertainty in science, teachers themselves should be familiar and comfortable with scientific uncertainty. To this end, this study examines how four teachers encounter uncertainty and persevere in their work over the course of a six-week science research experience. Drawing from interviews and field observations, we identify key resources that facilitated teachers' development of perseverance and consider implications for instructional practice.

Keywords: Uncertainty, Frustration, Perseverance, Research Experience for Teachers, Science

Major issues addressed

Uncertainty is an inherent part of scientific endeavors. As scientists engage in constructing new knowledge, they can only do so by wrestling with uncertainty (Pickering, 1995). From this lens, uncertainty can be understood as the aspects of "scientists' work that [are] non-obvious and contingent, which must be figured out by the scientists and negotiated in response to feedback from peers and the material world" (Manz, 2018, p. 288). Indeed, scientists grapple with many kinds of uncertainty (Latour, 1987; Pickering, 1995). For example, scientists may experience conceptual uncertainty as they develop and flesh out novel explanations or engage in argumentation and critique of ideas. They may experience instrumental uncertainty when encountering procedural ambiguity or setbacks in using material tools. They may experience analytical uncertainty as they work to interpret data or when encountering ambiguous measurements. While not exhaustive, these examples illustrate that scientific uncertainty is inextricably bound to the disciplinary work of scientists. It is then important to consider how one learns to experience scientific uncertainty as motivating rather than stymying, and in turn, persevere through it. Said differently, navigating uncertainty includes not only working to reconsider methods and conceptual understandings (Manz & Suarez, 2018), but also learning to attend to and regulate the emotions that emerge within such work (Davidson, Jaber, & Southerland, 2020; Jaber & Hammer, 2016a).

Taken together, these perspectives on uncertainty inform current science education reform efforts (NRC, 2012) which emphasize the need for students to experience science in ways that allow them to think, behave, act, and feel as scientists (Ford, 2008). This entails providing students with opportunities to encounter uncertainty (Manz & Suarez, 2018) and develop the perseverance necessary to work through that uncertainty (Davidson et al., 2020). We argue that if teachers are to provide students opportunities to grapple with scientific uncertainty, it is essential that they also develop comfort with navigating uncertainty. Yet, few teachers have had first-hand experiences with uncertainty in scientific work. One context that may afford such experiences is that of Research Experiences for Teachers (RET) programs. RET programs are professional development experiences housed within national laboratories and universities, wherein K-12 teachers are immersed in extensive scientific research through shoulder-to-shoulder work with scientists (SRI International, 2007). RET programs may be fertile contexts for teachers to learn to persevere through uncertainty, thus this study asks the following questions:

1. In what ways do teachers describe and reflect on their experiences of scientific uncertainty in the context of a scientific research experience?
2. What are the resources that teachers refer to as productive to their development of perseverance in science as they reflect on these experiences?

Significance of the work

While professional scientists have sustained opportunities to develop perseverance through encounters with uncertainty over the long-term of their careers, K-12 teachers—and students—likely require carefully designed opportunities to develop such perseverance. By investigating teacher learning in the context of a carefully designed RET program, this study promises to a) contribute new insights with respect to the resources that learners recruit to navigate emotions and develop perseverance when encountering uncertainty; and b) consider the ways in which particular resources may be useful starting points for supporting K-12 students' experiences with uncertainty in the classroom. Additionally, given that uncertainty—scientific or otherwise—is fundamental to the human experience more broadly (Anderson et al., 2019), the insights garnered from this study have far-reaching implications for theorizing about learning and for designing for productive encounters with uncertainty.

Methodological approach

This study takes a naturalistic approach (Rossman & Rallis, 2012) to examine teachers' encounters with scientific uncertainty and development of perseverance during a summer research experience at a national laboratory in the southeastern United States. Through field observations and interviews, this study aims to capture teachers' experiences with uncertainty and the resources involved in developing their perseverance in light of uncertainty.

Research context

The study focuses on participants in a six-week paid residential summer RET program situated at The Lab—an interdisciplinary science facility with over 600 scientific faculty and staff from applied physics, materials science, and engineering fields. The Lab is made up of smaller lab groups comprised of research scientists, technicians, postdocs, graduate students, and occasionally undergraduate students. The RET is designed to provide K-12 teachers with opportunities to participate in cutting edge research with the hope that these experiences will influence their classroom instruction (Davidson & Hughes, 2018). Teachers' genuine participation in scientific research is a core tenet of the RET program at the Lab. For this, teachers are paired, and each pair is assigned to a mentor scientist with whom they work closely for the duration of the program. As part of their active and ongoing participation in the research work, the teachers are given explicit roles and responsibilities (i.e. preparing samples for experimental trials, running experiments and collecting data, assisting with lab reports).

Study participants

This study is part of a larger project focused on elementary teachers' disciplinary engagement in science. As such, purposeful criterion sampling was applied to select four elementary teachers (from a cohort of ten K-12 teachers) as the focal participants for this study: Ava, Carrie, Lynette, and Miranda. The four participants taught in K-5 classrooms, had varying levels of teaching experience, and expressed an interest in science teaching and learning.

Data sources and analysis

Data sources include five semi-structured and multiple informal interviews, field memos, and audio-recordings for over 30 hours of naturalistic laboratory observations for each participant. The interview transcripts serve as the primary data source with other data serving as secondary sources for triangulation. The semi-structured interviews, conducted over the duration of the RET, focused on the content of the research work; the teachers' relationships with their mentor scientist, cohort partner, and others at the Lab; their understandings about the discipline of science; and their feelings and experiences in doing research. In addition, multiple informal interviews occurred throughout the program as 'check ins' with participants about their experiences.

Each interview set was batched by participant and read in chronological order, starting with the earliest interview. Taking a constructivist grounded theory approach (Charmaz, 2008), the data sets were examined for moments in which participants discussed encounters with uncertainty. For the first research question, we attended to the type of uncertainty prevalent in these moments, drawing from definitions of uncertainty from Buck et al. (2014) and Manz (2018). We also paid attention to the context within which uncertainty emerged and the emotions that participants brought up in relation to each moment. To answer the second research question, we examined the interview transcripts again for whether and how participants reflected on their perseverance in light of uncertainty. When participants referenced perseverance, the transcripts were examined for specific resources that may have supported the development of such stance. We then identified themes that depict the resources that participants drew upon to develop perseverance and to embrace uncertainty as part and parcel of science.

Findings, conclusions, and implications

The study findings suggest that engaging with research at the Lab afforded participating teachers with firsthand opportunities to grapple with various kinds of scientific uncertainty. Each teacher described strong emotional responses—typically feelings of frustration and anxiety—associated with such encounters. In spite of these negative valence emotions, all teachers developed a stance of perseverance that was linked to specific resources.

Research question 1: Teachers' encounters with uncertainty

The teachers described twenty-three separate encounters with scientific uncertainty over the course of their six-week research experience. Across all four cases, the participants primarily described grappling with conceptual uncertainty—difficulty explaining particular scientific ideas—and instrumental uncertainty—difficulties arising from working with physical equipment (Buck et al., 2014). As an example, Ava reflected on a particularly vexing experience with instrumental uncertainty as she and her lab mates, Carrie—a peer teacher—and Kevin—a graduate student lab member—repeatedly tried to create a single composite image file from many smaller files using unfamiliar computer software and a handout that their mentor scientist, Dr. Ji, had given them:

> We kept looking at [the handout] Dr. Ji had given us and every time—every single time—it just wouldn't work. One [of us] would say, 'did you try this?'—Yes—'what about this button?'—Yes—everything. I think we tried everything! And we couldn't make it work. We couldn't. Carrie would try and then Kevin would say, 'No, no! I'll try' and then he'd stop and I'd try—it was crazy. We had to take a break even, we had to walk away. (Interview 3)

When reflecting on their encounters with uncertainty, almost all participants expressed an emotional stance of frustration, anxiety, and feelings of discomfort. However, all four teachers described ways in which their frustrations were mitigated, normalized, and transformed to a stance of perseverance. As Ava noted after describing the composite image problem: "It was really frustrating! I could not believe how hard we had to think to do something so simple—well, it's not simple! We didn't know how to do it! But you have to practice and try and try and try, you have to see it as a challenge" (Interview 3). While she acknowledged her frustration, she also noted the importance of framing this encounter with uncertainty as "a challenge" along with noting the necessity of continuing to "try and try and try", a stance reflective of her emergent perseverance.

Research question 2: Key resources in teachers' development of perseverance

There were two prevalent resources that all four participants referenced as being most productive for developing perseverance in light of scientific uncertainty: Support from mentor scientists and peers.

Mentor scientists: Normalizers of uncertainty

Across all participants, the resource most often referred to was mentor scientists who were described as a source of help and comfort when encountering uncertainty. In each encounter, mentor scientists made explicit moves to normalize uncertainty. Ava noted across multiple interviews how "patient" her mentor scientist was. Reflecting on an instance when a scheduled power outage caused an experimental trial run to go awry, she noted:

> I felt really frustrated and upset when the furnace must have shut down during our [experimental] trial run, --like what do we do? How can we fix this and run it again? But [my mentor scientist] was like 'No no no, don't worry. This happens. This is part of it--part of, you know, science.' He didn't make me feel bad, but [rather] it's just part of science. (Interview 4)

Efforts to normalize scientific uncertainty on the part of the mentor scientists tended to emphasize forward movement—(e.g. acknowledging the difficulty but stressing that one must keep going)—a sentiment that aligns with perseverance. The mentor scientist's moves to support Ava by normalizing uncertainty and offering consolation (see above) exemplify similar moves made by other mentor scientists who, particularly in light of instrumental uncertainty, were quick to reassure the teachers that such encounters were "part of science".

Cohort peers and junior lab members: Commiseration in frustration

Another key resource in supporting all four teachers' development of perseverance was that of their RET cohort peers, as well as members of their lab groups who were *not* their mentor scientist. These more junior lab members typically included undergraduate and graduate students whose research was related to the work of their mentor scientist. We choose to present RET cohort peers and junior lab members as a single key resource in teachers' development of perseverance because of the comparable role they played in affirming and commiserating with our teachers' experiences of frustration and anxiety in light of uncertainty. Each of the four teachers in this study were able to articulate moments in which conversations with others served to reassure them that they were not the only ones experiencing frustration and anxiety, and that such feelings were warranted and reasonable responses for the moment. Having their feelings heard, acknowledged, and identified with by those in similar positions as themselves often served to motivate the teachers to persevere through the encounter with uncertainty, even if these commiserations did not necessarily eliminate teachers' frustration.

Conclusions and implications

Throughout the RET program, the four teachers encountered scientific uncertainty multiple times, experienced frustration in response to uncertainty, and developed a stance of perseverance over the course of the program. Developing perseverance in light of uncertainty, we have shown, was facilitated by interactions with mentor scientists and peers. This finding underscores the essential nature of social interactions as a core feature of productive scientific research experiences (Southerland et al., 2016). The roles of these two key actors (mentor scientists and peers) served different functions. Mentor scientists made moves that attempted to quell teachers' anxieties around uncertainty, as well as to normalize uncertainty as a natural part of scientific pursuits. Interactions with peers afforded teachers opportunities to identify and empathize with one another around their encounters with uncertainty and their related feelings of frustration. In tandem with this, having firsthand experiences with science and having commiserate peers allowed these teachers to begin to normalize and embrace the emotions inherent in scientific work (Davidson et al., 2020).

Teachers of science who have wrestled with scientific uncertainty and have been supported to develop a stance of perseverance may be well positioned to support their own students to productively navigate encounters with uncertainty—and corresponding feelings of frustration—in the science classroom. As the field continues to examine ways to incorporate scientific uncertainty into students' learning experiences (Manz & Suarez, 2018), we argue that both teachers and their students should have opportunity to feel as scientists do in relation to uncertainty and to be afforded opportunities to navigate their emotions in order to persevere in science.

References

Anderson, E., Carleton, N., Diefenbach, M., & Han, P. (2019). The relationship between uncertainty and affect. *Frontiers in Psychology, 10*, 2504.

Buck, Z. E., Lee, H.-S., & Flores, J. (2014). I am sure there may be a planet there: Student articulation of uncertainty in argumentation tasks. *International Journal of Science Education, 36*(14), 2391-2420.

Charmaz, K. (2008). Constructionism and the grounded theory method. In J. A. Holstein and J. F. Gubrium (Eds.) *Handbook of constructionist research.* Guilford Press.

Davidson, S.G. & Hughes, R. (2018). Communities of practice as a framework to explain teachers' experiences within the community of science. *Journal of Research in Science Teaching, 55*(9), 1287-1312.

Davidson, S.G., Jaber, L., & Southerland, S. (2020). Emotions in the doing of science: Exploring epistemic affect in elementary teachers' science research experiences. *Science Education, 104*(6), 1008-1040.

Enderle, P., Dentzau, M., Roseler, K., Southerland, S., Granger, E., Hughes, R., Saka, Y. (2014). Examining the influences of RETs on science teacher beliefs and practice. *Science Education, 98*(6), 1077-1108.

Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education, 92*(3), 404-423.

Jaber, L. & Hammer, D. (2016a). Engaging in science: A feeling for the discipline. *Journal of the Learning Sciences, 25*(2), 156-202.

Jaber, L. & Hammer, D. (2016b). Learning to feel like a scientist. *Science Education, 100*(2), 189-220.

Latour, B. (1987). *Science in action*. Cambridge, MA: Harvard University Press.

Manz, E. (2018). Designing for and Analyzing Productive Uncertainty in Science Investigations. *International Society of the Learning Sciences*, 288-295.

Manz, E. & Suarez, E. (2018). Supporting teachers to negotiate uncertainty for science, students, and teaching. *Science Education, 102(*4), 771-795.

National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas.* Washington, DC: National Academies Press.

Pickering, A. (1995). *The mangle of practice: Time, agency, and science*. Chicago, IL: University of Chicago Press.

Southerland, S., Granger, E., Hughes, R., Enderle, P., Ke, F., Roseler, K, Saka, Y., & Tekkumru-Kisa, M. (2016). Essential aspects of science teacher professional development: Making research participation instructionally effective. *AERA Open, 2*(4), 1-16.

SRI International (2007). *Evaluation of Research Experiences for Teachers (RET) program: 2001-2006.* Prepared for The National Science Foundation, Division of Engineering Education and Centers. Retrieved from http://nsf.gov/eng/eec/EEC_Public/RET.pdf

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International Society of the Learning Sciences

Agency and Expressivity in Programming Play

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Abstract: Computer programming has been conceptualized as an expressive medium, but little is known about how to best support students in exercising agency and engagement in coding tasks. This paper draws on data from a five-day summer camp for middle school students that integrated computer science and movement. We focus on an activity in which students created choreography and modeled it in the programming environment NetLogo. The task was designed with the goal of creating opportunities for students to exercise agency and expressivity while coding. We analyze the extent to which *incompatibilities*, or moments of mismatch between what is possible in the dance versus NetLogo environments, shaped students' agency and exploration. Our findings suggest that designing with incompatibilities positioned students with agency over their models and supported their own expressive goals.

Introduction and framing

Computer science has far-reaching connections to multiple fields that vary widely from science, to geography, mathematics, art, and beyond. Each application reveals new potential for the ideas, development, and applications of computer science. There are many questions about how these different contexts frame and support students' engagement in computer science. In this study we focus on computer programming as an expressive medium and explore how features of a designed space that intentionally constrains students' choices influence the ways they ultimately exercise agency in their own programming work.

The connection between computer science in general, and coding in particular, with art and artistic expression is not new, although it continues to be a less well-developed venue for computer science connections than other disciplines such as engineering or science (Arts Education Partnership, 2004; Maeda, 2001). There are some who argue that coding is a new medium that can be used to allow for maximum expression—an urgently needed new tool to ensure that artists communicate across all outlets (Edmonds, 2019). Others argue that the integration of technologies and computational thinking into the arts supports the development of an entirely new field, Media Arts (Peppler, 2010). Regardless of its name, coding languages can be seen as both expressive and representational systems, as they allow for the development of images, stories, and experiences that represent and make connections with the messages and experiences an artist conveys.

Coding can also be seen as an act of empowerment, in that telling stories and rewriting tools offers a new way to read and write the world (Freire, 1970/1996; Ryoo et al., 2020). Thus, coding has the potential to position students with agency as they determine for themselves how to tell their own stories. But how can programming environments best be designed to support exercising agency? In other fields it has been well-established that the mere fact that a discipline *can be* explored with agency and authority doesn't mean that it *will be.* Instead, careful attention must be paid to the nature of the tasks that organize activity, the norms of the classroom in which students are situated, and the ways students are positioned relative to each other if students are legitimately to have an opportunity to exercise their own agency (Gresalfi & Hand, 2019).

While the field of computer science education is still in the beginnings of exploring curriculum design for k-12 contexts, there are many places to look for insight into how to proceed, and indeed these ideas have already started to be taken up in the field. Specifically, the fields of math education and science education have a long history of emphasizing the potential of play and exploration as crucial ways of engaging with the core practices of problem posing, exploring structure, and problem solving, and such practices are likely central to supporting students to engage in programming with agency and authority (Wager & Parks, 2014). Bringing play into mathematics also provides opportunities for children to come to see themselves as "math people" (Parks, 2015). Reshaping mathematics norms and practices serves to position students differently with respect to the discipline, broadening not only the experiences that students might have, but also, how those experiences lead them to reach different conclusions about their abilities and preferences.

This analysis explores how particular features of task design invite students to exercise agency over and creative expression in their own coding and projects. We define agency as an act of volition, which can include making choices, defending decisions, or deciding when the model is correct. Expressivity is defined as an exploration of representational possibilities with a focus on artistic or aesthetic goals. We focus on a modeling activity that asks students to represent their own dance and translate it into NetLogo code, which requires that students determine for themselves whether their translation is sufficient. In what follows, we offer an overview of the study and the particular tasks that are the focus of this analysis, and then present findings that demonstrate how those tasks supported students to exercise agency and creative expression in their coding.

Study setting

We analyze data from a free five-day summer camp for middle schoolers held in a southeastern city in the United States in 2019. This camp integrated movement and computer science in order to leverage full body movements as an expressive form of computational learning. It utilized the programming environment NetLogo (Wilensky, 1999), a multi-agent environment in which students use text-based programming language to manipulate movable agents (turtles). There were two classrooms, one with 11 students and one with 13. Each classroom was staffed by two teachers and one teaching assistant. Additionally, two researchers moved through both rooms, providing coding help when requested.

This analysis focuses on an activity that occurred on the second day of the camp called the Telephone Game, co-designed by researchers, professional dancers, and the teachers that led the camp. In our variation, student quartets created a choreography "message" using a large square sheet of mylar, coded their choreography in NetLogo, and then switched models with another group and interpreted them as choreography. This paper considers the second phase of the activity: using NetLogo to model dance choreography.

Students were provided with two possible setup buttons, both consisting of four turtles connected in a square shape with links. As students coded, they were expected to encounter moments where they had to make decisions about how to model their dance because of differences between what is possible in the system of mylar/dance and what is possible in the system of NetLogo. For example, in the dance world, it is easy for people to let go of the mylar and move to another location, but in NetLogo, moving a turtle (often viewed by students as the people in their model) also causes the links (viewed as the mylar in the model) to move. We call these moments of mismatch between what is possible an *incompatibility.* Students encountered an incompatibility when their model behaved in NetLogo in a way that would be impossible using mylar and physical movement.

The activity was intentionally designed to engage students in the task of translating between incompatible systems, with the goal of creating opportunities for students to exercise their own personal agency in resolving these incompatibilities. The environments of the physical dance world (four people moving with a mylar prop) and the world of NetLogo (a two-dimensional space containing turtles, patches, and links) have vastly different constraints, providing space for making representational choices in NetLogo and interpretive choices with the mylar. In this way, unlike the traditional telephone game, the task was designed to not allow for a single correct answer or a more or less "accurate" interpretation. Rather, the task invited students to explore the expressive potentials of both environments and positioned them with agency to explain their discoveries.

Methodology

We examine screencaptures of six students independently coding their dances in NetLogo. We included only the students that worked independently (i.e. without the constant presence of a peer or teacher, though students did talk to each other and ask for help) in order to be able to understand students' decision-making process without guidance and suggestions throughout from a teacher. These students represent all the consented participants with screencaptures that worked independently on the task. Three students (Chris, Jonah, and Zaair) were in both the same classroom and the same quartet. The students in the other classroom were in two different quartets (Harrison and Xavier were in the same quartet and Kyle was in another).

As stated, one of our goals for the activity was to invite students to exercise personal agency and foreground their own expressive goals as they made representational choices. We seek to understand what students do when they encounter mismatches between what is possible in each context. Our research questions are:

1. How does working with representational systems with incompatibilities position students with agency in evaluating their models?
2. How does encountering incompatibilities invite expressivity?

Analysis

There were several phases of analysis. First, we watched students' NetLogo screencaptures multiple times, using principles of grounded theory (Strauss & Corbin, 1994) to write analytic memos for each student. Throughout this process, incompatibilities emerged as a theme across videos, and we began focusing on students' decision-making process in moments where the model did not behave as they expected. In order to further explore these moments, in our second round of analysis, we turned to open coding using the video coding software V-Note. The videos were parsed by marking each incompatibility and whether students reacted to it. This coding helped to highlight important or interesting decision points in students' coding practice. In a larger paper (Steinberg & Gresalfi, 2021), we share the details of the breadth of this coding. In this paper, we look closely at two particular phenomena: whether and how students seemed to exercise agency, and how incompatibilities led to exploration.

Findings

Agency

There were two features of the activity that appeared to support student agency. First, the task of translating between intentionally incompatible representational systems meant that students could not create a model that was an exact replica of their choreography. As they encountered incompatibilities, they had to make decisions about whether and how to address them. This decision-making was inherently personal; some students were satisfied with representations that portrayed only the movement of the mylar while ignoring what the people did, while others wanted to accurately portray both. Students demonstrated agency in navigating these incompatibilities. Second, the activity was designed to allow students to model a dance that they created, which positioned students to determine for themselves when their representation was finished. For example, Jonah believed that he captured the dance with his model (Figure 1 Image A), but when he showed it to Chris, a peer in his quartet, Chris saw lots of things that needed to be changed. When Jonah told Chris that he was done, Chris responded by questioning why the person was running backwards and explained that "it should be going in the middle, and those two guys'll come in closer, and then they'll go back out." Jonah rejected Chris's advice, by saying "Ok, no I was gonna do something..." and edited his model so that two turtles moved in and out instead of just one (Figure 1 Image B). Jonah again showed Chris his model and asked Chris if it looked like they're trading places. Even though Chris responded "It's going so fast you can't see it," Jonah remained confident in his own interpretation, and said "See, they're switching spots for a second, then they're going back." Jonah made a final move to set the shape of his turtles to people, and then a teacher checked in. Jonah told the teacher, "I think I may have completely done one of them" (Figure 1 Image C). While Jonah and Chris disagreed on how to represent the dance, Jonah followed his own instincts and was ultimately satisfied with his representation.

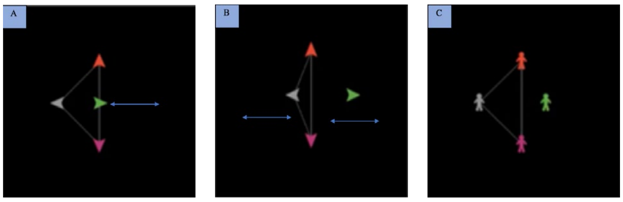

Figure 1: Jonah's NetLogo choreography as he negotiated his own and a peer's representational interpretations. Blue arrows demonstrate movement of turtles.

Incompatibilities created opportunities for choice, which led to model diversity and afforded agency to students. Because of the personal nature of the dance, there was no one correct answer, and even students with the same choreography ended up with different final models. To show letting go, Zaair deleted the links completely, Chris drew the mylar using the pen function, and Xavier used turtle size to show who was holding on. Students were positioned as the only ones that could decide when their model was "good enough".

Expressivity

While students were often frustrated by the presence of incompatibilities, there were some cases where students were inspired by the incompatibility and used it as an opportunity to extend the model artistically. For example, Kyle chose to represent the person/mylar system using a single turtle shaped square, and as he made his square mylar grow and rotate, it eventually became so big that the turtle wrapped (an incompatibility). Capitalizing on the appearance of this model, Kyle began adding more square turtles to the model, creating an aesthetically pleasing effect. Here, Kyle built on and extended the incompatibility, deviating from his choreography. The goal of his model changed from representing his choreography to creating a work of art of another form.

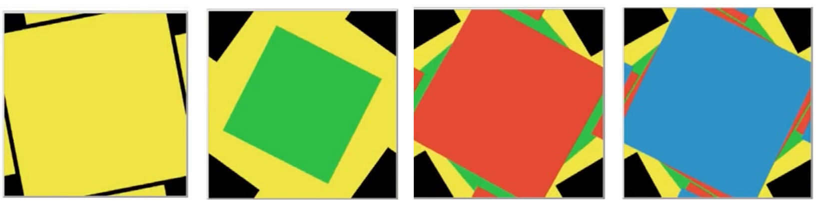

Figure 2: Kyle's artistic expansion of an incompatibility.

Other students also commented on the artistic quality of their models. As Harrison tried to figure out rotating, he expressed, "That's a cool animation but it's not what we need." When Jonah encountered the world wrapping, he said, "Hahah, I ripped it into pieces!" While not all movements explored made it into the choreography, exploring them helped to broaden what students understood as possible in the environment. Incompatibilities prompted exploration of the boundaries of a representational environment and invited artistic expression that was different from the straight modeling task. Students were able to exercise their own agency as they imaginatively explored the space of possible mappings between their NetLogo representation and their dance and moved from describing the dance towards expanding it.

Discussion and conclusion

In our analysis, we found that as students encountered incompatibilities, they exhibited personal agency over their coding as they made choices about which elements of the dance were important to foreground in their models to create a satisfying representation of their dance. Incompatibilities helped students to see the expressive possibilities available in NetLogo. Our findings reveal that bringing computer programming together with an embodied, creative experience like dance can support student agency and expressivity. Specifically, asking students to model a phenomenon that they created themselves and that had different properties than the programming environment was productive. Brady (2018) suggests that it might be desirable to pose problems where learners encounter limitations in order to prompt them to move beyond the target concepts to build more sophisticated understandings. Likewise, in encountering the limitations of NetLogo to create an exact replica of the dance, our students engaged in representational play and demonstrated agency in evaluating their models.

References

Arts Education Partnership (US), & United States. Dept. of Education. (2004). *The arts and education: New opportunities for research*. Arts Education Partnership.

Brady, C. (2018). Modelling and the representational imagination. *ZDM*, *50*(1–2), 45-59.

Edmonds, E. (2019). Programming as Art. In E. Edmonds and M. Boden (Eds.), *From Fingers to Digits, an Artificial Aesthetic*, (pp. 209-222). Cambridge, MA: MIT Press.

Freire, P. (1970/1996). *Pedagogy of the Oppressed*. New York: Continuum.

Gresalfi, M., & Hand, V. M. (2019). Coordinating situated identities in mathematics classrooms with sociohistorical narratives: A consideration for design. *ZDM*, *51*(3), 493-504.

Maeda, J. (2001). Design by numbers. Cambridge, MA: MIT press.

Parks, A. N. (2015). *Exploring mathematics through play in the early childhood classroom*. New York, NY: Teachers College Press.

Peppler, K. (2010). Media arts: Arts education for a digital age. *Teachers College Record, 112(8)*, 2118-2153.

Ryoo, J. J., Tanksley, T., Estrada, C., & Margolis, J. (2020). Take space, make space: How students use computer science to disrupt and resist marginalization in schools. *Computer Science Education*, 1-25.

Strauss, A., & Corbin, J. (1994). Grounded theory methodology. *Handbook of qualitative research*, *17*(1), 273-285

Steinberg, S., & Gresalfi, M. (2021). *Coding choreography: Understanding student responses to incompatibilities between possibilities in programming and dance.* [Manuscript submitted for publication].

Wilensky, U. (1999). Center for connected learning and computer-based modeling. In *NetLogo*. Northwestern University.

Wager, A., & Parks, A. N. (2014). Learning mathematics through play. In L. Brooker, M. Blaise, and S. Edwards, (Eds.), *Play and Learning in Early Childhood (pp.* 216-27). Thousand Oaks, CA: Sage.

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Interactions with Peers on the Path to Math Success

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Abstract: A key strategy to being successful in math is help-seeking. Much research has focused on how students seek help from teachers, but students also benefit from peer assistance. We analyzed conversations from eight focus groups related to students' paths to success in math. We found that students frequently brought up peer interactions as critical to their success. Three emergent themes were: support versus comparison, balance of effort within study groups, and friends versus peers. Our findings qualitatively extend current research by highlighting key ideas that impact peer interactions, such as increased reluctance to seek help in larger classes. Our findings have implications for classroom and group structures, including encouraging peer help-seeking and help-giving, as well as addressing belonging and sense of community.

Introduction and background

As students learn, they may face challenges that require assistance to overcome. However, in the face of adversity, students do not always seek help, which can inhibit their academic achievement. In school environments, students are shaped by their interactions with peers. With more detailed accounts of how peer interactions can aid or harm students' paths to math success, educators can orient their classrooms to set students up for math achievement, potentially through peer interactions and collaboration. While the current literature focuses on quantitative patterns, this study seeks to learn more about how students describe their lived experiences.

Seeking help when navigating obstacles to learning is a key self-regulated learning skill (Karabenik, 2011). Although students tend to focus on teachers for learning support, using peers as a resource has additional benefits. Access to multiple explanations (i.e., beyond that of the teacher or text) of mathematical concepts can help students experience new perspectives (Tripathi, 2008). Moreover, helping others and seeing peers model success can increase self-efficacy and ownership in learning (Walker et al., 2010). Help-seeking from peers can also increase socialization, an important developmental skill for younger students (Newman, 2000).

Despite the benefits, some students still avoid seeking help for many reasons. For some, the likelihood of seeking help is negatively related to the perception of subsequent psychological risks (Peeters et al., 2020). These can include embarrassment in admitting confusion or errors (Karabenik, 2011), fear of frustrating the teacher or slowing down the class (Peeters et al., 2020), indebtedness to the help-givers (Karabenik, 2011), and negative social comparison to other more-capable peers (Newman & Schwager, 1993). Additionally, if students lack confidence in their peers' (or even the teacher's) ability to understand their confusion and provide adequate help, they will likely not seek help (Newman, 2000; Peeters et al., 2020).

Students' help-seeking behaviors and peer interactions are also related to their academic achievement goals (Roussel et al., 2011; Shim & Finch, 2014). Compared to students focused on demonstrating competence in relation to the task itself or their own previous competence (mastery goals), students focused on demonstrating competence in relation to others (performance goals) are less likely to engage in productive help-seeking behaviors or see peers as instructional and emotional supports (Shim & Finch, 2014). Naturally, when students focus on their own learning and improvement, rather than in relation to others, they are less likely to fear social comparison (Roussel et al., 2011) or engage in competitive, maladaptive behaviors' (Newman & Schwager, 1993).

Most studies on peers as a resource are quantitative, focusing on identifying variables that impact help-seeking behavior and learning (e.g., Roussel et al., 2011). More research is needed to understand how students think about interactions during peer support and how these can help them overcome challenges while learning math. Therefore, in this qualitative study, our research question is: *How do students describe interactions with peers on their paths to math success?*

Methods

We conducted focus groups twice weekly for four weeks (n = 8) to learn more about students' experiences while learning math. We posed pre-scripted questions to the students in these structured sessions, which were held online virtually due to the COVID-19 pandemic. Our recruitment targeted identity-based affinity groups at nearby colleges, from whom we recruited current undergraduates, graduate students, or recent graduates. The participants (n = 25) were students from universities mainly in the northeastern United States and one student who attended a university in the southeastern United States. Results from an optional demographic survey show a diverse group of participants for both race (12% Asian, 20% Black, 16% Latinx, 4% White, 2% Multi-race, 1% Other, 36% Unspecified) and gender identity (20% Male, 40% Female, 4% Genderqueer, 36% Unspecified).

This study is part of a larger project aimed at understanding student experiences in overcoming challenges to achieve math success. In each focus group, we asked students to describe past challenges during math learning, the effects on their sense of belonging, overcoming these challenges, facing new challenges, and advice for others. Although participants were not explicitly asked about their peers, we found that peer interactions was an emergent theme, particularly when participants were asked about their experiences, resources, and belonging. The codes we used to describe these interactions were peer relationships, peers as a resource, and belonging among peers.

We developed a codebook to capture students' experiences and challenges based on their discussions in the focus groups. This codebook used deductive codes based on the current literature and inductive codes that emerged throughout our research process. We coded for students' experiences with support and resources, identity and belonging, and persistence. Each focus group transcript was double-coded, and researchers met to reconcile any differences. The overall interrater reliability was over 80% and 100% once reconciled. For each segment of the focus group transcripts with a peer-related code, we identified the student's description of their experience and added an analytic memo regarding the key idea that the student discussed. After completing this for every mention of peer interaction, we derived three common themes. Students described (1) themselves as supported by or in comparison to their peers, (2) the need for balance of effort within study groups, and (3) describing other students as "friends" vs. "peers." We then chose representative excerpts for each of these themes to illustrate how the students (using pseudonyms) articulated their experiences with peers.

Results

The students' descriptions of interactions with peers included asking for instructional help, seeking emotional support, and working in study groups. We found three emergent themes related to how students described their peers and peer interactions as they discussed their paths to success in math.

Support versus comparison

Many students noted the benefits of getting peer help, specifically the positives of studying in small groups. For example, Sunny (Black, genderqueer) noted that "developing a more group style of working helped a lot," adding how they initially worked alone in college and would go to office hours for help. In later years, however, they "learned how to work with [their] classmates and set up study sessions sometime in the evening. Then if [their group] couldn't get it on [their] own, then [the group] would go to TA office hours together." Lucia (Latina, female) expanded this idea by also recommending a friend group "that's supportive of you and understands how you're feeling and knows that everyone struggles with something and math may be the thing you're struggling with." Eliza (no demographic data) also discussed the importance of having "more knowledgeable peers" (Newman, 2000, p. 352) in the study group: "there was usually one person that understood everything the professor said the most, so [the group] would just make him or her the teacher in a sense, and it was a smaller class. It was like five people." Zora (Black, female) added that even when no one in the group understood the instructor, there was a sense of community in the confusion that helped prevent feelings of isolation.

Conversely, some students describe peers more as a unit by which to compare their understanding and performance. This could be seen in Mario's (Latino, male) description of his struggles in a college math course, stating, "[my peers] had an idea of what was going on and I didn't. Even when we got together in groups to study and whatnot, I was the one that was making the really dumb questions." He later admitted that he thought that he was so far behind that the professor and classmates would think less of him because he "wasn't at their level." In his case, the support given by his study group was overshadowed by the insecurities he felt when he compared himself to his classmates. Interestingly, Eliza also noted a similar comparison in extracurricular activities, discussing how they joined an engineering club in which they were "scared to ask questions to [other club members]." Eliza ultimately left the club due to overwhelming feelings of discomfort and questioning their self-worth. Eliza went on to describe finding an identity-based organization for Latinx students, noting that many of these members also questioned their daily worth. Through this organization, Eliza learned about imposter syndrome and found a sense of community: "These are my people. This is where I need to latch on and just trust that we'll all make it through together. It did challenge me, but then I also was able to find my niche." Eliza's example demonstrates the importance of a sense of belonging and community within a peer group.

Balance of effort within study groups

Several students discussed the importance of balance with regards to effort within peer study groups. Lucia stated that she would "spread [her] asks around" to avoid "burdening any one person" and that this strategy would increase everyone's willingness to help. Ryder (no demographic data) discussed the reciprocality of asking help from and giving help to peers: "I get very worried about being parasitic, but it felt a lot more mutual, so it was nicer in the long run." Eliza discussed group members taking turns going to office hours. When personally confused about the content, Eliza would always volunteer to go from the group. These students' statements imply an attentiveness to group functioning and highlight a key give-and-take mechanism for productive study groups.

Friends versus peers

As seen throughout the previous examples, there was a clear divide in how students referred to those from whom they sought help. Some referred to them warmly as "friends." Lucia stated, "I know a lot of my friends have been really understanding. I've definitely broke down crying about stupid math problems before to multiple of them, and they've all been really understanding, and they're just really reassuring." Others, as seen in the comparison examples above, referred to them as peers, implying a detachment or weak relationship with them. We had two graduate students discuss a possible explanation for these differences: class or cohort size. Eliza stated that issues with belonging in their undergraduate program were related to the "size of the group or the class." Eliza elaborated to describe how the uncomfortable feeling in one large class: "If you ask a question, it spooks you out a bit because you have 300 faces looking at you wherever you're at." Ryder expanded this idea by describing the differences between their master's and undergraduate programs. The master's program was "pretty small" with around 14 full-time students, which allowed students to "[get] to know each other really well." Ryder added, "It was easier to ask people I knew because with the high student-teacher ratio in undergrad, it just really meant that I still didn't know any of my classmates for whatever reason, whether I felt like I belonged or not." Ryder also explicitly stated, "grad school math definitely went a lot better because I did ask for help from somebody."

Discussion and conclusion

In this study, we qualitatively analyzed students' descriptions of interactions with their peers in their path to math success. To date, most research on this topic has been quantitative, focusing on factors influencing peer help-seeking such as the perception of psychological risks and negative social comparison. Our study confirms many of these findings but benefits from an in-depth qualitative analysis to further explain and expand the current literature. For example, we had descriptions of insecurities and low self-worth, resulting from social comparisons, that interfered with peer help-seeking. We also saw expressions of a spectrum of achievement goals from performance-oriented (e.g., Mario comparing his performance to his classmates') to mastery-oriented goals (e.g., Lucia working with peers to gain a better understanding of the content).

We also had findings that extend the literature. First, our findings related to belonging and community were connected to a new important consideration for peer help-seeking: class or cohort size. The graduate students in the study were able to provide a clear comparison between large undergraduate and smaller master's class sizes, demonstrating the difference in their ability to know and connect to their peers. Next, we found that students discussed the balance of effort in small peer groups and how knowledge and tasks can be distributed among group members. Interestingly, even when no one in the group understood the content or task, there was still a need for non-content support (e.g., validation). This extends the current literature on help-seeking by connecting to research on socioemotional regulation strategies (c.f., Lobczowski et al., in press). These findings highlight the importance of a sense of belonging among peers, as well as building a community, especially among small groups.

Implications, limitations, and future directions

Our study has implications for both research and practice. First, it highlights the importance of setting group norms related to balancing effort. Similarly, students should not only be encouraged to seek help when needed but also volunteer assistance when applicable. This will help create a culture of peer support in the classroom. Instructors of large classes also need to find ways for students to interact and get to know one another. For example, students could participate in partner discussions during class or collaborate on group projects. Each of these ideas can help increase a sense of belonging and community with the classroom and small peer groups.

Although we had a limited sample of participants (*n* = 25) in our focus groups, this allowed us to hear more from each participant and dive deeper into their experiences. In the future, our findings could be used to create a survey to reach a broader audience. Despite our efforts to recruit participants from a variety of universities, our pool represented a smaller group of institutions. However, the participants comprised a diverse group of majors and disciplines. Going forward, we will seek out participants from institutions varying in size, both large and small. During the focus groups, we did not explicitly ask participants about their peer interactions, yet it was mentioned in all but one focus group and emerged as an overall theme. In future research, we would like to ask participants directly about their experiences with their peers.

References

Karabenick, S. A. (2011). Methodological and assessment issues in research on help seeking. In B. Zimmerman & D. Schunk (Eds.), *Handbook of self-regulation of learning and performance* (pp. 267-281). Routledge.

Lobczowski, N. G., Lyons, K., Greene, J. A., & McLaughlin, J. E (in press). Socioemotional regulation strategies in a project-based learning environment. *Contemporary Educational Psychology.*

Newman, R. S. (2000). Social influences on the development of children's adaptive help seeking: The role of parents, teachers, and peers. *Developmental Review*, *20*(3), 350-404.

Newman, R. S., & Schwager, M. T. (1993). Students' perceptions of the teacher and classmates in relation to reported help seeking in math class. *The Elementary School Journal*, *94*(1), 3-17.

Peeters, A., Robinson, V., & Rubie-Davies, C. (2020). Theories in use that explain adolescent help seeking and avoidance in mathematics. *Journal of Educational Psychology*, *112*(3), 533.

Roussel, P., Elliot, A. J., & Feltman, R. (2011). The influence of achievement goals and social goals on help-seeking from peers in an academic context. *Learning and Instruction*, *21*(3), 394-402.

Shim, S. S., & Finch, W. H. (2014). Academic and social achievement goals and early adolescents' adjustment: A latent class approach. *Learning and Individual Differences*, 30, 98-105.

Tripathi, P. N. (2008). Developing mathematical understanding through multiple representations. *Mathematics Teaching in the middle school*, *13*(8), 438-445.

Walker, E., Walker, S., Rummel, N., & Koedinger, K. R. (2010). Using problem-solving context to assess help quality in computer-mediated peer tutoring. In *International Conference on Intelligent Tutoring Systems* (pp. 145-155). Springer.

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Developing Social Empathy through Human-Centered Design: The Iterative Journey of Designing an Instructional Booklet for Pre-Service Teachers

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Abstract: A critical goal of teacher preparation programs is to support pre-service teachers (PSTs) in understanding their future students and communities. One way to do this is by assisting PSTs in developing social empathy. This paper describes the design and implementation journey of three prototypes of a social justice in education instructional booklet that aims to engage PSTs in developing their social empathy through human-centered design (HCD) processes that aim to help them understand people from varied backgrounds and their unmet needs. Our prototypes were informed by a conceptualization of social empathy that encourages PSTs to understand people who come from different social backgrounds and findings from research that define concrete techniques to empathize with the users. We discuss the design and implementation of the fourth prototype of this booklet and propose a study to evaluate the impact of the booklet on PST's development of social empathy.

Keywords: human-centered design, social empathy, culturally responsive, teacher education

Introduction

In culturally responsive teaching, teachers embrace students' diverse "cultural knowledge, prior experiences, frames of reference, and performance styles … to make learning encounters more relevant to and effective for them," (Gay, 2010, p. 29). While pre-service teachers (PSTs) may come in with a desire to support diverse students, effectively preparing them to do so starts by fostering their development of social empathy – empathy for those outside your own group identity (Segal, 2011). Social empathy, paired with a clear understanding of social justice and culturally responsive pedagogy, allows teachers to embrace their students' funds of knowledge (Gonzalez, et al., 1995). Nevertheless, our knowledge of pedagogical approaches that can engage PSTs in learning experiences where they practice and develop social empathy is limited.

One potential pedagogical approach is to engage PSTs in human-centered design (HCD), a problem-solving approach that identifies the unmet needs of a population to collaboratively and iteratively develop solutions (Brown, 2008). Research shows that when educators explicitly engage learners in HCD, they develop several mindsets including human-centeredness (Goldman & Kabayadondo, 2017). Social empathy, a component of this mindset, manifests when people "begin to move beyond egocentric views of the world and no longer design based on their own needs, desires, experiences or preferences" (Goldman et al., 2012 p. 17). HCD fosters the development of this mindset by having people actively engage in empathic techniques (Hess & Fila, 2016) such as being immersed in a person's world, interacting with them in interviews, and reflecting on their perspectives.

Considering the capability of HCD experiences to assist learners in developing social empathy, this paper addresses the question of how we might engage PSTs at an historically white institution (Dancy, 2018) in HCD experiences that assist them in developing their ability to empathically understand their students and communities. The paper describes the design and implementation of an instructional booklet that aimed to engage PSTs in empathic moves, as part of HCD, to complete a community placement assignment in an introductory social justice in education course at a land-grant institution in the Midwest. The booklet takes us one step further toward supporting PSTs in practicing social empathy and addresses the need in the field of teacher education to support PSTs in developing human-centered mindsets so they can better serve their future students and communities.

Conceptual framework

Research on empathy is grounded in the fields of social work and psychology. Segal et al. (2017) define empathy as a cognitive-affective construct. "Affective empathy describes the physiological aspects of vicariously feeling what another person is feeling, while cognitive empathy involves the mental processing of another's feelings, thoughts, or intentions" (p. 11). Segal et al. label this interpersonal empathy. It includes taking the perspective of others while maintaining self-other awareness and regulating one's own emotions. Interpersonal empathy is the basis for social empathy, which is the ability to understand people by perceiving or experiencing their life situations and as a result gain insight into structural inequalities and disparities" (Segal, 2011, p. 266-267). They described social empathy as having both a macro self-other awareness and macro perspective-taking ability that tasks us with understanding people different from ourselves "by putting ourselves in the situations of others with different characteristics of group identity, such as race, gender, sexual orientation, ability, age, and class background" (p. 27). Social empathy responds to the systemic barriers affecting people in marginalized groups.

In the context of HCD, designers use social empathy to truly understand those for whom they design. Hess and Fila (2016) highlighted this in examining how undergraduate engineering students engaged in empathic techniques as they engaged in HCD to design an accessible zipline experience for youth campers with disabilities. These undergraduates demonstrated 12 empathic techniques: direct observation, empathy by proxy, interaction, projection, empathic concern, synthesizing empathic knowledge, design for user-centered criteria, integration, refine user suggestions, check with user, and imagined use. These empathic techniques support the authors' conceptualization of empathy, which is similar to Segal et al. (2017). Their model explicitly addresses a self-other dimension. They described this dimension as being a dichotomy where people are "imagining how another feels or thinks" or "imagining how one would think and feel in another's situation" (p. 94). This emphasis on self-other awareness aligns with the characteristics present in both a human-centered mindset and HCD. Finally, the concept of social empathy, in the context of HCD, is not complete without the ethical perspective (Boylston, 2019; Segal, 2018) that urges designers to take on the role of creating socio-cultural solutions by being aware of their ethical obligations (Manzini, 2015; Reznick, 2019) and setting aside biases and assumptions. The ethical component challenges those using HCD to question who the best person(s) is to respond to the unmet needs faced by others.

PSTs are the future designers of learning experiences for students from diverse backgrounds. Therefore, it is important that PSTs develop social empathy during their teacher preparation programs so they can better understand, support, and include their future students and communities in their instructional designs, especially when the majority are white. For example, PSTs must examine the biases they bring to designing innovative learning experiences, particularly for those in marginalized populations. Without this step, their concern for social justice issues will be hindered by the simple fact they may be designing from biased perspectives. Engaging PSTs in HCD experiences, specifically the empathic techniques identified by Hess and Fila (2016), may assist them in developing social empathy. Nevertheless, we still lack research-informed instructional tools that can engage PSTs in learning about and implementing these techniques to recognize, develop, and practice social empathy.

Design solution

To support PSTs in developing social empathy, we co-designed an instructional booklet that guides PSTs in implementing the processes of the Understand, Synthesize, and Ideate spaces of the HCD taxonomy (Lawrence et al., 2021) with instructors and teaching assistants (TAs) of a social justice in education course. The activities in the booklet specifically engaged PSTs in exploring and observing an educational setting, empathizing with the stakeholders in the setting, reflecting on their biases, organizing collected information, identifying patterns, defining design opportunities, and suggesting potential solutions. These activities provided explicit experiences and instruction that align with five of the 12 empathic techniques identified by Hess and Fila (2016) (see Table 1). In their research, they determined that students participating in an immersive HCD experience were able to demonstrate these empathic techniques because they actively interacted with actual users as part of the service-learning opportunity. While their research focused on what they observed, we took their work further by designing specific activities that explicitly engage students in each of these techniques both in theoretical and practical ways. Our goal is to further develop PSTs social empathy by explicitly engaging them in these techniques as they navigate through HCD, so they better understand their stakeholders and determine their unmet needs.

Iterative design process

First iteration: Spring 2019 and Fall 2019

The introductory social justice in education course is a required course for future PSTs that focuses on identity and difference. This course has three central components: course lectures, teaching assistant-led discussion sessions, and a community placement experience where PSTs are required to visit and engage in an educational setting to apply the course content to explore, and understand the setting, and reflect on their experiences in the setting. Prior to Spring 2019 semester, the course did not explicitly include any elements of HCD.

In Fall 2018, a newly established design center at this university contacted the course professor to discuss potential collaboration as part of the center's initiative to integrate HCD in higher education courses. In our initial conversations with the course instructor, he noted that the three previously mentioned course components worked well independently, however, he noted it was hard for students to connect the learning outcomes from these components. The professor wanted to design an instructional tool that would help students make strong connections across course lectures, discussions, and their community placement experiences in their final reflection paper for the course. However, he insisted that he wanted this done with minimal change to the existing course curriculum and structure. After brainstorming a set of ideas, we decided to design an instructional booklet that would assist students in approaching the community placement experience using HCD. In our design of the booklet, we aimed to assist students in connecting the course content to how they implement HCD processes and document their learning outcomes during their community placement experiences. We also aimed to foster students' development of human centeredness. In this first iteration, IDEO's human-centered field guide (IDEO, 2015) informed our design of the instructional booklet. It was composed of five sections: Assumptions and Hypotheses, Observations, Interviews, Patterns, and Insights, and Design opportunities. Each section included prompts that guided the students in implementing the relevant HCD processes and documenting the outcomes.

Table 1: The five techniques from Hess and Fila (2016) reflected in the booklet.

Empathic Technique	**Definition**
Direct Observation	Observing stakeholders in the context where the problem/design challenge exists to understand the context, problem, and users.
Empathy by Proxy	Speaking with intermediaries who act on behalf of users or who are middlemen between the designer and user in order to define constraints.
Interaction	Interviewing and talking with potential users of your design to develop understanding of their needs.
Projection	Mentally putting oneself into the shoes of the users to encourage reflection and deeper understanding of the users.
Empathic Concern	Using learnings about potential users to help set design criteria that align with the users' well-being. This typically relates to safety concerns and design constraints.
Synthesize Empathic Knowledge	Often in concert with empathic concern, synthesizing all learnings to set design criteria - including defining constraints and design opportunities.

At the end of Spring 2019, we administered a post-course survey to assess students' knowledge of HCD processes and acquiring HCD skills (Shehab et al., 2021). The 23-item survey used a 5-point Likert Scale with 1 = strongly disagree and 5 = strongly agree. Forty students completed the survey; many were neutral toward almost all items. Instructor and TA interviews further explained this finding, stating the booklet added more structure to the community placement exercise, however, they mentioned that the booklet did not make the necessary explicit connections between the course content and the different HCD processes, including those on empathy.

In light of the collected data, we developed a second prototype of the booklet in Fall 2019 by making minor changes. We added an Introduction section where we explicitly stated the definition of HCD and the purpose of the booklet as a tool to apply HCD processes to design relevant and meaningful solutions to problems identified during the community placement experience. We also met with the instructor and the teaching assistants who suggested reducing the number of interviews that the students were required to conduct. The booklet was implemented again in the Fall 2019 semester. To gain a better insight of how the students were using the booklet, one researcher from the center observed one discussion section whenever the TA was engaging the students in the content of the booklet. Observations suggested the need to guide the TAs through assisting the students as they use the booklet. Seven students consented to share their completed booklets with the research team. Examining the content of the booklets suggested that the students are using the course content to complete some sections; however, we still needed to add sections that could help students think about and reflect on their participation in the HCD processes, which in turn, can promote their development of social empathy.

Second iteration: Fall 2020

Prior to Fall 2020, we designed a third prototype of the booklet based on the first iteration. We incorporated three central changes. The first focused on building in instructional activities that explicitly engaged students in the five empathic techniques that are described in Table 1. For example, we included an interview planning guide that asked students to think through who they needed to interview and what kinds of questions they needed to ask them. We also added reflective practices (Goldsmith, 2012), such as self-assessment rubrics, that allow students to reflect on how well they engaged in HCD processes throughout the booklet. These changes made HCD processes more transparent for the students, the TAs, and the instructor of the course. Finally, to support TAs, we built in guided notes in a teacher's edition of the booklet. These guidelines gave TAs explicit tips to help students engage and reflect on HCD processes more fully. For instance, in the student's edition, students were asked to answer the question "Who are you?". To support TAs in helping students to critically answer that question, we included guidelines that encourage TAs to "unpack" that question by describing positionality and perspective.

Discussion

Navigating the iterative process of designing this booklet required aligning the needs of the course with the possibilities of integrating the HCD processes. Each iteration built off feedback from instructors and students as well as researchers' observational data. Additionally, as the booklet evolved, research on HCD, particularly on empathy education, has influenced the types of activities that are included in the booklet, particularly in the third prototype. The first two iterations revealed that students have a somewhat clearer understanding of how to implement HCD processes after the course. However, we still have little insight into how effectively this booklet supports students in developing a human-centered mindset, specifically social empathy. Further research must be done to establish the booklet's effectiveness in developing social empathy in future PSTs. Therefore, we propose to conduct future research that seeks to explore the question: how does an HCD booklet impact students' generation of empathic solutions to educational problems and the development of social empathy? This study will conduct both pre- and post-surveys that seek to measure students' social empathy levels. Additionally, the research team will gather observational data of discussion sessions to document the interaction between TAs and students with the booklet. Finally, we will collect students' completed booklets and conduct content analysis to examine if students demonstrated evidence of effectively engaging in the empathy techniques promoted in the booklet and generating empathic solutions to educational problems. We will also conduct interviews with students to understand the impact of the booklet on their development of social empathy and their perceptions of its use in designing curriculum for their future students and communities. The proposed study has the potential to impact our understanding of using HCD pedagogy in teacher preparatory programs. Particularly, evidence that the booklet does in fact help PSTs develop social empathy as part of a human-centered mindset as they engage in Hess and Fila's (2016) empathic techniques will support the argument that empathy is teachable, and explicitly engaging learners with these empathic techniques in instructional activities fosters that learning.

References

Boylston, S. 2019. *Designing with Society: A Capabilities Approach to Design, Systems Thinking and Social Innovation:* Routledge.

Brown, T. (2008). Design Thinking. *Harvard Business Review*, *86*(6), 1–9.

Dancy, T.E., Edwards, K.T., & Davis, J.E. (2018). Historically white universities and plantation politics: Anti-Blackness and higher education in the Black lives matter era. *Urban Education, 53*(2), 176-195.

Gay, G. (2010). *Culturally responsive teaching: Theory, research, and practice.* Teachers College Press.

Goldman, S., Carroll, M. P., Kabayadondo, Z., Cavagnaro, L. B., Royalty, A. W., Roth, B., Roth, B., Kwek, S. H., & Kim, J. (2012). Assessing d.learning: Capturing the Journey of Becoming a Design Thinker. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design Thinking Research* (pp. 13–33). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-31991-4_2

Goldman, S., & Kabayadondo, Z. (2017). *Taking Design Thinking to School: How Technology of Design Can Transform Teachers, Learners, and Classrooms*. Routledge.

Gonzalez, N., Moll, L.C., Tenery, M.F., Rivera, A., Rendon, P., Gonzales, R., & Amanti, C. (1995). Funds of knowledge for teaching in Latino households. *Urban Education, 29*(4), 443-470.

Hess, J.L. & Fila, N.D. (2016). The manifestation of empathy within design: findings from a service-learning course. *Codesign, 12*(1-2), 93-111.

IDEO. (2015). *The field guide to human-centered design*. Canada: IDEO.org. Retrieved from http://www.designkit.org/resources/

Lawrence, L., Shehab, S., Tissenbaum, M., Rui, T., & Hixon, T. (2021, June). *Human-Centered Design Taxonomy: Case study application with novice, multidisciplinary designers.* Poster to be Presented at the American Education Research Association Virtual Conference.

Manzini, E. 2015. *Design, when everybody designs: an introduction to design for social innovation:* The MIT Press.

Reznick, E. 2019. *The social design reader:* Bloomsbury Visual Arts.

Segal, E.A. (2011). Social empathy: A model built on empathy, contextual understanding, and social responsibility that promotes social justice. *Journal of Social Service Research, 37(3)*, 266-277.

Segal, E.A., Gerdes, K.E., Lietz, C.A., Wagaman, M.A., & Geiger, J.M. (2017). *Assessing empathy:* Columbia University Press.

Segal, E. A. 2018. *Social empathy: The art of understanding others:* Columbia University Press.

Shehab, S., Lawrence, L., Tissenbaum, M., Rui, T., & Hixon, T. (2021, June). *Integrating Human-Centered Design in higher education classrooms: Evaluating the first iteration*. Paper to be Presented at the American Education Research Association Virtual Conference.

Ideologies, Teacher Discourse, and Language Learning in the Elementary Science Classroom

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Abstract: The monolingual ideologies that are systemically reproduced in the United States educational system impede equitable learning for all students, and particularly for multilingual learners. Drawing on Philip's (2011) ideologies in pieces framework, this study seeks to understand what elementary science teachers' discourse reveals about their ideologies surrounding language and science learning. Using qualitative video analysis, I analyzed discourse from three elementary science teachers. I found that teachers' discourse about language learning both reproduced and contested systemic monolingual ideologies, while their discourse about science learning was primarily asset-based. Implications include design suggestions for professional development as well as further research to gain a deeper understanding of how teachers might transfer asset-based ideologies across learning contexts.

Introduction and theoretical framework

Monolingualism is positioned as normative in U.S. education, despite an increasingly ethnically and linguistically diverse student population. Reforms such as the Next Generation Science Standards (NGSS) push for rigorous content for all learners, but the language demands required by these standards often remain invisible for teachers working with multilingual learners (Buxton & Caswell, 2020). Ideologies, defined by Louie (2020) as "a resource—not necessarily good, and not necessarily bad—that teachers use to make sense of their work" (p. 3), impact the instructional practices teachers use to support multilingual learners (Lemmi et al., 2019). It is important to note that monolingual ideologies are systemically reproduced and lead to inequitable learning opportunities (Valdez et al., 2016). For example, the ideology that language proficiency is a necessary prerequisite to engaging with science concepts (Lee et al., 2007), might lead teachers to lower expectations and provide less ambitious science learning opportunities for multilingual learners.

Teachers may inherit monolingual perspectives reproduced by the educational system and (un)consciously express them through their instructional practices. However, recent research has shown how professional development (PD) can help teachers interrogate and disrupt these ideologies and shift their practice in ways that are more inclusive to multilingual learners (Lemmi et al., 2019; Menken & Sánchez, 2019; Pacheco et al., 2019). Because discourse is one way in which ideologies are made manifest (Pacheco et al., 2019), this study considers elementary science teachers' talk about their multilingual learners in the context of a PD and what their discourse reveals about common language ideologies in relation to science learning.

In considering teachers' ideologies, I draw on Philip's (2011) framework of "ideologies in pieces." Philip views ideologies as a tool born through a *sensemaking* process that comes from one's own or others' lived experiences or from social assumptions. These *commonsense* elements of ideologies are widely accepted in a community with little need to justify them and are often difficult for individuals who hold them to articulate or explain. Similarly, because monolingual ideologies are reproduced by the educational system, many teachers accept them without question based on the cultural assumptions about language learning. Over time, ideologies within a community may go through a *rearticulation of meanings* as the accepted commonsensical meanings are questioned and new meanings are negotiated (Philip, 2011). Philip also notes that because ideologies are context-specific, conflicting ideologies can coexist for an individual. Thus, teachers may hold problematic monolingual ideologies alongside predominately asset-based science learning ideologies.

Methods

As Pacheco et al., (2019) note, "discourse not only provides a lens into teacher thinking but gives shape to ideologies that inform practice" (p. 198). Thus, by analyzing teachers' talk about their practice, I seek to identify the inherited ideologies that emerge through the teachers' *sensemaking* process about their multilingual learners, as well as if and how the *commonsense* elements of those ideologies undergo any *rearticulation* of meanings (Philip, 2011). Finally, I contrast these language ideologies with teachers' discourse about their science practice.

Nine teachers from a large urban school district in the southeast U.S. participated in this study, which was part of a multi-year PD project designed to focus on the use of representations in inquiry-based science. This data came from the first year of the project, which included an initial five days of summer PD where teachers were positioned as learners and as instructional designers. One hour of this initial PD focused on strategies for supporting English learners (EL). Participants then met quarterly during the school year for video clubs. At each club, teachers analyzed and reflected on student work and on video of their classroom science instruction (Sherin & Han, 2004). Reflecting on multilingual students and their science learning was a discussion prompt at each video club but was not always discussed. The last club of the year focused explicitly on ELs.

Data sources for this study included the four video club sessions from Year 1 of the project. All video recordings of the sessions were transcribed and reviewed for teachers' turns of talk focused explicitly on ELs, which became the units of analysis. These units were then studied using a qualitative content analysis of video data (Powell et al., 2003) to identify language ideologies as manifest through teachers' discourse. A representative five-minute clip is highlighted in this paper. The clip came from the final video club of the year, in which three of the nine participating teachers were discussing a science lesson taught by Soren, a kindergarten teacher. The three teachers included Soren; Kourtney, a third-grade teacher; and Toni, a fourth-grade teacher. In Soren's lesson, students were using a representation to identify objects in the schoolyard as living or non-living. The facilitator, also a research team member, asked Soren if she felt that the words or the pictures on the representation were more helpful to the students. Over the course of the next five minutes, all three teachers shared narratives about their ELs. These individual narratives are presented below, as well as an analysis of some of the ideologies that emerged from this discussion about the language learning process in the context of science learning.

Findings

The teachers' discourse about their ELs sometimes reified and sometimes challenged monolingual ideologies about language, but their discourse was consistently more asset-based when discussing science. These coexisting ideologies were reflected in the contrast between participants' narratives and sensemaking around their ELs and the language learning process and their analysis of their science practice. Soren's narrative began in response to the facilitator's question about words or pictures being more helpful to her kindergarten students. Soren noted that one of her ELs began the school year easily able to understand "pictorial representations," and because both of her ELs are "very bright", they quickly learned vocabulary and caught up to participate along with the class. Toni responded to Soren's narrative by highlighting the importance of students having content knowledge about science in their home language before learning science in English. Soren agreed and attributed her students' success to the fact that most of the ELs at her school have parents who are involved with research at universities in the area, so the students come in with background content knowledge. Kourtney provided an additional example as she shared a narrative of two students in her class, one of whom was not literate in Spanish and struggled learning English, while the other student was literate in Spanish and quickly achieved some English proficiency. Toni built on this example with her narrative of a student from last year who started the year and "knew absolutely no English, yet he exited out of EL at the end of the year." Toni attributed this success to several factors, including intelligence, language skills in his home language, prior academic success in his home country, parental support, and parental knowledge of English. Figure 1 highlights the different ideologies that the teachers used as tools to make sense of the narratives and of the language learning process.

Language Ideology 1: There is an important relationship between students' prior knowledge & their emerging English abilities.	
Soren	"He **came in understanding pictorial representations** nicely but **adding the vocabulary** to it was a lot of what we did at the beginning of school for him especially…[he's] coming from a background where **[he has] all of that [background knowledge]**."
Kourtney	"I have one [student] who can [read and write in Spanish]…And **she is speaking in English**. She came in the first day of school and **she wrote me three paragraphs about herself in Spanish. She is writing paragraphs in English now**"
Toni	"When they have **the content knowledge in their own language first** it makes a big difference. … So like, that's huge, I mean to be able to go from no English to exiting EL in one year. It's crazy, but it's because **he was just making a connection to what he already knew**."
Language Ideology 2: Successful language learning is a result of students' innate abilities & attributes.	
Soren	"He caught on pretty fast, **and he's a very, very intelligent child**. …Somehow I'm blessed with these two babies who came in not speaking much English or understanding much English **but they're so bright** that they have not made me work very hard."
Kourtney	"And so the one who was literate…is writing paragraphs in English now…in less than a school year, because she had those skills…but it does illustrate, I mean **part of it is motivation**."
Toni	"I had a kid last year who came in first day of school knew absolutely no English, yet he exited out of EL at the end of the year, but **he was really bright in Spanish**."
Science Ideology: Students bring a wide range of resources with them that can be drawn on to engage in rigorous scientific sensemaking.	
Soren	"I was trying to ask them questions **based on themselves**, often, **or other living things that they understood**."
Kourtney	"So they might **make a connection** between one of the representations…Oh, now that I see this other one, **I can relate it to something else that I already know**."
Toni	[Questions to help students make connections] "What does that **mean**? Where is this **happening**? How could **you describe that to someone that wouldn't know** what the Ring of Fire is?"

Figure 1. Representative ideologies about language learning and science

Figure 1 highlights three representative examples of the teachers' ideologies. The first demonstrates a language ideology with elements that contest systemic framings of monolingualism as normative, while the second appears to reify traditional monolingual ideologies. The third presents a contrasting asset-based science ideology. The first ideology teachers articulated was that there is an important relationship between students' abilities in their first language and their emerging English abilities. Teachers' talk showed a fairly sophisticated understanding of the support that first language literacies can provide when learning an additional language. They recognized that existing skills in other languages serve as vital resources for students as they learn English (Menken & Sánchez, 2019). This framing begins to contest monolingual discourses that position students with emerging English proficiency as not having the language resources necessary to engage in scientific sensemaking (Lee et al., 2007). At the same time, teachers' articulation of this ideology was limited to identifying how multilingualism supports language learning; the articulation did not extend to consider how first language resources might be leveraged in science learning.

The second ideology, that students who successfully learn English do so as a result of innate abilities, revealed ways that participants viewed language learning as something exceptional that they as teachers played little role in supporting. The participants' discourse connected their multilingual learners' English abilities to personal attributes such as being "bright" or "intelligent" or "motivated." Such perceptions echo the ways that monolingualism is positioned systemically as normative. In the U.S., access to studying languages in other than English in school is limited most often to academically successful, primarily white monolingual English speakers (Reagan & Osborn, 2002). On the other hand, minoritized learners' skills in languages other than English are seen as deficit (Flores & Rosa, 2015). Thus, participants' discourse implied that "successful" English language learning was positioned as an exceptionality attributed to intelligence or other external factors.

The teachers' discourse surrounding language learning both reinforced larger, societal ideologies and began to challenge some of these ideologies. In contrast, the teachers' discourse about their science practices throughout the video club conversation highlighted ideologies that primarily challenged traditional conceptualizations of science. Rather than viewing science as an abstract set of facts to be learned with students entering as blank slates, all of the teachers recognized that students brought a wide range of experiences with them that could become important resources for engaging in rigorous scientific sensemaking. For example, Soren drew on students' lived experiences and prior knowledge as valuable resources in understanding scientific concepts (Lee et al., 2007). Similarly, Kourtney described using multiple representations to support students in making connections across contexts, allowing them to build their understanding of scientific concepts over the course of instruction instead of expecting them to memorize decontextualized facts (Lee et al., 2019). Finally, in reflecting on a lesson about volcanoes, Toni identified an opportunity where she could have pressed on one student's background knowledge about the Ring of Fire to push her student's thinking further. Toni saw using questions as a discourse strategy that engaged students in scientific sensemaking while attending to audience and register (Lee et al., 2019). All three of the participants' discourse about science practices pushed back on dominant ideologies of science to describe science through inquiry-based, student-centered ways.

Discussion

The teachers' discussion about their English learners and science practice reflected multiple aspects of Philip's (2011) ideology in pieces framework. Rather than drawing on their own personal experiences as learners, they used their *commonsense* lived experiences as teachers to "make sense of, define, figure out and render intelligible the way [language learning] works" (Hall, 1996, as cited in Philip, 2011, p. 300). The narratives of students served as a *sensemaking* tool as the teachers articulated their understanding of the language learning process to and with each other. It is noteworthy that the teachers did not challenge each other's narratives in any way, nor did the facilitator challenge the teachers' narratives. In other words, the ideologies expressed about language learning did not undergo any *rearticulation of meaning* in this community at this time. Instead, participants built on one another's ideas to co-construct the ideologies presented in Figure 1, suggesting that for this group of teachers, the ideologies represented "socially communicated assumptions or experiences of others taken for granted" (Philip, 2011, p. 302). The participants made sense of language learning for ELs in ways that often reified but occasionally challenged dominant ideologies. By contrast, their sensemaking about science was primarily asset-based, likely a result of shared understanding about science learning developed through PD participation. Because language ideologies often go unexamined (Lemmi et al., 2019), as was the case in our PD design, we wonder how teachers might shift toward asset-based framings when invited to examine these assumptions.

Philip (2011) also notes that "people are not compelled to reconcile their sensemaking across contexts, and they may make sense in seemingly contradictory ways without being troubled by it" (p. 300). Evidence of the fact that these teachers' ideologies were in pieces could be seen in the contrast between the teachers' discourse about language learning and their discussion of science learning. The discourse surrounding language learning drew heavily on others' experiences, discussing students and "their" work connecting, thinking, and learning in a somewhat detached way. Although teachers started to contest some monolingual norms in their ideologies, their discourse fell short of discussing how they as teachers could leverage all students' language resources for scientific sensemaking (Pacheco et al., 2019). By contrast, participants' discourse surrounding science learning was grounded in their own experience in the classroom. Teachers discussed things "I" could do, providing examples of their own instructional decision making to center and honor the knowledge students brought with them into science lessons. The co-existence of somewhat deficit-based language discourse alongside more asset-based science discourse highlighted the contradictory ideologies Philip identifies. Because ideologies are context-specific (Philip, 2011), this group of teachers may be ready to engage in *rearticulation of meanings* if facilitators on the research team made salient the dominant monolingual ideologies and invited them to challenge some of the commonsensical meanings of their language learning narratives to create new meanings that pull teachers' asset-based views of science learning across the two contexts.

Implications and potential impact

An immediate implication of this analysis is in the design of future iterations of this PD project. In reviewing findings from the first year, the research team recognized a greater need to attend to the relationship between science and language. Key goals moving forward include (1) drawing attention to deficit discourse surrounding multilingual learners that is embedded in educational systems and taken up by participants and facilitators, and (2) providing perspectives and asset-based language that contest monolingual norms. It is our hope that the asset-based ideologies teachers express with regard to science learning can be extended to other learning contexts. Furthermore, this work may contribute to a deeper understanding of how ideologies about language learning are taken up, expressed, and contested, leading to more equitable learning opportunities for all multilingual learners.

References

Buxton, C. A., & Caswell, L. (2020). Next generation sheltered instruction to support multilingual learners in secondary science classrooms. *Science Education, 104*(3), 555-580.

Flores, N., & Rosa, J. (2015). Undoing appropriateness: Raciolinguistic ideologies and language diversity in education. *Harvard Educational Review, 85*(2), 149-171.

Lee, O., Llosa, L., Grapin, S., Haas, A., & Goggins, M. (2019). Science and language integration with English learners: A conceptual framework guiding instructional materials development. *Science Education, 103*(2), 317-337.

Lee, O., Luykx, A., Buxton, C., Shaver, A. (2007). The challenge of altering elementary school teachers' beliefs and practices regarding linguistic and cultural diversity in science instruction. *Journal of Research in Science Teaching, 44*(9), 1269-1291.

Lemmi, C., Brown, B. A., Wild, A., Zummo, L., & Sedlacek, Q. (2019). Language ideologies in science education. *Science Education, 103*(4), 854-874.

Louie, N. (2020). Agency discourse and the reproduction of hierarchy in mathematics instruction. *Cognition and Instruction, 38*(1), 1-26. DOI: 10.1080/07370008.2019.1677664

Menken, K., & Sánchez, M. T. (2019). Translanguaging in English-only schools: From pedagogy to stance in the disruption of monolingual policies and practices. *TESOL Quarterly*, *53*(3), 741-767.

Pacheco, M. B., Kang, H., & Hurd, E. (2019). Scaffolds, signs, and bridges: Language ideologies and translanguaging in student-teaching experiences. *Bilingual Research Journal, 42*(2), 194-213.

Philip, T. M. (2011). An "ideology in pieces" approach to studying change in teachers' sensemaking about race, racism, and racial justice. *Cognition and Instruction, 29*(3), 297-329.

Powell, A. B., Francisco, J. M., & Maher, C. A. (2003). An analytical model for studying the development of learners' mathematical ideas and reasoning using videotape data. *Journal of Mathematical Behavior, 22,* 405-435.

Reagan, T. G., & Osborn, T. A. (2002). The foreign language educator in society: Toward a critical pedagogy. New York, NY: Routledge.

Sherin, M. G., & Han, S. Y. (2004). Teacher learning in the context of video club. *Teaching and Teacher Education, 20*(2), 163-183.

Valdez, V. E., Freire, J. A., & Delavan, M. G. (2016). The gentrification of dual language education. *Urban Review, 48*(4), 601-627.

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CS1 Student Assessments of Themselves Relative to Others: The Role of Self-Critical Bias and Gender

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Abstract: University introductory computer science courses (CS1) present many challenges. Students enter CS1 with varying backgrounds and many are evaluating their potential for success in the major. Students often negatively self-assess in response to natural programming moments, such as getting a syntax error, but we have a limited understanding of the mechanisms that drive these self-assessments. In this paper, we study the differences in student assessments of themselves and their assessments of others in response to particular programming moments. We analyze survey data from 214 CS1 students, finding that many have a *self-critical bias*, evaluating themselves more harshly than others. We also found that women have a stronger self-critical bias, and that students tend to be more self-critical when the other is female. These insights can help us reduce the impact of negative self-assessments on student experiences.

Introduction

The rapid growth of computing has prompted learning scientists to study approaches for broadening participation and improving learning experiences in computer science (CS). In this paper, we study student experiences in introductory CS courses at the university level, often referred to as CS1. CS1 courses are the entry point to the CS major, but often suffer from learning challenges as they serve students with a wide range of prior experience in computing. Specifically, students who are new to programming often struggle when grouped in classes with more experienced peers (Ott et al., 2018), and feel pressure to quickly evaluate their ability to succeed in CS due to the need to choose a major (Lewis et al., 2011). These challenges are often amplified for women and students of color, who are underrepresented in CS and drop out of the major at higher rates (Cohoon, 2006).

Recent research has shown that CS1 students frequently assess their own ability (Kinnunen & Simon, 2012). While evaluating progress is important for self-regulation (Butler & Winne, 1995), these studies show that students negatively assess themselves in response to programming moments that are natural parts of professional practice (LaToza et al., 2006), which are therefore not helpful indicators of ability. For example, many students believe that they are performing poorly when they stop to think or plan, get a compiler error, or forget syntax (Gorson & O'Rourke, 2019). Students who negatively self-assess more strongly in response to these moments have lower self-efficacy on average, an important factor that predicts persistence in CS (Lewis et al., 2011).

To address these issues in student experience and persistence, we need a better understanding of the mechanisms that drive student self-assessments in CS1. While there are likely many factors that contribute to these self-assessments, in this paper we specifically explore how students assess themselves in comparison to how they assess others. Studies show that people tend to have a self-enhancement bias when evaluating themselves compared to others, rating themselves more favorably (Alicke, 1986; Kwan et al., 2004). At the same time, women tend to under-evaluate their performance in science (Ehrlinger & Dunning, 2003), and have a weaker self-enhancement bias (Kurman, 2004). Given the challenging learning context that CS1 presents for many students, we were interested in understanding how factors such as gender might shape negative self-assessments.

Student self-assessments in CS1

Studies show that CS1 students frequently assess their own ability (Lewis et al., 2011; Kinnunen & Simon, 2012). Through an interview study, Lewis et al. (2011) discovered that self-assessments play an important role in CS1 students' decisions to major in CS. Kinnunen & Simon (2012) found that students often evaluate programming experiences negatively even when they are successful, especially when the experience does not match their expectations. More recently, we built on this research to identify criteria that students use to assess programming ability, such as writing code that runs on the first try (Gorson & O'Rourke, 2019). Through a survey study with 214 students, we found that many negatively self-assess in response to these natural programming moments, and that those who report stronger negative self-assessments have lower self-efficacy (Gorson & O'Rourke, 2020).

This body of research highlights the prevalence of negative self-assessments in CS1. However, we still have a limited understanding of the factors that drive these assessments. Our previous study revealed correlations between students' beliefs about professional practice and self-assessments for a few of the moments (Gorson & O'Rourke, 2020), however these effects do not fully explain students' negative views of their own ability. In this paper, we explore another factor that could explain negative self-assessments, namely differences in how students assess themselves in comparison to others and the role of gender in these self-assessments.

Differences in assessments of the self and assessments of others

Social psychologists have studied differences in the ways individuals assess themselves and others extensively (Kwan et al., 2004). In many domains, people tend to hold overly positive views of their own abilities, an effect that is referred to as *self-enhancement bias* (Alicke, 1986; Kwan et al., 2004). For example, Alicke (1985) asked college students to rate the degree to which a set of trait adjectives characterize themselves and the average college student, finding that students rated themselves significantly higher than others for desirable traits.

Self-enhancement bias does not necessarily arise as strongly for students who experience stereotype threat. Ehrlinger and Dunning (2003) gave college students a pop quiz on scientific reasoning and found that female students rated themselves more negatively on scientific skills and estimated performance on the quiz than male students, even though there were no gender differences in actual performance. While we are not aware of any studies of self-enhancement in the CS domain, we might expect to see similar effects as in other STEM domains. Women are notably underrepresented in CS (Cohoon, 2006) and prevalent stereotypes depict computer scientists as male, technologically oriented, and socially awkward (Master et al., 2016). Given this context and the frequent negative self-assessments of CS1 students, we wondered whether there are any differences in student assessments of themselves and others, and how gender might shape these assessments.

Research questions

The goal of this paper is to study differences in how students assess themselves and others in response to particular moments that arise during the programming process. Towards this end, we conducted a secondary analysis of the data from our previous survey (Gorson & O'Rourke, 2020) to answer two research questions: (1) are there differences in students' assessments of themselves and their assessments of others? (2) Are the differences in these assessments impacted by the gender of the student or the other? We aim to understand whether any self-assessment biases might help explain the prevalence of the negative self-assessments while programming in CS1.

Methods

This paper reports on a secondary analysis of data we collected in February 2019 (Gorson & O'Rourke, 2020). We recruited participants from three universities of different types and with different levels of selectivity in the midwestern United States. All participants were enrolled in an introductory course at their university and 36% of participants identified as female. See our previous paper for a complete description of the data collection methods. In this section, we review the subset of the survey that is most relevant for understanding the present analysis.

The survey was designed to uncover student self-assessments in response to specific moments that might arise during the programming process. We designed a set of thirteen vignettes that each describe a fictional character encountering one of the programming moments that may prompt negative self-assessments. An example vignette is: "*Diego starts working on a programming problem. He writes a few lines of code. He realizes that he is confused about what to do next. He pauses and plans his next steps. Diego wishes that he did not have to stop writing code to plan*." After each vignette, students were asked how much they agree that the character or themselves are performing poorly when they encounter that moment, on a six-point forced-choice Likert scale. For this vignette, the statements were: "*Since Diego had to stop and think, he didn't do well on the problem*" and "*When I have to stop programming to plan, I feel like it means that I'm not doing well on the problem*." The gender of the vignette character was communicated through the name and the pronouns used in the vignette. To control for any biases in participant responses, we randomized the names of the characters across vignettes.

Findings

Students evaluate themselves more critically than they evaluate others

To answer our first research question, we measured whether there were differences in students' assessments of themselves and their assessments of the vignette characters. We first converted the responses to the two forced-choice Likert-scale questions following each vignette to a numerical scale ranging from -3 (strongly disagree) to 3 (strongly agree). By agreeing to a statement that follows a vignette, participants demonstrate a belief that they (or the characters) are performing poorly during that moment. Therefore, to calculate self-critical bias we subtracted their response to the question about themselves from their response to the question about the character for each vignette question. For example, a participant may *slightly agree* (1) that the character is performing poorly in a particular moment, and *slightly disagree* (-1) that they are preforming poorly. We would calculate 1 minus -1 resulting in a self-enhancement bias of 2 for that vignette. A positive value indicates a self-enhancement bias in participants' responses. We grouped participants into three categories for each vignette based on the bias they exhibited: a positive self-enhancement bias, no bias, and a negative self-enhancement bias.

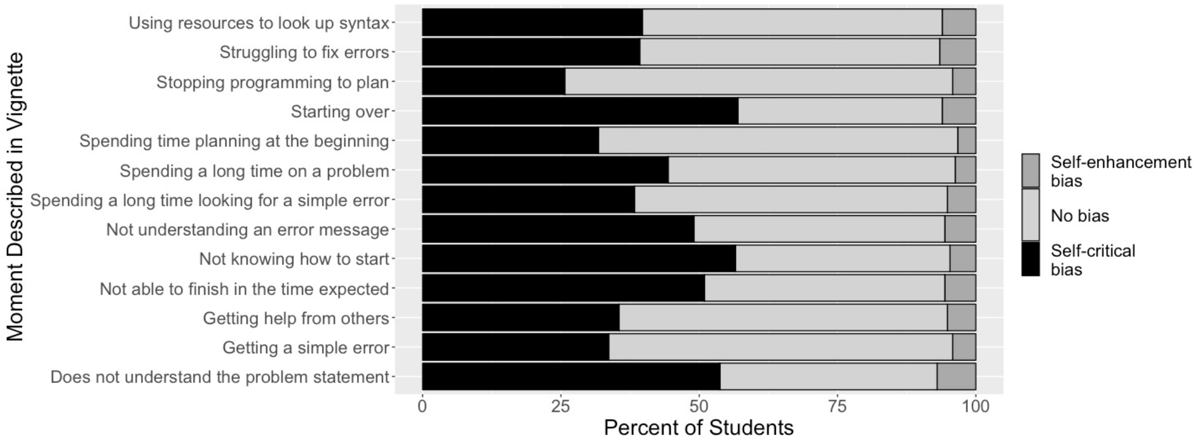

Figure 1. Graph showing the percentage of participants who exhibited a self-enhancement bias, a self-critical bias, and no bias, when comparing their responses to the questions following each of the thirteen vignettes.

Surprisingly, we found that very few students exhibited a self-enhancement bias. As shown in Figure 1, only 3-5% of participants had a positive self-enhancement bias for each question, while 25-60% of students had a negative self-enhancement bias. For the rest of this paper, we refer to a negative self-enhancement bias as a *self-critical bias*. Overall, these findings suggest that CS1 students tend to be more critical of themselves than of others, which is surprising given previous findings on the prevalence of self-enhancement biases.

This self-critical bias could manifest in two ways. Students could believe that both they and the character were performing poorly or well, but to different degrees (e.g. *slightly agree* for the character, *agree* for themselves). Or they could believe that they are performing poorly (e.g. *slightly agree*) but make no negative assessment of the character (e.g. *disagree*), or vice versa. To capture this second type of bias, we counted how often participants' responses to the two vignette questions fell on different sides of the Likert scale for each vignette. We found that 85% of students negatively assessed themselves but not the character for at least one vignette, while only 18% of students assessed the character but not themselves for at least one vignette. This effect was most common for the moments *starting over* and *does not understand the problem statement*, in which 35% and 33% of students respectively assessed themselves but not the character negatively. These findings show that a significant number of students negatively assess themselves at moments that they think are acceptable for others.

Self-critical bias is stronger when the student or the vignette character is female

Next, we analyzed whether self-critical bias was influenced by gender. We used non-parametric methods because the Shapiro-Wilk test showed that our data has a non-normal distribution. For the remaining analyses, we did not include the five students who reported non-binary gender identities because we feared the size of the group would result in an inaccurate representation of their experience. For the binary students, we conducted a Mann-Whitney U test, and found that female students were significantly more likely to have a self-critical bias than male students ($Z = 3484.5$, $p < 0.001$), with a median bias of 0.46 for male students and 0.92 for female students.

Given the prevalent stereotypes that depict computer scientists as male (Master et al., 2016), we wondered if students would assess themselves differently in relation to female and male vignette characters. We averaged the self-critical bias that each participant reported for the vignettes with female characters and with male characters. Then, we compared these values using a Wilcoxon signed-rank test (nonparametric t-test) and found that participants were significantly more self-critical when the vignette character was female ($Z = 8688$, $p < 0.05$). The median self-critical bias was 0.57 when the vignette character was male, and 0.71 when they were female.

After finding that students are generally more self-critical in comparison to female vignette characters, we wondered if this effect is impacted by the gender of the participant. To answer this question, we conducted an Aligned Rank Transform (non-parametric ANOVA) finding that individually both the gender of the character ($F(1, 206) = 4.39$, $p < 0.05$) and the gender of the participant ($F(1,206) = 14.90$, $p < 0.001$) had significant effects on self-critical bias. However, we did not find a significant interaction between these factors ($F(1, 206) = 0.36$, n.s.). We often think of female students as being most affected by stereotypes about who belongs in CS, however these findings show that male students are also influenced by these narratives.

Discussion and design implications

This research aimed to study the differences in how students assess themselves and others in response to moments that arise during the programming process. Through a secondary analysis of our survey data (Gorson & O'Rourke, 2020), we found that very few students exhibit a self-enhancement bias in this domain. Instead, many students exhibit a *self-critical bias*, with 96% of participants rating themselves more harshly than the vignette character in response to at least one vignette. We also found that female students are significantly more likely to have a self-critical bias than male students, and that both male and female students are more critical when the vignette character is female. This research has a few limitations. Since our data is quantitative, we cannot explain why some students evaluate themselves more critically than the vignette characters. Furthermore, many factors beyond gender may influence self-assessments, including race, sense-of-belonging, and perceptions of professionals.

Given the established phenomena of self-enhancement bias in other domains, we were surprised to see the prevalence of self-critical bias for both male and female students in this context. We believe these findings have important implications for the design of CS1 curricula and interventions. For example, we previously argued that CS1 courses should explicitly teach about professional programing practices to help students develop accurate expectations (Gorson & O'Rourke, 2020). While this could help some students, our new findings suggest that some students do not view these programming moments as universal signs of poor performance. Instead, they view these moments as more problematic for themselves than for others. To better support this group of students, CS1 teaching staff could call attention to moments when students may be assessing themselves particularly harshly, and help students reframe their perceptions of these moments. Additionally, our findings reveal that students have a stronger self-critical bias when the vignette character is female, suggesting that the stereotypes about who belongs in computer science may lead students to have lower expectations of women. We believe this provides compelling evidence for designing diversity events and initiatives that help both male and female students shift their expectations to see women as belonging and excelling in computer science.

References

Alicke, M. D. (1985). Global self-evaluation as determined by the desirability and controllability of trait adjectives. *Journal of personality and social psychology, 49*(6), 1621.

Butler, D. L., & Winne, P. H. (1995). Feedback and self-regulated learning: A theoretical synthesis. Review of educational research, 65(3), 245-281.

Cohoon, J. M. (2006). Just get over it or just get on with it: Retaining women in undergraduate computing. *In J. Cohoon & W. Aspray (Eds.), Women and information technology: Research on underrepresentation*, 205-238. Cambridge, MA: MIT Press

Ehrlinger, J., & Dunning, D. (2003). How chronic self-views influence (and potentially mislead) estimates of performance. *Journal of personality and social psychology, 84*(1), 5.

Gorson, J., & O'Rourke, E. (2019, July). How Do Students Talk About Intelligence? An Investigation of Motivation, Self-efficacy, and Mindsets in Computer Science. In *Proceedings of the 2019 ACM Conference on International Computing Education Research* (pp. 21-29).

Gorson, J., & O'Rourke, E. (2020, August). Why do CS1 Students Think They're Bad at Programming? Investigating Self-efficacy and Self-assessments at Three Universities. In *Proceedings of the 2020 ACM Conference on International Computing Education Research* (pp. 170-181).

Kinnunen, P., & Simon, B. (2012). My program is ok–am I? Computing freshmen's experiences of doing programming assignments. *Computer Science Education, 22*(1), 1-28.

Kurman, J. (2004). Gender, self-enhancement, and self-regulation of learning behaviors in junior high school. *Sex Roles, 50*(9-10), 725-735.

Kwan, V. S., John, O. P., Kenny, D. A., Bond, M. H., & Robins, R. W. (2004). Reconceptualizing individual differences in self-enhancement bias: An interpersonal approach. *Psychological review, 111*(1), 94.

LaToza, T. D., Venolia, G., & DeLine, R. (2006, May). Maintaining mental models: a study of developer work habits. In Proceedings of the 28th international conference on Software engineering (pp. 492-501).

Lewis, C. M., Yasuhara, K., & Anderson, R. E. (2011, August). Deciding to major in computer science: a grounded theory of students' self-assessment of ability. In *Proceedings of the Seventh International Workshop on Computing Education Research* (pp. 3-10).

Master, A., Cheryan, S., & Meltzoff, A. N. (2016). Computing whether she belongs: Stereotypes undermine girls' interest and sense of belonging in computer science. *Journal of educational psychology*, 108(3), 424.

Ott, L., Bettin, B., & Ureel, L. (2018, July). The impact of placement in introductory computer science courses on student persistence in a computing major. In *Proceedings of the 23rd Annual ACM Conference on Innovation and Technology in Computer Science Education* (pp. 296-301).

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Understanding Students' Representations of Mechanism through Modeling Complex Aquatic Ecosystems

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Abstract: This study examines how 5th grade students represent the mechanisms of a complex aquatic ecosystem in the Modeling and Evidence Mapping Environment (MEME), a software tool designed to support students in iteratively modeling the elements within a complex system, and their relationships to each other. We explore the various ways students represented mechanisms of an aquatic ecosystem through their models and present our findings on the patterns that emerged and the unexpected ways that mechanisms were utilized within student models.

Keywords: modeling, mechanistic reasoning, science education, complex systems, CSCL

Introduction

Modeling is a difficult practice for young students (Pierson et al., 2017), but is also important in contexts where relationships between elements of a phenomena are unclear, such as in complex systems. An increasing amount of research demonstrates that elementary students can learn and engage with complex systems concepts (Hmelo-Silver & Azevedo, 2006; Danish, 2014; Yoon, Goh, & Park, 2015). When modeling a complex system, it is particularly important for learners to explore and represent the underlying mechanisms rather than just the superficial or surface-level details (Russ et al., 2008).

This study is part of a larger project Scaffolding Explanations and Epistemic Development for Systems (SEEDS), which aims to understand how fifth grade students engage with disparate forms of evidence as they explore complex aquatic ecosystems through modeling. To support these modeling practices, we developed the *Model and Evidence Mapping Environment* (MEME): a software tool that helps students create a simple model of a complex system (Figure 1).

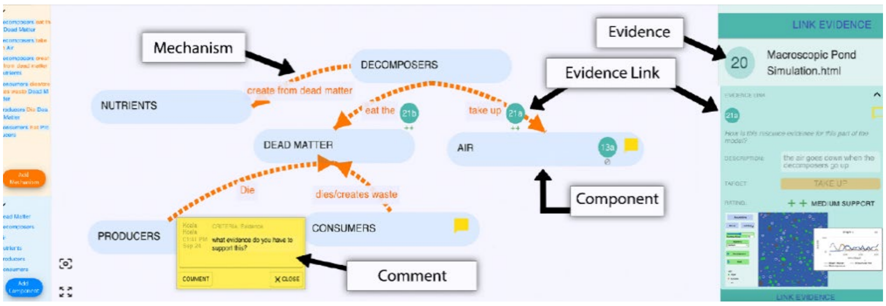

Figure 1: Screenshot of the MEME Software

The aim of this study is to examine how students represent mechanism when modeling complex aquatic ecosystems in MEME. In doing so, we seek to answer the research question: how are students representing mechanisms in different ways within MEME? Are these ways of representing mechanism being recognized and validated by peers?

It has been shown that young students can engage with and develop nuanced understandings of complex systems, such as the water cycle and honeybees working together to obtain nectar (Danish, 2014; Hmelo-Silver et al., 2015). Prior research has shown that the *Phenomenon-Mechanism-Components* (PMC) conceptual framework can aid students in attending to key dimensions of systems as they attempt to model it (Hmelo-Silver et al., 2017). Models that align with the PMC framework explicitly represent complex systems through the combinations of various **components** within a system, and represent the relationships between them through descriptive **mechanisms**, resulting in the **phenomena** being investigated.

Methods

This study was conducted as a five-week long unit with a grade five classroom of 20 students (15 boys and 4 girls consented) at a public elementary school in the U.S.Midwest in the spring of 2020. Students worked in dyads together in the MEME software to iteratively build models and look at evidence. Students also participated in an activity where they reviewed two other groups' models, and left critiques through MEME's commenting feature. While we intended the project to continue past this activity, we were cut short due to the Covid-19 pandemic.

Data for this analysis consists of the final models students completed. We coded students' models in two passes and looked closely at video data capturing the creation of mechanisms in models, and the interactions between peers that produced them. The first pass at coding involved looking at the isolated mechanisms (arrows) of each of the nine final models created in MEME. On this first pass we developed four codes based on Pierson et al.'s (2017) conception of learning progressions of scientific modeling. Our codes were adapted to fit 5th grade students and ranged from 0-3 for the intricacy of mechanism (see Table 1).

Table 1: Table of codes adapted from Pierson et al. (2017) used in analysis.

Code Level	Description
(0)	Mismatch between the mechanisms and components of the model, where the mechanistic explanation could not be interpreted in the context of the model.
(1)	Just an arrow being made to connect to components, with no mechanistic reasoning provided to why they might be connected in the system.
(2)	Some explanation provided for the mechanism but illustrated a vague sense of explaining the relationships beyond the source and target component.
(3)	Representation of a mechanism to explain the underlying relationships of the complex system, often supported by forms of evidence.

In examining the models, we noticed that students often captured robust mechanisms but did so using multiple unlabeled arrows. In looking at the level (1) codes across the models, a pattern emerged wherein students expanded their mechanistic reasoning by combining multiple components connected with unlabeled mechanisms. Therefore, we created two additional codes for a second pass, which we called expanded level (2) mechanisms, and expanded level (3) mechanisms. We unpack how this emerged in the findings below.

We utilized interaction analysis (IA; Jordan & Henderson, 1995) to carefully examine the interactions between peers surrounding the critique of coded level (3) mechanisms, including the expanded level (3) mechanisms. We looked closely at whether students appeared to understand their peers' mechanistic reasoning represented in their models. In these instances, we examined what occurred when the mechanism was understood by critiquing students, as well as what was happening where students failed to recognize their peers' mechanism when coded as level (3). Our results below outline the patterns that emerged in both the creation of mechanisms in modeling, and students' interpretation, or lack thereof, of peers' representations of mechanism across models.

Findings

The results of our coding (Table 2) showed that students ranged in their complexity in representing mechanism across their final models, and that while it appeared that the intricate level (3) codes were sparse on the first pass, they ended up emerging nearly as often in the second pass. Our second round of coding revealed multiple causal mechanisms represented through chains of level (1) codes and components where students conflated mechanisms as components of their models. The most common of these were three interconnected components with two unlabeled mechanisms, where the middle component represented either a level (2) or level (3) mechanism explaining the relationship between the other two components. Our results from the second round of coding found 10 expanded level (2) codes, and 18 expanded level (3) codes across the nine models.

Table 2: Results of the two rounds of coding

Coding Pass	Level 0	Level 1	Level 2	Level 3
1 (Simple Mechanisms)	5	28	29	16
2 (Expanded Mechanisms)	0	0	10	18
Total	5	28	39	34

Across models, level (2) mechanisms tended to be the first connections created by students in their simplified models containing just a few components at the start of the modeling activities (Figure 2). As time went on, level (3) mechanisms began to emerge, but so did many of the level (1) mechanisms of blank arrows. Many of these level (1) components connected chains of components formed the expanded level (3) mechanisms.

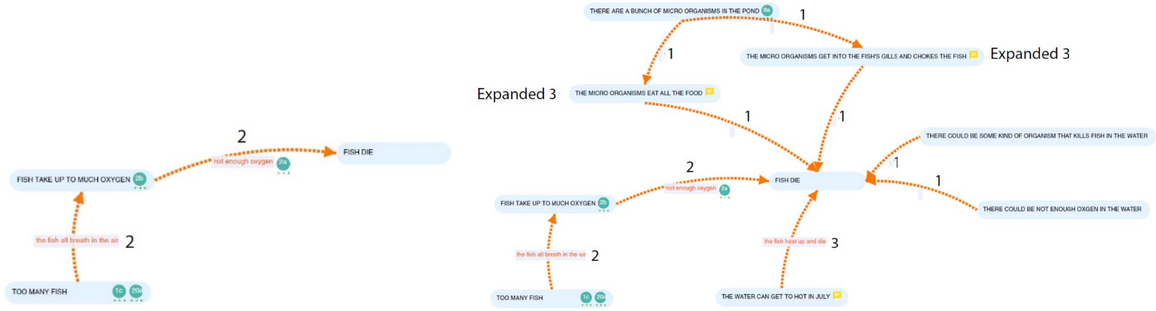

Figure 2. One group's initial (left) and final (right) model pulled from MEME with their mechanisms labeled.

Within interaction students tended to reference their resource library for a specific piece of evidence to support their reasoning before creating a component or mechanism that would end up being coded as a level (3). For example, in the model above (Figure 2), the students looked at one piece of evidence that cited the existence of microorganisms within ponds. They created the component "There are a bunch of microorganisms in the pond" and cited their evidence. The group then created two competing ideas to why the "fish die" because of this. Two additional components were created, "The microorganisms get into the fishs gills and choke the fish" and "The microorganisms eat all the food" and connected to "fish die" through unlabeled mechanisms. These two were coded on the second round as expanded level (3) mechanisms to explain the relationship between the "microorganisms" component and fish dying in the pond. A similar pattern emerges across students' models.

Despite the overall prevalence of level (3) mechanisms within models, they ultimately went unnoticed by peers in their feedback. In the example above, students never commented on any of the level (3) mechanisms, and only ever critiqued expanded level (3) mechanisms as not being labeled. This suggests that student peers may not recognize the representations of high-level mechanisms in scientific models. These instances within and across models reveal that while young students are fully capable of engaging with these complex phenomena, they further scaffolding to productively participate in these expert practices and to help distilling their complex thoughts about systems in precise ways to represent system mechanisms.

Discussion

Our findings revealed that students' models produced unexpected ways in which complex mechanistic reasoning was represented in their models, but ultimately went unnoticed by student peers. These patterns of model construction show that while students' mechanistic reasoning develops along a learning trajectory as they engage with iterating on models of complex systems, they still tend to conflate the concepts of **component** and **mechanism** when engaging in modeling. This may be an indication that students' representations may degrade in clarity as their model and the evidence they work with becomes increasingly complex as they iterate but didn't take the time to refine. Continuing to attend to the ways in which young students represent mechanism in models in ways that their peers can explicitly interpret them, we can further develop scaffolds to promote deep engagement with complex systems concepts for elementary students.

References

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. *Journal of the Learning Sciences, 23*(2), 100-148.

Hmelo-Silver, C. E., & Azevedo, R. (2006). Understanding Complex Systems: Some Core Challenges. *Journal of the Learning Sciences, 15*(1), 53-62.

Hmelo-Silver, C. E., Liu, L., Gray, S., & Jordan, R. (2015). Using representational tools to learn about complex systems: A tale of two classrooms. *Journal of Research in Science Teaching, 52*(1), 6-35.

Hmelo-Silver, C. E., Jordan, R., Sinha, S., Yu, Y., & Eberbach, C. (2017). PMC-2E: Conceptual representations to promote transfer. In *Promoting Spontaneous Use of Learning and Reasoning Strategies* (pp. 276-291). Routledge.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The journal of the learning sciences, 4*(1), 39-103.

Pierson, A. E., Clark, D. B., & Sherard, M. K. (2017). Learning progressions in context: Tensions and insights from a semester-long middle school modeling curriculum. *Science Education, 101*(6), 1061-1088.

Russ, R. S., Scherr, R.E., Hammer, D., Mikeska, J. (2008). Recognizing mechanistic reasoning in student scientific inquiry: A framework for discourse analysis developed from philosophy of science. *Science Education, 92*(3), 499-525.

Yoon, S.A., Goh, S., Park, M. (2018). Teaching and learning about complex systems in K-12 science education: A review of empirical studies 1995-2015. *Review of Educational Research, 88*(2), 285-325.

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Scaffolding Multiple Document Comprehension: Students' Representations of Documents Models

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Abstract: Multiple document comprehension is a challenging task that involves evaluating, selecting, organizing, and connecting sources and their claims. In this paper, we examine how 9th grade students utilized a digital document mapping scaffold to visually represent multiple scientific documents. Analysis of students' document maps revealed that most students were able to use the scaffold to appropriately evaluate documents' sources, represent the main claims that emerged from the documents, connect these claims to their respective sources, and identify agreements and disagreements between sources. However, some students focused more on constructing a highly elaborate representation of document claims, whereas other students focused more on integration of the documents through representation of the network of connections among sources and claims. These findings suggest a potential trade-off between elaboration and integration processes in multiple document comprehension that may require instructional attention and support.

Introduction

We live in an era which information is highly accessible and increasingly diverse. Consequently, students need to be able to construct knowledge and make informed decisions using multiple information sources or documents. Central challenges in comprehension of multiple documents are understanding the relations between the documents, making sense of their overall meaning, and reasonably weighing claims using reasons and evidence from the documents and in light of the trustworthiness of their sources (Barzilai & Ka'adan, 2017).

According to the Documents Model Framework (Britt & Rouet, 2012), in order to form an integrated understanding of multiple documents, competent readers create a *documents model.* This model includes two interconnected components: an *integrated mental model* and an *intertext model*. The integrated mental model is an internal representation of the situations or phenomena described in the texts, including their overlaps and inconsistencies. The intertext model involves a representation of the sources of the documents (including their positions, trustworthiness, etc.), the connections between sources and their contents (source-content links, who said what), and the connections between the sources (source-source links such as addition, support, or opposition). Connecting the contents of the documents to their respective sources enables readers to make sense of the differences between the documents and to weigh their claims in light of source characteristics.

Multiple document comprehension poses many challenges to students. Because information is spread over separate documents, students can find it difficult to recall information from previous documents and form cross-textual connections (Britt & Rouet, 2012; Goldman et al., 2012). When selecting documents and information, students may tend to choose according to fit with their prior knowledge, rather than according to source trustworthiness (Bråten et al., 2018). Students may also have insufficient meta-epistemic understanding of evaluation and integration strategies and criteria (Barzilai & Ka'adan, 2017).

Visual organizers and maps could potentially help students integrate multiple documents. Mapping may support comprehension of multiple documents by reducing the lower-order cognitive demands that characterize integration tasks and enabling high-order processing (List, 2019). Mapping can also cue construction of links among documents and increase students' understanding of how different ideas relate to each (Barzilai et al., 2020).

Nonetheless, relatively few prior studies have examined how students map multiple documents. Kiili (2013) found that construction of an argument map led high-school students to spend more time on integration and increased their awareness of the relations between arguments. Barzilai and Ka'adan (2017) found that using a paper-and-pencil integration map had a positive effect on middle-school students' integrative essays. List (2019) found that undergraduates were more successful in representing multiple texts through diagrams then through written essays. Specifically, the visual diagrams reflected more intertextual connections and citations.

A limitation of generic mapping tools is that they do not support construction of documents model elements such as source evaluations, source-content links, and source-source links. This led Barzilai et al. (2020) to develop an online learning environment called the Knowledge Society Sandbox which includes a document mapping scaffold that was designed to support construction and representation of documents models. Barzilai et al. (2020) qualitatively described how students used the document mapping scaffold as they engaged in inquiry with multiple historical documents. The aims of the current study were to conduct a close analysis of students' document maps in order to examine how they utilize the document mapping scaffold to represent multiple scientific documents. Our research question was: How do students use the document mapping scaffold to visually represent multiple documents and what do their maps reveal about their multiple document comprehension?

Method

The sample included 40 9^{th} grade students, 21 girls and 19 boys, who studied in an urban junior high-school in the North of Israel. Participants individually performed two multiple document tasks using the document mapping scaffold. The scaffold enables students to evaluate source relevance and trustworthiness (on a scale of one to four), to identify the main claims that emerge from the documents, and to map the connections among claims and sources. Each source is represented using a round source node. The size of the source node represents the relevance level, and the color of the source node represents the trustworthiness level. Each claim is represented as a blue rectangular node ('claim box'). There are three types of connections available: source-source links, source-claim links, and claim-claim links. Each link can be marked as a reference (black), support (green), or opposition (red) link. Examples of document maps are available in the findings section.

Before the first task, students watched a ten-minute video tutorial which demonstrated how to use the document mapping scaffold. In the first task, students examined if chocolate is healthy using five documents. In the second task, which took place about a week after the first task, students were asked to answer the question: "Is drinking bottled mineral water healthier than drinking tap water?" using seven documents. In this paper, we focus on analysis of the document maps created in the second task because this was a more complex task that was performed after the students were well familiar with the mapping tool.

The water bottles task included seven adapted online documents. Two documents presented arguments for drinking bottled mineral water, four presented arguments against this, and one document discussed the environmental impact of plastic bottles and had low task relevance. Three documents were published by trustworthy expert science or government sources, three documents had low trustworthiness (two were published by sources with explicit commercial interests and one was a personal blog with questionable credentials), and one source had a medium level of trustworthiness (popular science magazine). Students were asked to evaluate source trustworthiness and relevance, to map the documents, and to write essays that addressed the inquiry question.

Analysis of the maps that students created was informed by the Documents Model Framework (Britt & Rouet, 2012). We counted all claim boxes, source nodes, and links that appeared in students' maps. Claims were coded as *intratextual* if they were connected to only one source, and as *intertextual* if they were connected directly or indirectly to more than one source. We also coded whether the claim boxes included macro-claims or reasons for each of the positions presented in the documents (for or against bottled mineral water). Links were coded as *intratextual* if they connected a single claim to its source, and as *intertextual* if they connected two sources, if they connected a source to an intertextual claim, and if they connected claims from different sources or intertextual claims. We also coded agreements and disagreements between sources as follows: Sources were coded as *agreeing* with each other if they were directly linked using a support link or if they both supported or both opposed the same claim. Sources were coded as *disagreeing* if they were directly linked using an opposition link or if they had different relations to the same claim (support vs. opposition).

Findings

Representation of sources and claims

The maps included 5.33 (SD =1.79) source nodes on average out of 7 available sources. The mean trustworthiness rating of the three sources that had low trustworthiness was lower than the mean trustworthiness rating of the three trustworthy sources, $M = 2.28$, $SD = 0.53$ vs. $M = 3.53$, $SD = 0.42$, $t(39) = 11.88$, $p < .001$, $d = 1.88$. The relevance rating of the irrelevant source was lower than the mean relevance rating of the relevant sources, $M = 1.65$, $SD = 0.92$ vs. $M = 3.05$, $SD = 0.45$, $t(39) = 8.77$, $p < .001$, $d = 1.39$. This indicates that students were generally able to discern and appropriately represent source trustworthiness and relevance in their maps.

The maps included 5.73 ($SD = 3.88$) claim boxes on average. Most claims were intratextual claims ($M = 3.98$, $SD = 4.26$). Less common were intertextual claims ($M = 1.75$, $SD = 1.35$), $t(39) = 2.82$, $p = .007$, $d = 0.45$. Nevertheless, 75% of the maps included at least one intertextual claim. Furthermore, 77.5% of the maps included a representation of macro-claims and/or reasons both for and against water bottles. Although only few of the maps represented a full two-sided argument including macro-claims and reasons for both positions (17.5%).

Representation of connections between sources and claims

The maps included 9.53 (SD = 4.71) links on average. Students created more source-content links than source-source links, M = 7.43 SD = 4.44 vs. M = 0.68 SD = 1.31, $t(39) = 8.99$, $p < .001$, d = 1.42. They also created significantly more intertextual than intratextual links, M = 6.38, SD = 4.12 vs. M = 3.15, SD = 3.54, $t(39) = 3.36$, p = .002, d = 0.53. Additionally, the maps represented 2.93 agreements (SD = 3.11) and 1.33 disagreements (SD = 2.29) between sources on average, indicating that students were able to represent relations between sources. Interestingly, agreements were represented more often than disagreements, $t(39) = 3.50$, p = .001, d = 0.55.

Integration vs. elaboration in students' multiple document representations

Students' maps were diverse. Some included only a few intertextual claims that were connected to multiple sources, and some had many intratextual claims and relatively few intertextual connections. Figure 1 charts the maps according to their level of elaboration and integration. The X-axis represents the degree of elaboration based on the amount of claims in the map. The Y-axis represents degree of integration based on the amount of intertextual links in the map. As can be seen in Figure 1, some maps had low or zero integration, although a few of these maps were highly elaborated (e.g., map a). Some maps had high integration and relatively low elaboration (e.g., map b). Few maps were both highly elaborated and integrated (e.g., map c). We next take a closer look at these three maps.

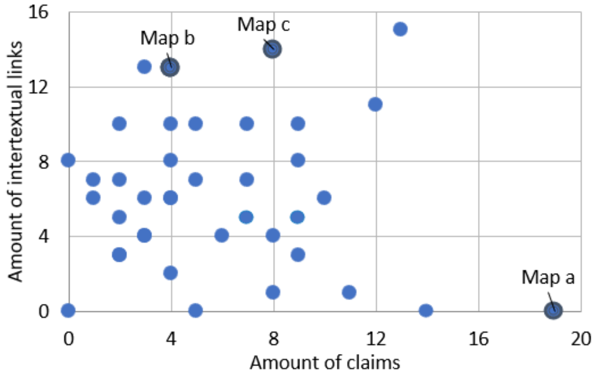

Figure 1. Integration vs. elaboration in students' documents maps

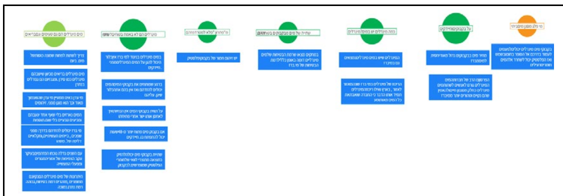

Figure 2a. Map 1: High elaboration and no integration

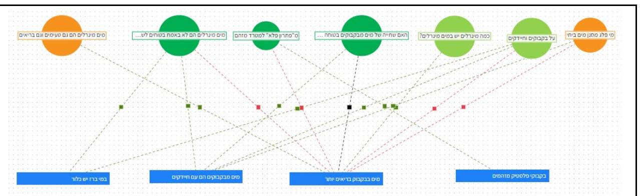

Figure 2b. Map 2: High integration and low elaboration

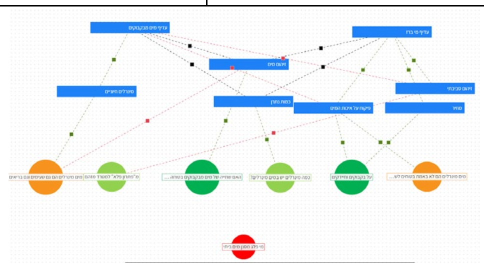

Figure 2c. Map 3: High elaboration and high integration

Figure 2. Examples of students' documents maps.

Map a (Figure 2a): High elaboration and no integration. This student extracted multiple claims from the documents and placed them under their respective source nodes in a table-like format. The map did not include any intertextual claims or links, suggesting that the student did not engage in integration. In terms of the documents model framework, this map represented connections between sources and contents, but did not represent source-source connections or an integrated model of the contents. Such a representation precludes weighing claims in light of breadth and strength of support.

Map b (Figure 2b): High integration and low elaboration. This student created one macro intertextual claim ("bottled water is healthier") which was linked to all seven sources. Four sources were linked using opposition links, two were liked using support links, and one using a reference link, clarifying that the claim that bottled water is healthier than tap water was disputed more than it was supported. However, this map had only three additional claims, two of them intertextual and one intratextual. Thus, although the map was highly integrated, it represented a relatively low number of ideas from the documents.

Map c (Figure 2c): High integration and high elaboration. This map had many direct and indirect links between sources and claims as well as fair amount of content representation. This student placed two macro intertextual claims on the top of the map ("bottled water is better" and "tap water is better"). In the middle layer of the map, the two macro claims were connected to six intertextual and intratextual claims. These claims were in turn connected to a row of sources on the bottom of the map. This student judged one source as highly untrustworthy (red source node) and placed it beneath all other sources. This source (a Facebook post by a commercial company) was not linked to any claims, indicating that the student decided not to integrate it.

Discussion

We found that students were able to construct rich documents models using the online document mapping scaffold. The maps revealed that most students were able to discern source trustworthiness and relevance, to identify claims from the texts, and to construct intertextual claims. Most students were also able to connect claims to their sources and to identify relations of agreement and disagreement between the sources. Students were not provided any direct instruction other than a brief tutorial on how to use the scaffold. This suggests that the representational affordances of the scaffold supported construction of documents models.

Students represented more source-claim links than source-source links. Source-claims links may be easier to grasp because the proximity of content and source information in the documents. Source-source links require forming inferences across documents and may also be more abstract. When students represented relations between sources this was mostly done by connecting sources to the same claim. Students represented more agreement relations than disagreement relations between sources, suggesting that they focused more on identifying similarities than differences.

Students had diverse approaches to mapping. Some focused more on elaborating the content of the documents, while others focused more on integrating the documents. Relatively few students constructed maps that were both highly elaborated and highly integrated. These findings suggest a potential trade-off between elaboration and integration processes in multiple document comprehension. This trade-off might be due to the high complexity of constructing coherent documents models. Different mapping approaches might also be due to students' perceptions of the aims of the map: Some students may view the map as a tool for gathering content from the documents, whereas others might view it as a tool for understanding how multiple sources relate to competing claims.

To conclude, the results indicate that a visual document mapping scaffold can support construction of documents models. However, students may need additional soft scaffolds that will adaptively draw their attention to various dimensions of representation, so that they can create well-integrated and elaborated documents models.

References

Barzilai, S., & Ka'adan, I. (2017). Learning to integrate divergent information sources: The interplay of epistemic cognition and epistemic metacognition. *Metacognition and Learning, 12(2)*, 193-232.

Barzilai, S., Mor-Hagani, S., Zohar, A. R., Shlomi-Elooz, T., & Ben-Yishai, R. (2020). Making sources visible: Promoting multiple document literacy with digital epistemic scaffolds. *Computers & Education, 157*, 103980.

Bråten, I., Stadtler, M., & Salmerón, L. (2018). The role of sourcing in discourse comprehension. In M. F. Schober, D. N. Rapp, & M. A. Britt (Eds.), *The Routledge handbook of discourse processes* (2nd. Ed., pp. 141–166). Routledge.

Britt, M. A., & Rouet, J. F. (2012). Learning with multiple documents: Component skills and their acquisition. *Enhancing the quality of learning: Dispositions, instruction, and learning processes,* 276-314.

Goldman, S. R., Braasch, J. L., Wiley, J., Graesser, A. C., & Brodowinska, K. (2012). Comprehending and learning from Internet sources: Processing patterns of better and poorer learners*. Reading Research Quarterly, 47*(4), 356-381.

Kiili, C. (2013). Argument graph as a tool for promoting collaborative online reading. *Journal of Computer Assisted Learning, 29*(3), 248-259.

List, A. (2019). Drawing is integrating: An examination of students' graphic representations of multiple texts. *Reading Psychology, 40*(6), 491-524.

Computational Thinking as a Context for Ambitious Math Instruction

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Abstract: Current efforts to improve math education often call for *ambitious math instruction*, which promotes student thinking and conceptual understanding. Such instruction can be difficult for many teachers because it differs from how they learned math. Incorporating computational thinking (CT) into math teacher education might support teacher learning of ambitious math because it moves teachers out of their familiar math context. We use data from a middle grades math and science methods course to show how some pre-service teachers tend to focus on ambitious math goals to make sense of CT and its connections to math.

Introduction

In math education, many have sought to improve K-12 mathematics through *ambitious math instruction*. Ambitious math instruction promotes student inquiry, communication of mathematical ideas and connecting different math content (NCTM, 1989). Yet, many teachers struggle to teach according to ambitious math practices because it asks them to think about math differently than how they were taught (Ball, 1988; Borko et al., 1992).

One way to help teachers shift toward ambitious teaching might be to change their familiar math context. Computational thinking (CT), which is currently expanding in schools, might be that context change. CT includes the skills and ways of thinking in computer science and uses practices like pattern recognition and abstraction (Grover & Pea, 2013). Engaging students in such practices are also goals of ambitious math. By incorporating CT into an undergraduate math and science methods course, we noticed that pre-service teachers (PSTs) often focused on these practices as they learned about CT. Based on our observations of PSTs, we posit that including CT in math teacher education might be a helpful context for learning about ambitious math instruction.

The purpose of this paper is to discuss the possible affordances of CT to teach teachers about ambitious math. We first review the literature on ambitious math and CT and how they overlap. We then use data from a middle grades math and science methods class to show that PSTs seem to center ambitious math practices and goals in a CT context, making CT a plausible path for developing teachers' ambitious math instruction.

Background

Ambitious math instruction calls for teachers to engage students in solving open-ended problems, to facilitate math discussions, and to guide students as they construct math ideas (Fennema et al., 1993). The goals include helping students to reason mathematically, make content connections, and communicate their thinking. Standards like the Common Core State Standards for Mathematical Practice (SfMPs) reinforce these goals (CCSS, 2010).

However, it can be difficult for teachers to learn and use ambitious teaching. Many teachers learned math through traditional instruction that involves procedure memorization and routine problem solving. Shifting to ambitious teaching often asks teachers to rethink how math is learned and taught (Ball, 1998; Borko et al., 1992).

While most research promotes ambitious instruction in the current school math context, another path might be through CT. There are differing definitions of CT, but it is generally thought of as the practices and strategies used in computing (Grover & Pea, 2013). Many have worked to define CT in the context of education (Barr & Stephenson, 2011; Dong, et al. 2019; Weintrop et al., 2016). For example, in their teacher-friendly CT framework known as PRADA, Dong et al. (2019) defined the key components of CT as (1) pattern recognition, which is using patterns in meaningful ways; (2) abstraction, which is determining the general properties of a problem that are useful; (3) problem decomposition, which is breaking a problem into tractable component parts; and (4) algorithmic thinking, which involves solving a problem through a series of steps. CT can give students technological skills and can help to develop dispositions like persistence in problem solving and the ability to collaborate (CSTA & ISTE, 2011; NRC, 2010).

Recently, there has been a push to expand CT in K-12 classes (White House, 2016). In addition, researchers have highlighted the role that math plays in science fields, like computer science, and have argued that math education should reflect this connection (NRC, 2013). In response to these calls, efforts have often examined possible areas of CT-math overlap (Fofang et al., 2020; Pérez 2018). For example, Pérez (2018) developed a framework to show how CT dispositions can support mathematical thinking. He also noted the potential for a CT context to help teachers maintain the cognitive demand of math tasks, which is important to ambitious math teaching (Stein et al., 1996).

Others have reported important differences between CT and math (Rich, et al., 2020; Tatar et al., 2017). In one study, Rich, et al. (2020) looked for intersections between CT ideas and mathematical thinking seen in the Common Core State Standards (CCSS). They found that CT and math thinking can intersect in ways that are productive for student learning, but that not all mathematical thinking skills correspond to similar ideas in CT.

The ways that teachers connect CT and math has also been a research focus. (Duncan et al., 2017; Rich, et al., 2019; Walton et al., 2020). For example, Rich et al., (2019) examined elementary school teachers' thinking on the connections between CT and the math they teach. They found that some teachers could relate CT practices and the SfMPs, which could be leveraged during CT professional development.

Efforts by Rich and others are a great start in understanding how math and CT connect. However, their work is primarily from a computing perspective; they aim to develop teachers' CT understanding to expand computing in classrooms. Bringing computing to more students is certainly a worthwhile goal, but we argue that CT can also be valuable from a math perspective, like for teachers' ambitious math learning. Pérez (2018) showed what a math perspective could look like in his discussion of CT as a context for task implementation. We build on this work as we describe how CT seemed to provide a context for PSTs to highlight ambitious math goals.

PSTs' identification of ambitious math goals in a CT context

The following examples were taken from data collected over two years in a middle grades (grades 4-9) math and science methods course at a large mid-Atlantic university. There was a total of 32 PSTs in the two years. The course included a three-class CT module aimed at introducing PSTs to key CT components and at helping them integrate CT into their instruction. Activities included reading practitioner-focused articles that introduced key CT ideas (Years 1 and 2), discussions about how CT connects to the SfMPs (Year 1), and discussions about how CT fits into math and science classrooms in general (Years 1 and 2).

In both course years, we recorded class discussions about CT and how it relates to math and science instruction. We also conducted semi-structured interviews with four PSTs (two in each year) at the conclusion of the module. The four PSTs were chosen because they made strong connections between CT and classroom instruction during discussions, and we wanted to explore their thinking further. The questions we aimed to answer were (1) How do PSTs begin to conceptualize computational thinking? and (2) How do PSTs begin to learn about CT practices in relation to teaching math? While reviewing the data, we noticed that PSTs often centered ambitious math goals when making sense of CT and connecting CT to their instruction.

The first example is from an interview with a PST named Amy that took place at the conclusion of the CT module in Year 1. Throughout the interview, Amy seemed to ground her understanding of CT in *pattern recognition*. Pattern recognition is an important ambitious math idea for connecting different math topics and for problem solving. Early in the interview, when asked if she had seen CT in any previous experiences, Amy referred to activities from her teaching methods classes. She said, "Well whenever I think of computational thinking, I think about patterns...kind of like what we did in class earlier today [with a math task]." She continued by discussing another math methods class and said, "I had seen those concepts of, like, building and constructing a pattern from something you observe."

Amy also made connections between CT dispositions and ambitious math goals related to student discourse. When asked how she thought CT related to the SfMPs, Amy connected the CT ideas of *negotiation* and *consensus building* to SfMP3, *construct viable arguments and critique the reasoning of others*. Amy said,

> Collaboration and consensus building...ties into this other practice of constructing arguments and critiquing… Students should engage with their peers and if they're given a task where it's not so straight forward, then they should be having discussions where they say, "Hey this doesn't look right," or, "I agree with you because," or, "I disagree with you because…" And it ties into [SfMP3] because there's a collaboration of students working together and negotiation of what's actually correct, and from that cooperation and negotiation they build a consensus.

Here, the terms *negotiation* and *consensus building*, important to the CT disposition of collaboration, came from one of the articles PSTs read during the CT module (Barr & Stephenson, 2011). Amy connected collaboration with students critiquing each other's ideas, an important ambitious math practice and part of communication in mathematics.

Similarly, Cara, another student in year one of the course, related the CT idea of *abstraction* to SfMP6, *attend to precision,* when asked to make connections between CT and the SfMPs. In her interview, she said,

> The goal of abstraction in CT is to take something that's very complex and muddled and make sense of it, which relates to Standard Six because attending to precision… it's very difficult to communicate your thoughts clearly and precisely to others when in your head you're like, "Oh, this does that with this number…" In your head it's different from what you actually verbalize to your classmates...so I think that's how they're related because abstraction is trying to understand and make clarity of a situation.

Like Amy, Cara focused on the importance of being able to communicate mathematical ideas and saw the generalization involved in abstraction as helpful for that goal.

We also saw instances of PSTs identifying ambitious math practices in the context of CT with different PSTs in Year 2 of the CT module. It is important to note that in Year 2 PSTs were never prompted to make connections between CT and the SfMPs. One example again related to abstraction. After reading the practitioner articles, PSTs engaged in group discussions about what CT means and how what it could look like in K-12 classrooms. One PST, Jackie, said,

> I feel like [the articles] also talked a lot about… this is part of that abstraction, but generalizing a situation for problem solving. Because when you think through it you try to create this general situation where if you change factors about your problem you could still use that method.

Later in the class, she related this idea to deriving a general formula in math. She said, "If you show students the derivation, that's more of the process of how you get this generalized formula, but then they know the reasoning behind why they use a generalized formula and why their inputs will get the correct outputs." She later continued, "So students know why they can use that formula as a general rule for a specific type of problem." Here, Jackie showed abstraction could give students a better conceptual understanding of the math, while also giving them an appreciation of the power of using one formula for multiple situations, which are both aspects of ambitious math.

Discussion and conclusion

The examples above show some of the ways we saw teachers highlight ambitious math as they tried to make sense of CT. PSTs connected CT ideas, like pattern recognition, collaboration, and abstraction, to ambitious math goals like communicating thinking, critiquing others' reasoning, and building conceptual understanding. These observations are similar to Rich et al.'s (2019) findings that show that teachers can connect CT, the SfMPs, and other areas of their math instruction. Our work is notable because PSTs made these connections with and without prompting. This not only shows the potential for CT to reinforce ambitious math standards in math instruction, but also that teachers may tend to naturally incorporate ambitious math practices into their CT lessons.

Rich et al. (2019) see CT-math connections as an entry point for teaching teachers more about CT. We see an additional benefit of supporting teachers' ambitious math instruction. Our examples of PSTs show that CT could also provide a context for teachers to focus on ambitious math goals. Current ambitious math efforts often try to support teachers' learning of these ideas solely in a math context. As seen in our examples, a more indirect approach that uses CT might be helpful because it takes teachers out of their math context, where their apprenticeship of observation (Lortie, 1975) could direct them toward traditional math instruction. Instead, CT might place teachers in a context where they can more readily focus on ideas related to ambitious math.

More work is needed to determine whether such an approach could be successful. Given that others have found that CT and mathematical thinking overlap in some ways but not others (Rich et al., 2020), future studies could examine whether there are more or less productive ways that CT can support ambitious math. In addition, while the PSTs here highlighted ambitious math in the context of CT, our work does not address how teachers would develop instructional moves that would achieve such goals. Future work could look at how teachers' focus on ambitious math goals in a CT context might be leveraged to also support instructional practices.

Finally, the increasing push to include computing in school disciplines, like math, adds to teachers' constantly growing list of responsibilities. It is important to consider how these additions benefit teachers and grow their current practice. In the case of CT, we think it could provide a valuable context for teachers to focus on ambitious math goals and develop their ambitious math instruction.

References

Ball, D. L. (1988). Unlearning to teach mathematics. *For the Learning of Mathematics*, *8*(1), 40–48.

Barr, V., & Stephenson, C. (2011). Bringing computational thinking to K-12: What is involved and what is the role of the computer science education community? *ACM Inroads*, *2*(1), 48–54.

Borko, H., Eisenhart, M., Brown, C. A., Underhill, R. G., Jones, D., & Agard, P. C. (1992). Learning to teach hard mathematics: Do novice teachers and their instructors give up too easily? *Journal for Research in Mathematics Education*, *23*(3), 194–222.

Computer Science Teachers Association (CSTA) and International Society for Technology in Education (ISTE) (2011). *Operational definition of computational thinking for K-12 education.* Retrieved from https://csteachers.org/documents/en-us/3d01754c-e7eb-4b8d-889e-51532a2158b2/1/.

Duncan, C., Bell, T., & Atlas, J. (2017). What do the teachers think? Introducing computational thinking in the primary school curriculum. *ACM International Conference Proceeding Series*, 65–74.

Dong, Y., Cateté, V., Jocius, R., Lytle, N., Barnes, T., Albert, J., Joshi, D., Robinson, R., & Andrews, A. (2019). PRADA: A practical model for integrating computational thinking in K-12 education. *SIGCSE 2019 - Proceedings of the 50th ACM Technical Symposium on Computer Science Education*, 906–912.

Fennema, E., Franke, M. L., Carpenter, T. P., & Carey, D. A. (1993). Using children's mathematical knowledge in instruction. *American Educational Research Journal*, 30, 555–583.

Fofang, J. S., Weintrop, D., Walton, M., Elby, A., & Walkoe, J. (2020). Mutually Supportive Mathematics and Computational Thinking in a Fourth-Grade Classroom. In Gresalfi, M. and Horn, I. S. (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 3 (pp. 1389-1396). Nashville, Tennessee: International Society of the Learning Sciences.

Grover, S., & Pea, R. (2013). Computational Thinking in K-12: A review of the state of the field. Educational Researcher, 42(1), 38–43.

Lortie, D. C. (1975). Schoolteacher: A sociological study. Chicago: University of Chicago Press.

National Council of Teachers of Mathematics (NCTM). (1989). Curriculum and evaluation standards for school mathematics. Reston, VA: National Council of Teachers of Mathematics.

National Governors Association Center for Best Practices & Council of Chief State School Officers (CCSS). (2010). Common core state standards for mathematics. Washington, DC: Authors.

National Research Council (NRC) (2010). Report of a workshop on the scope and nature of computational thinking. The National Academies Press, Washington, DC.

NRC (2013). The mathematical sciences in 2025. Washington, DC: National Academies Press.

Pérez, A. (2018). A framework for computational thinking dispositions in mathematics education. *Journal for Research in Mathematics Education*, *49*(4), 424–461.

Rich, K. M., Spaepen, E., Strickland, C., & Moran, C. (2020). Synergies and differences in mathematical and computational thinking: implications for integrated instruction. *Interactive Learning Environments*, *28*(3), 272–283.

Rich, K. M., Yadav, A., & Schwarz, C. (2019). Computational thinking, mathematics, and science: Elementary teachers' perspectives on integration. *Journal of Technology and Teacher Education*, *27*(2), 165–205.

Stein, M. K., Grover, B. W., & Henningsen, M. (1996). Building student capacity for mathematical thinking and reasoning: An analysis of mathematical tasks used in reform classrooms. *American Educational Research Journal*, *33*(2), 455–488.

Tatar, D., Harrison, S., Stewart, M., Frisina, C., & Musaeus, P. (2017). Proto-computational thinking: The uncomfortable underpinnings. In P. J. Rich & C. B. Hodges (Eds.), Emerging research, practice, and policy on computational thinking (pp. 63–81). Cham: Springer International Publishing.

Walton, M., Walkoe, J., Elby, A., Fofang, J. S., & Weintrop, D. (2020). Teachers' Conceptualizations of Computational and Mathematical Thinking. In Gresalfi, M. and Horn, I. S. (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 4 (pp. 2053-2060). Nashville, Tennessee: International Society of the Learning Sciences.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147.

White House. (2016, January 30). Computer science for all [Blog post]. Retrieved from https://obamawhitehouse.archives. gov/blog/2016/01/30/computer-science-all.

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Learning with and through Evaluation as Social Practice

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Abstract: Learning as social practice attends to the situatedness of learning and the co-emergence of persons and practices. We argue evaluation should be viewed from this same lens. We present findings from an evaluation project at a high school. Using the project as a case study, we show that evaluators make consequential boundary judgments that either restrict or expand what counts as legitimate knowledge in a given situation as well as whose stakeholder's interests are validated.

Introduction

A salient feature of the Learning Sciences has been—and will continue to be—how we design and organize for learning. Our interventionist approaches to research, such as design-based research (Barab, 2006) and formative interventions (Penuel, 2014), require us to embrace a vision of how we think the world *ought* to be. Our challenge is to make our normative decisions explicit by defining not only *how* we design for learning but more importantly *for whom, with whom* and *for what* of our endeavors (Philip, Bang & Jackson, 2018). In this paper, we analyze how the practice of evaluation and the role of the evaluator contribute to the design and organization of learning. More specifically, we argue that evaluation is itself a social practice enacting boundary judgments that shape practices and it ought to be leveraged to support expansive learning as well as the changes in learning for which we design.

Recognizing evaluation as a social practice is an extension of our view of learning as social practice (Holland & Lave, 2009). We take learning to be situated in activity, mediated by cultural tools, and inherently contextual (Lave & Wenger, 1991; Wertsch, 1998). Learning is an ontological process: a coming to be of valued persons, activities, and objects (Packer & Goicoechea 2000; Weidler-Lewis, Wooten, McDonald, 2020). This process is ongoing and never fully determined; we can analyze how practices and learning outcomes came to be, but we cannot know *a priori* what organizational features will prevail in the future (Latour, 2005). However, as participants in social practices our agency and decision making have the potential to shape and inform practices despite not determining them (Pickering, 2005). We intend to make explicit how theory driven evaluation as a social practice (Schwandt, 2018) plays a role in promoting certain valued practices over others and the consequential decisions an evaluator can make enhancing or denigrating learning related to a research project or a research practice partnership.

Researching evaluation as a particular form of participation in the design of learning contributes to our understanding of how valued and normative practices come to be. Evaluators are often bracketed off from research projects in order to provide an external assessment of the project. Such removal from the ongoing coordination of practice has the potential to contribute to the reproduction of dominant evaluative logics that serve the powerful at the expense of the powerless under the guise of neutrality (e.g., Boyce, 2019). Alternatively, embracing evaluation as being pivotal and consequential in the practices of designing for learning has the potential to create new opportunities for designing towards socially valued futures. In the subsequent sections, we further articulate our view of evaluation as social practice and the importance of judgments that provide the shape and boundaries to our designs. Drawing on data collected from administering and debriefing an evaluation survey in a newly formed and emergent research practice partnership (RPP) between the authors and an experiential learning high school, we highlight key decisions made as evaluators that became consequential in shaping how and what was taken up for future action and inquiry to guide the school's practice, and thereby influencing possibilities for learning and becoming. We conclude by suggesting further lines of inquiry into the social practice of evaluation.

Theory driven evaluation as social practice and boundary judgments

We draw on the scholarship of Thomas Schwandt (2018) to claim that evaluation is a social practice that affords our ability to make evaluative judgments (i.e., claims about merit, worth and/or significance). Theory driven evaluation (TDE) provides information about the performance of a program or practice while also reporting on how and why the program achieved these results in order to guide practitioner actions (Coryn, Noakes, Westine & Schröter, 2011). TDE holds that evaluative evidence should have both scientific credibility (i.e., trustworthiness, validity, and reliability) as well as "practical worth" for stakeholders to improve their practices (Chen, 2013). The inclusion of practical worth for stakeholders in TDE is seemingly aligned with learning practice theorists who recognize relevance to practice as an important criterion for rigor (e.g., Gutiérrez & Penuel, 2014). However, TDE is routinely conceptualized from cognitive perspectives that promote evaluative thinking, reasoning, and sensemaking as primarily individual accomplishments and ignore the myriad ways that evaluative decisions are made collectively and situated within particular contexts (Schwandt, 2018).

Schwandt (2018) identifies three reasons for understanding evaluation as social practice facilitated by an evaluator. First, the identification of facts to measure, and their associated value or worth in a program, generally unfold in an interactive process among the multiple stakeholders who come to agreement or point of view on which to evaluate an intervention, also known as "stakeholder-making." Second, extensive literature on sensemaking demonstrates that individuals are not lone actors but are rather situated in contexts that impact their choices and action. For example, in education, teachers' sense-making of policy standards and their subsequent classroom activities are shaped by their organization context (e.g., Allen & Penuel, 2014). Lastly, evaluation should have as its aim practical action such that the evaluator supports "we-judgments" spanning matters of facts and values to answer "what should we do?" Or in the case of learning: *how ought we design for learning?* When evaluation is seen as a social practice and a joint accomplishment of participation by the evaluator and stakeholder community, the decisions made by the evaluator must be analyzed not according to only abstract theory (be it statistical or otherwise), but rather, evaluator decisions should be analyzed within their embedded context and in relation to the practice seeking improvement.

In order to make evaluative decisions for practical action, we must engage in "boundary judgment making." Any given situation or context cannot be studied in its totality; a boundary judgment is a decision regarding what should be included in the given situation and what should be left out (Schwandt, 2018). Given that evaluation is a social practice including multiple stakeholders, boundaries are not set or given; they are negotiated through collective sensemaking and require normative reasoning. By critiquing multiple boundary judgments, we determine how to proceed. First, judgments are critiqued by invoking morality and asking if a given phenomenon (i.e., policy, program, strategy) is *good* or the *right* thing to be doing. Second, critiques consider alternative arrangements and what *should be* done rather than what is currently happening. Lastly, there is no single or correct answer to what boundaries in an investigation ought to be. Therefore, critique in boundary judgment making is important to: (a) "make sense of a situation," including its values, motivations, power structures, relevant knowledge, and moral bases as well as "to bear the consequences of what will be done, as well as what we may fail to do;" (b) "unfold multiple perspectives and promote mutual understanding," by recognizing how different individuals and groups frame situations differently; and (c) "promote reflective practice" through both analysis and change (Schwandt, 2018, p.132). Because as evaluators we embrace TDE as social practice and recognize the need for reflection in our practice, this research seeks to understand both "what are the consequential boundary judgments for learning we made during our evaluation?" and "who and what practices were served by these boundary judgments?

Background and methods

As mentioned in the introduction, this work stems from a fledgling RPP involving the authors and an experiential learning high school (ELS). Frickey, the internal coordinator of evaluation & monitoring enlisted the help of Weidler-Lewis to begin research endeavors into both school improvement measures at the local level and more robust inquiry into experiential learning writ large. The timing of our partnership coincided with the 25th anniversary of ELS and was an ideal time to collect data on former students regarding their high school experience. Prior to our work, no systematic follow-up of former students was conducted. Given our mutual goals of serving both ELS and the broader experiential learning community, we decided to survey former students using a combination of psychometric scales used in other educational contexts, items measuring attitudes towards ELS values, practices and other key school indicators, and a single, open-ended prompt for former students to share any information they felt pertinent to our endeavor. In developing the survey, we considered the possibility of creating a single measure of "experiential learning success" to be iterated on by the already validated psychometric scales we employed that could be used in varied experiential learning contexts. We considered our survey to be a pilot of such measure knowing that given limitations, the survey would primarily be used for ELS evaluation. Our purpose in this paper is not to provide an empirical analysis of the survey design, implementation, and/or results. Rather, we endeavor to use the practice of surveying former students and the process of stakeholder-making to underscore how we engaged in TDE social practice and the boundary judgments we made alone and in collaboration with ELS stakeholders.

The data for our analysis comes from email correspondence about the survey between the authors, design documents and notes regarding the survey, the survey itself and its findings, the evaluation report presented to ELS, and the notes and records of the presentation of survey findings to ELS stakeholders. These stakeholders included the head of school, the director of curriculum, the director of student services, the associate head of student services, the director of professional development, and the former director of professional development who had been an original founder of the school. For purposes of anonymity we do not attribute views to stakeholder role. We first coded our data deductively by analyzing them for boundary judgments according to 1) moral claims (i.e., that which is *right* or *good*), 2) claims about what *should* be occurring at ELS, and 3) claims that interpreted the situation in one of many possible ways that could have been interpreted differently. After coding, we, looked for emergent themes and explicit connections between our codes, the stakeholders, and the different positions the stakeholders held (Saldana, 2009).

We present our initial findings detailing consequential boundary judgments in our evaluation practice. We demonstrate that even though key stakeholders were identified at the outset, whose interests were taken-up—and therefore pursued—emerged in interaction. We show how deference to scientific credibility in TDE can easily usurp its practical worth. This work is still ongoing, as such, we consider it to be exploratory in nature in that we are trying to surface the important tensions in TDE as social practice that will foster further study in this area (Stebbins, 2001).

Findings

From the outset, proponents of social practice theory might be confused as to why we would employ a survey of psychometric measures to evaluate student "success" when such measures assume psychological and cognitive orientations to the world. Indeed, this was one of the first boundary judgments made collectively among the stakeholders insofar as we all agreed that a succinct survey with limited questions would be an ideal starting point to begin an evaluative relationship. Reasons for this decision included time and financial constraints related to gathering data prior to ELS's anniversary celebration. It is important to note, historically, ELS had a culture of eschewing most forms of quantitative data on students including not assigning students grades and instead favoring students' lived, experiential data. While such evidence demonstrating student success at ELS was documented in several book publications, little sustained inquiry existed for why some ELS students succeeded when others did not. All parties agreed a survey had the potential to reveal previously undocumented categorical differences (i.e., race, gender, cohort, etc.) with explanatory power for "success" in the ways we defined. The ELS stakeholders saw the potential for quantitative evidence to support their intuitions regarding categorical differences in students' experience. For example, such a survey might help explain why female students were more likely to graduate despite being more difficult to recruit. The survey might also provide insight into racial difference, which had been a concern of many but not all at the school. As evaluators, we saw the potential for creating a survey measure applicable in other contexts. However, our survey results did not yield any statistically significant difference in any demographic category on any of our items or constructs. As evaluators, we could attribute this lack of evidence to the small student population of the school (266 graduates over its 25 years), the overwhelmingly positive skew of the respondents, and other survey limitations.

While the survey yielded a plethora of descriptive statistics, its lack of any evidence for causal inference was taken up differently by the different stakeholders. For example, the lack of causal evidence seemed to support the historic view that experiential data should be favored over quantitative data, a view contested by current stakeholders. Others remained agnostic of the survey's usefulness, withholding judgment regarding its potential to compare results over time in relation to program initiatives, so it served its purpose as starting point for future comparisons. Another stakeholder thought the survey data was detecting or could with revision detect differences in student experience. This stakeholder examined the descriptive statistics for evidence to support what they (and many other students and staff) knew to be true and had other forms of evidence regarding the experiences of students of color. These differences no matter how small could and should contribute to the ongoing discussion at the school regarding both how to approach broader, national narratives of race as well as any direct incidents of racism. This stakeholder believed direct anti-racist programming was needed, a position not shared by all, and thus, quantitative data could provide further justification for this targeted programming. As the evaluators, we had the opportunity to contribute to the collective boundary judgment making regarding the survey's usefulness in supporting conversations on racism in education. However, because no causal inferences (e.g., $p<0.10$) could be detected from the survey, and because the survey skewed positive, we defaulted to "scientific credibility" as a reason to exclude discussions of students' racialized experience in ways productive for both this stakeholder and the community. Our unilateral judgment shifted the ways in which we constructed this stakeholder: we focused on the lack of causal inference (one aspect of knowledge present in the situation) rather than what other forms of evidence could or should be brought into our discussion that ultimately shape students' experience at the school. In answer to the question who was served by this boundary judgment, we conclude that this stakeholder was not, and likely neither were the students for whom they were advocating.

Discussion and conclusion

While our findings may be brief, we believe they offer the powerful conclusion that just as social practice views of learning guide learning designers to create expansive, rather than reductive, opportunities for learning, so too can evaluators and their evaluations support this cause. In order to do so, evaluators must recognize the ways in which their decisions and judgments hamper or enable reflective inquiry into the very practices they are purporting to serve. The stakeholders came together to support inquiry into understanding varied student experience and implicit in this coming together was a hope to have further answers to and further evidence for, "what should we do?" One stakeholder had evidence, including individual experience as a student, that they were bringing to the process of evaluation; we failed to legitimize it by limiting the discussion of 'evidence' only to the causal claims missing from the survey. We bounded the survey discussion to only include causal inference reliably shown in the survey data despite knowing the school legitimized many other forms of data and the survey could have been used to further those alternative conversations. Moving forward, our role in facilitating stakeholder-making is to continually ensure that we are accurately representing the mutual agreement among stakeholders and to whatever extent possible include multiple forms of evidence in addition to multiple stakeholder perspectives. Part of our evaluation practice, then, must include processes to reengage and reassess if and how our shared agreement has been sustained as well as what dominant logics persist at whose expense. Because stakeholder-making is an on-going practice, a productive line of future inquiry is to trace this process over time and continue to iterate on how best ensure a relationship of reciprocity that values and builds on each other's expertise.

References

Allen, C. D., & Penuel, W. R. (2015). Studying teachers' sensemaking to investigate teachers' responses to professional development focused on new standards. *Journal of Teacher Education*, 66(2), 136-149.

Barab, S. (2006). *Design-Based Research: A Methodological Toolkit for the Learning Scientist.* Cambridge University Press.

Boyce, A. (2019). A Re-imagining of evaluation as social justice: A discussion of the Education Justice Project. *Critical Education*, 10(1).

Coryn, C. L., Noakes, L. A., Westine, C. D., & Schröter, D. C. (2011). A systematic review of theory-driven evaluation practice from 1990 to 2009. *American Journal of Evaluation*, 32(2), 199-226.

Gutiérrez, K. D., & Penuel, W. R. (2014). Relevance to practice as a criterion for rigor. *Educational Researcher*, 43(1), 19-23.

Holland, D., & Lave, J. (2009). Social practice theory and the historical production of persons. *Actio: An International Journal of Human Activity Theory*, 2(1), 1-15.

Latour, B. (2005). *Reassembling the social: An introduction to actor-network theory*. Oxford, England: Oxford University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Packer, M. J., & Goicoechea, J. (2000). Sociocultural and constructivist theories of learning: Ontology, not just epistemology. *Educational Psychologist*,35(4), 227–241.

Philip, T. M., Bang, M., & Jackson, K. (2018). Articulating the "how," the "for what," the "for whom," and the "with whom" in concert: A call to broaden the benchmarks of our scholarship. *Cognition & Instruction* 36 (2): 83–88.

Pickering, A. (1995). *The Mangle of Practice: Time. Agency, and Science*. University of Chicago Press.

Penuel, W. R. (2014). Emerging forms of formative intervention research in education. *Mind, Culture, and Activity*, 21(2), 97-117.

Saldaña, J. (2013). *The Coding Manual for Qualitative Researchers* (2nd Ed.). In SAGE Publications Inc.

Schwandt, T. A. (2018). Evaluative thinking as a collaborative social practice: The case of boundary judgment making. *New Directions for Evaluation*, 2018(158), 125-137.

Stebbins, R. A. (2001). *Exploratory research in the social sciences* (Vol. 48). Sage.

Weidler-Lewis, J., Wooten, M., & McDonald, S. P. (2020). The ontological construction of technology and behavior through practice. *Human Behavior and Emerging Technologies*, *2*(4), 377-386.

Wertsch, J. V. (1998). New York, NY: Oxford University Press.

Modeling Unstructured Data: Teachers as Learners and Designers of Technology-enhanced Artificial Intelligence Curriculum

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Abstract: In this paper, we present a co-design study with teachers to contribute towards development of a technology-enhanced Artificial Intelligence (AI) curriculum, focusing on modeling unstructured data. We created an initial design of a learning activity prototype and explored ways to incorporate the design into high school classes. Specifically, teachers explored text classification models with the prototype and reflected on the exploration as a user, learner, and teacher. They provided insights about learning opportunities in the activity and feedback for integrating it into their teaching. Findings from qualitative analysis demonstrate that exploring text classification models provided an accessible and comprehensive approach for integrated learning of mathematics, language arts, and computing with the potential of supporting the understanding of core AI concepts including identifying structure within unstructured data and reasoning about the roles of human insight in developing AI technologies.

Introduction

Artificial Intelligence (AI) has become a ubiquitous facet of our daily lives. Our young generation should be given high-quality academic training and environments in which they are empowered to participate in the public discourse about AI (AI4K12, 2019; Zimmermann-Niefield et al., 2019). It is a challenge to position youth to be thought leaders in this public discourse without fostering an in-depth understanding of what exactly AI is, how AI works, and why and where AI is used.

Data is the raw material from which artificial intelligence is imbued in artifacts through design. Learning from data is the process through which an AI program gains its "intelligence", and one that we argue is critical for students to devote more focus to. The growing attention to data literacy in pre-college education (e.g., Haldar, Chopra, Wong, Heller, & Konold, 2018) has partially responded to this learning goal. However, the data literacy community has primarily focused on structured data, which has already been quantified and distilled into variables arranged in tables, ready for modelers to manipulate and analyze (Haldar et al., 2018; Lee & Wilkerson, 2018). What has been neglected is the highly consequential and highly subjective process of operationalizing those variables from unstructured and semi-structured types of data such as text, image, audio, and video. The ISLS research community has acknowledged the great deal of creativity, insight, and variation that can be brought to bear in this process of operationalization in its investigation into Multivocality (Suthers et al., 2013). The message of the active and iterative role that data analysts must play when applying modeling technologies is one that we as researchers must also remind ourselves about (Rosé, 2018). Modelers need to extract features that define a representational space in which meaningful distinctions can be made between subsects of instances that take on different significance within an application or a conceptual model. This is what it means for AI developers to do the work of making a prediction problem learnable (Witten et al., 2016). Identifying the iterative process of structuring data, building models, and troubleshooting them in order to understand what their weaknesses tell us about how the structuring needs to be adjusted are the core activities that developers of AI need to be educated in, and which we attempt to make accessible to students. These foundational data practices are critical for students to understand the role of human insight in developing AI technology, but currently are missing in k-12 education.

Much is unknown about ways to advance students' understanding of the above-mentioned core AI concepts. Built on earlier work on student engagement in data wrangling practices (Jiang & Kahn, 2020), this study aimed to evaluate an initial design of a text classification learning activity and explore possible ways to incorporate the design into high school classes, especially non-computing classes. We report a co-design study of a three-year design-based research program (Brown, 1992) that aims to create a high school curriculum powered by StoryQ to engage students in practices of modeling unstructured data. In particular, we guided teachers to test-drive (Penuel et al., 2007) a text classification learning activity using StoryQ prototype and conducted a semi-structured interview to elicit teachers' thoughts on the activity. Specifically, we examined:

1. How do teachers come to understand modeling unstructured data?
2. In what ways do teachers think modeling unstructured data can be integrated into their classes, especially non-computing classes?

Methods

Participants and context

Two teachers, Martin and Hector (pseudonyms), participated in co-designing the unit and technology. The research team met with them prior to the co-design session to discuss the project. Martin has taught ELA (i.e., English Language Arts) for 20 years and Hector had 21-year teaching experience in mathematics and computer science (CS). He was actively learning about teaching AI. We intentionally selected two teachers from different backgrounds as the curriculum will integrate the learning of mathematics, ELA, and computing. In addition, we envision that the curriculum will be co-taught by ELA and mathematics/CS teachers in future iterations.

The co-design session was conducted remotely via Zoom, a video conferencing tool, and included three sections: a five-minute introduction, one-hour clickbait activity, and one-hour semi-structured interview. We first described the goal of the co-design session and emphasized that teachers were expected to experience the learning activity as a user, learner, and teacher. Afterward, we walked teachers through our prototype and associated learning activities to understand how human and computer models determine whether a headline was a) clickbait for encouraging visitors to click on a link or b) news from professional news agencies. The clickbait activity was an exemplar topic for introducing text classification models. The prototype uses logistic regression over unigram features (i.e., single words) as the classification model, which allows predicting headlines into discrete labels by learning the relationship from a given set of headlines with actual labels. We chose it for our prototype as it is easy to interpret for novices and efficient to train (Witten et al., 2016). To solicit feedback, we conducted a semi-structured interview after the clickbait activity. In addition to the co-design session, teachers wrote reflections and contributed ideas about designing the curriculum and platform.

Data collection and analysis

We collected video recordings of the co-design session, including 1) teachers' interactions with the prototype when exploring text classification models to address RQs 1 and 2 and 2) their responses to interview questions to answer RQs 2 and 3. For analysis, we used interaction analysis (Jordan & Henderson, 1995), thematic coding (Braun & Clarke, 2006), and peer debrief. Three researchers developed analytics memos of video recordings, followed by peer-debriefing with four other researchers to ensure validity. Furthermore, we collected and coded teachers' written reflections and ideas throughout the project to gain more insights about their views of learning opportunities in modeling unstructured data and integrating the activity into high school classrooms.

Findings

RQ1: How do teachers come to understand modeling unstructured data?

We found that teachers' understanding of modeling unstructured data evolved after connecting human insight and computer decision making. First, Martin created a dot graph and then they discussed why a headline could be a clickbait or news based on their interpretation of the headline and prior knowledge. Since Martin had not interacted with the prototype and Hector used the prototype before, the research team asked Martin to share the screen. When reading and interpreting headlines, they wrote down rules (Martin typed based on discussions) for clickbait and news headlines and described the process of reading samples and generating rules as inductive reasoning.

Teachers then created a confusion matrix (Witten et al., 2016) to compare actual and predicted labels. Confusion matrix is a performance measurement for machine learning classification that compares predicted and actual labels in a two-dimensional array. As Martin described, "I'm immediately interested in all the ones that where the computer predicted incorrectly." In addition, he not only noticed errors from the computer model but also proposed how we could use the error as guidance to revise the model. Furthermore, Martin and Hector constantly drew on prior knowledge, such as equating the process of computer decision making as advanced search (e.g., headlines with superlative language were more likely to be clickbait).

After investigating the confusion matrix, Martin and Hector probed into computer decision making by creating a frequency and feature weight graph from the features table (Figure 1). They were prompted to investigate the graphs of a) distribution and b) frequency and feature weight together to understand where the weights came from. Martin clicked feature “you” (the highest positive weight, representing that a headline containing “you” would more likely be predicted as clickbait) in the frequency and feature weight graph. Immediately, they noticed that only one headline containing “you” was not clickbait in the distribution graph. While they wondered why it had the highest positive weight, the research team explained that the high proportion of clickbait headlines to news headlines containing “you” contributed to the high positive weight. They came to understand that the feature weight was related to the proportion of clickbait headlines to news headlines containing the feature in the training data, which is the dataset that we used to train a machine learning model. The clickbait activity ended with teachers discussing sources of error from features and possible ways to improve the model.

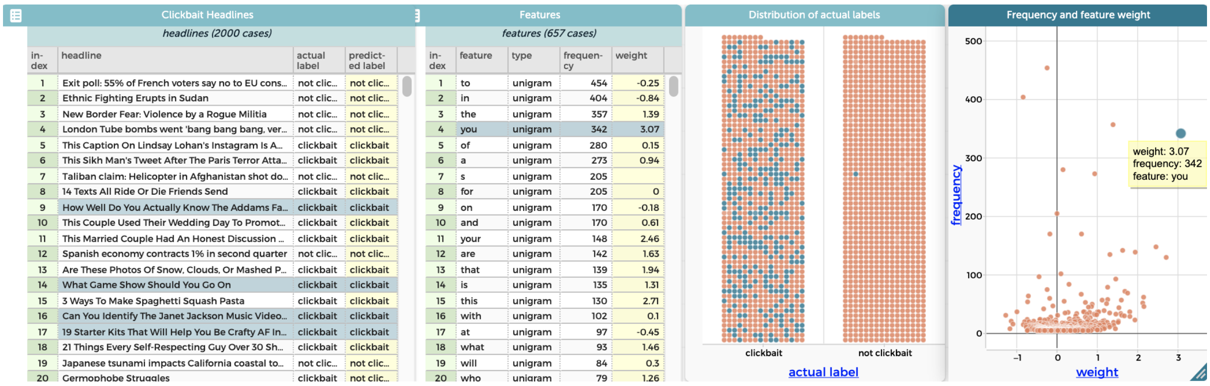

Figure 1. Features table (second) and graph (fourth). Unstructured texts needed to be converted to structured features for machine learning algorithms to exploit. One type of feature is unigram, or single word.

We can clearly see that teachers (in particular Martin, the ELA teacher) became highly engaged in reasoning about rules that computers could learn well, or not, such as the content. They developed an informal understanding of “feature” as “representation that the model can use.” In general, while they were comfortable with connecting human insight and AI models, proposing ideas for programming rules into AI models for text classification, they (especially Martin) needed further guidance to interpret graphs with mathematical reasoning and understand how learning weights on features works from a machine learning perspective.

RQ 2: In what ways do teachers think modeling unstructured data can be integrated into their classes, especially non-computing classes?

Martin and Hector identified learning opportunities from different perspectives. Martin emphasized different layers of learning in ELA, from word choice and sentence structure to interpreting broader contexts, such as historical contexts surrounding text producers. He mentioned that models with basic features (e.g., unigram) might not be able to predict themes of stories without adding advanced features related to information about writers of stories. In addition, he suggested engaging students in analyzing misclassifications (i.e., predicted labels are different from actual labels) within and beyond texts, such as history surrounding the text. In terms of Math and CS learning, Hector discussed that the activity could introduce students to graph literacy, mathematical reasoning, error analysis in rich contexts, and the importance of human insight in developing AI technologies.

Both Martin and Hector suggested leveraging the exploration of text classification models as an interdisciplinary learning approach. They described the learning activity as a focused data analysis of language and a comprehensive approach to and unique context for integrating STEM and the humanities. Also, as described earlier, they stressed the need of helping students to interpret text by drawing on knowledge beyond text. Martin further framed the exploration of models as an innovative way of addressing the criticism in ELA, “most of the language arts for the last 20 years or so have been a form of new criticism, they call it new criticism, where you analyze a text using only the data within the text.” From his perspective, when conducting error analysis, students could be guided to draw personal experience and knowledge about broader contexts to identify sources of error in computer models. In addition, he suggested integrating the activity into traditional writing lessons, such as having students write texts and using their writing as test data to measure model performance.

Discussion and implications

In this study, we examined how teachers began to understand models that were built from unstructured data and ways of integrating modeling unstructured data into their classes, especially non-computing classes. Specifically, the activity sequence of HCC (Human decision making, Confusion matrix, Computer decision making) created an exciting opportunity for participants to understand the role of human insight in developing AI technology as well as reasoning about computer decision making in rich contexts. The confusion matrix, in particular, triggered in-depth error analysis such as analyzing the severity, number, and types of errors that models might produce and how models could be modified by applying human intelligence. While teachers had rich discussions about computer decision making by referring to rules that they identified, they were confused about the feature table, including how models learned feature weights. In the next round of co-design, we will extend the HCC into HC**P**C sequence. **P** stands for adjusting **perspectives** on models and modeling (i.e., practicing the iterative process of updating rules based on insights gained through probing into the behavior of models). We expect that this modified activity sequence might help participants to reason about model performance from a machine learning perspective.

Notably, teachers drew on prior knowledge and personal experience in the discussions about texts and contexts surrounding texts. Future studies could examine other text classification tasks and strategies to create broadly inclusive learning experiences that engage participants from diverse backgrounds in expressing their cultures and personalities. Also, teachers rarely questioned where the dataset came from and who created the actual label. Having participants manually label a small data set and create labels for classification might support them in questioning modeling processes instead of assuming the objectivity of data science and that labels come from nowhere (D'Ignazio & Klein, 2020). In summary, this work contributes to the research on creating a scalable learning environment for high school students to participate in text mining practices in an accessible, relatable, and empowering way, develop understandings of core concepts including machine learning and unstructured data, and envision their own future lives that are centered on or powered by artificial intelligence.

References

AI4K12.org (2019). *Five big ideas in AI* (Poster). Retrieved from https://bit.ly/ai4k12-five-big-ideas.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative research in psychology, 3*(2), 77-101.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating complex interventions in classroom settings. *The journal of the learning sciences, 2*(2), 141-178.

D'Ignazio, C., & Klein, L. F. (2020). *Data feminism*. Cambridge, MA: The MIT Press.

Haldar, L. C., Wong, N., Heller, J. I., & Konold, C. (2018). Students Making Sense of Multi-level Data. *Technology Innovations in Statistics Education*, *11*(1).

Jiang, S., & Kahn, J. (2020). Data wrangling practices and collaborative interactions with aggregated data. *International Journal of Computer-Supported Collaborative Learning*, *15*(3), 257-281.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences, 4*(1), 39–103.

Lee, V. R., & Wilkerson, M. (2018). Data use by middle and secondary students in the digital age: A status report and future prospects. Commissioned Paper for the National Academies of Sciences, Engineering, and Medicine, Board on Science Education, Committee on Science Investigations and Engineering Design for Grades 6-12. Washington, D.C.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and practice in technology enhanced learning*, *2*(01), 51-74.

Rosé, C. P. (2018). Learning analytics in the Learning Sciences, invited chapter in F. Fischer, C. Hmelo-Silver, S. Goldman, & P. Reimann (Eds.) *International Handbook of the Learning Sciences*, Taylor & Francis.

Suthers, D. D., Lund, K., Rosé, C. P., & Teplovs, C. (2013). Achieving productive multivocality in the analysis of group interactions. In *Productive multivocality in the analysis of group interactions* (pp. 577-612). Springer, Boston, MA.

Witten, I. H., Frank, E., Hall, M., and Pal, C. J. (2016). *Data Mining: Practical Machine Learning Tools and Techniques*, fourth edition, Elsevier: San Francisco.

Zimmermann-Niefield, A., Turner, M., Murphy, B., Kane, S. K., & Shapiro, R. B. (2019, June). Youth Learning Machine Learning through Building Models of Athletic Moves. In *Proceedings of the 18th ACM International Conference on Interaction Design and Children* (pp. 121-132). ACM.

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Zooming In: Exploring the Construction of Professional Vision in Teachers' Reflection with Visualizations of Classroom Discourse

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Abstract: This paper explores one slice of a design-based research project (*ClassInSight)* that aims to support teachers' facilitation of dialogic discussions in secondary school science classrooms. Reviewing representations of discourse in their own classrooms via a desktop app, teachers reflect on the *when, how, and why* of facilitation moves and student contributions. This paper delves into one cycle of reflection and teacher learning. Teachers reflected on representations (at three grain sizes) of their own practice. We unpack teachers' reflection with visualizations that moved from percentages of student and teacher talk (coarse grain) to student and teacher turn taking (medium grain) to line-by-line transcript level detail (fine grain)—unpacking affordances and constraints of each representation of practice and using teacher voices to inform the design of personalized professional development.

Introduction

Teachers are constantly engaged in the work of constructing and enacting professional vision (PV) as they highlight specific features of their surrounding environment, interpret these features, and take action in real time (van Es & Sherin, 2007). An important mechanism of this PV is pedagogical reasoning (PR)—the sensemaking that occurs in planning, facilitation, and assessing student learning (Shulman, 1987). As teachers engage in PR and construct PV, they grapple with the *when, how, and why* of their actions. As they hone their craft, teachers have limited access to individualized representations of their own teaching and modes for reflecting on these representations (McNeill & Knight, 2013). This study examines the facilitation of science discussion and explores how reflection with a variety of visual representations of classroom discourse can support teachers' learning.

When teachers facilitate structured classroom discussions that foster shared reasoning, students benefit with steep increases in learning (Clarke et al., 2015). However, such discussion is rare, particularly in science classrooms that serve students from historically underserved backgrounds (Resnick et al., 2015). Prior research on teacher professional development has focused on equipping teachers with pedagogical content knowledge and discussion facilitation strategies, which is often abstracted from teachers' own contexts (McNeill & Knight, 2013). Few studies have generated robust evidence of how PD supports substantive changes in teachers' *discussion* facilitation (McNeill & Knight, 2013). We work to address this gap as we explore secondary science teachers' reflections with visualizations of their own classroom discussion. Further, we respond to recent calls for microgenetic studies of teacher learning (Walkoe & Luna, 2020)—attending to the interactional construction of PV (an indicator of teacher learning) as teachers engage with representations of their own practice.

Conceptual framework: Teacher learning

Our conceptual framework of teacher learning includes four iterative stages navigated by teachers: 1) pedagogical actions which are used to generate representations of practice, 2) noticing features of teaching, leading to 3) scaffolded reflection, which then grounds 4) data-driven planning for the next actions for discussion lessons. As teachers reflect, they may experience productive dissonance (c.f. Boekaerts & Corno, 2005) when expectations do not align with representations of practice. We conceptualize productive dissonance as critical for teachers' motivation to engage with their classroom discourse data and to make sense of it.

ClassInSight is a digital tool that can be used by teachers to reflect on facilitation of classroom science discussion and act on productive dissonance. The *ClassInSight* visualizations are designed to scaffold teachers' noticing, make visible dialogic aspects of classroom dialogue, and create space for goal setting. In this paper, we examine 12 secondary science teachers' reflections with three *ClassInSight* representations of practice (visualizations). We consider the affordances of these designs for supporting the development of robust science discussion and argumentation. We ask*: How is PV constructed in teachers' reflection with visualizations of their own classroom science discussions?*

Methods

As a design-based research (DBR) effort (Barab & Squire, 2004), our research team works alongside practitioners to develop solutions that work in specific contexts. We privilege teacher voices and work to co-design a model of teacher learning that is shaped by teachers themselves. To trace patterns in noticing, interpretation and response moves (key elements of PV), we use discourse analysis methodologies (Potter, 2012).

Participant demographics and data collection

Participants included 12 middle and high school science instructors in a school district in the Western U.S. These instructors teach within a district that serves a student population that is 60% Latinx, 28% White, 3% Asian, 4% African- American, and 5% of mixed ethnicity. The district reports 58% of students qualified for free or reduced-price lunch. Participating instructors include 5 high school instructors and 6 middle school instructors teaching a variety of science disciplines (e.g., general science, chemistry, engineering). Teachers range in teaching experience from 5 - 30 years.

We observed 12 class sessions flagged by instructors as experiences where they planned to have extended discussion. We recorded classroom audio and took detailed field notes. De-identified transcripts of audio data were coded by three researchers at the sentence level. Raters independently coded five lessons for features of classroom discussion (question and response moves) and achieved 91.3% agreement. Coded files were transformed into visualizations (accessible in the *ClassInSight* app) for teachers to reflect with, and researchers created individualized reflection session protocols for each teacher. 60-minute reflection session protocols included the teacher's visualizations, a set of open-ended questions about teacher noticings and interpretations, and a layer of researcher-selected noticings and interpretations. Reflection sessions were conducted with each teacher 2-4 weeks after the classroom observation. Data collected during reflection sessions included audio data, screencast data of teacher engagement with visualizations, and all artifacts referenced or created during the session.

Visualization design: Coarse, medium, and fine grain design principles

Our PD and visualization design builds on prior work that leverages representations of teachers' own practice and provides opportunities to break these representations down (e.g., Sherin, 2007). Our first iteration of visualizations focused on teacher and student question and response codes. Recognizing the important role of questioning, collaborative reasoning, and equitable participation in dialogic discussion (Michaels et al., 2010), we worked to capture open and close-ended questions and responses, student talk that connected explanation to evidence, and *who* was speaking *when*.

Visualizations occurred across three grain sizes—coarse, medium, and fine (Figure 1). We conjectured that these grain sizes could work together to scaffold noticing—providing moments of productive dissonance that could be reasoned about as instructors "zoomed in" from coarse to fine grain.

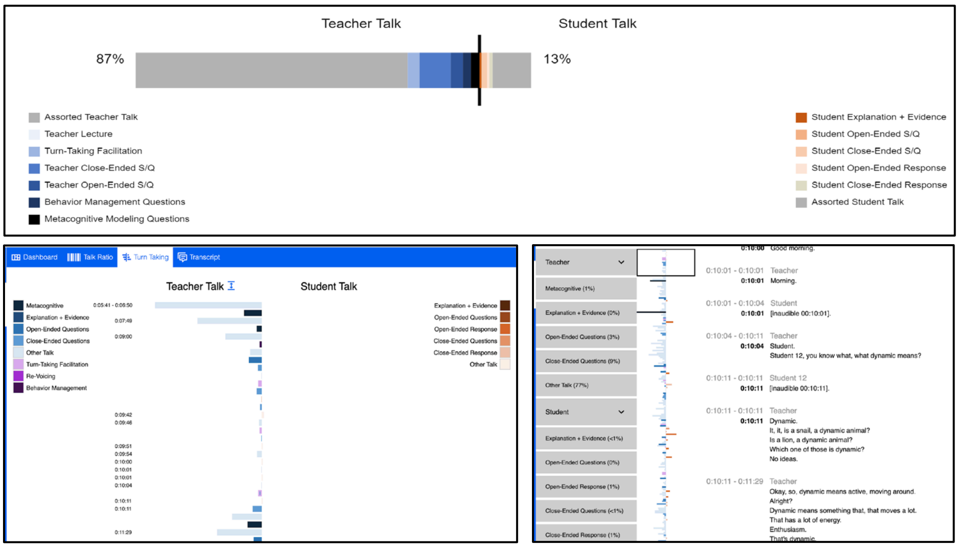

Figure 1. Representations of coarse (*top)*, medium *(left)*, and fine grain (*right) ClassInSight* visualizations.

At the *coarse grain level*, we designed for attention to *how much* teachers were speaking in relation to *how much* students were speaking as well as what kinds of talk moves occurred. Here, a bird's eye view of talk across a class period shows percentages of student and teacher talk—including a breakdown of question and response categories. Productive dissonance at this grain size might look like a recognition that there is more teacher talk than expected. At the *medium grain*, teachers are able to see classroom dialogue represented in turns (sequence and length)—supporting noticing around how talk time is exchanged throughout the class session and where extended exchanges between students might be occurring. Here, cause/effect relationships were also made visible (i.e., "when I asked X, I got Y"). At the medium grain, productive dissonance might look like recognition that there are unexpected sequences of talk (e.g., several questions asked with no student responses received). At the *fine grain*, we designed to support attention to what specific questions were asked and responses achieved, as well as reasoning around "why?" and "what if?" At this grain size, teachers are able to review classroom dialogue at the transcript level. At the fine grain, productive dissonance might look like recognition that a specific prompt was not taken up by students as intended.

Data analysis

This study centers on data collected from reflection sessions with our 12 participating teachers. Engaging in discourse analysis (Potter 2012), we iteratively explored how PV was constructed in teachers' reflection sessions—unpacking indicators of PV line-by-line. Transcripts of reflection sessions were memoed with attention to noticing, interpretation, and response moves. Salient extracts were collaboratively analyzed in a series of data sessions with research team members. We held additional data sessions to validate and elaborate upon themes and select representative extracts related to teacher PV trajectories across visualizations.

Findings

As teachers engaged with each of the three visualization grain sizes, a pattern emerged that helped us to understand the ways in which teachers' noticing and reflection were mediated by these visualizations. In the following section, we illustrate how PV was constructed and refined *across* grain sizes.

The coarse grain: Perturbation and quantitative goal setting

Reflecting with coarse grain visualizations, teachers made high-level noticings and set high-level goals grounded in these noticings. An emergent theme at this grain size was that teachers (nine out of 12) were quick to highlight disproportionate student and teacher talk, and often set goals around "talking less" and creating more space for student voices. As one middle school teacher, Sara, put it, "My first reaction is the gray is me talking, which seems like a really high amount. Too high." Here, Sara notices that student and teacher talk are disproportionate, and interprets this imbalance—a point of dissonance.

Beyond highlighting the amount of teacher talk at the coarse grain, teachers (10 out of 12) noticed absences of codes/discourse indicators that they hoped to see (e.g., the absence of student explanation that included evidence). We interpret this attention to absence as an indicator of productive dissonance. At this grain size, teachers' noticing generated a need for more information about the discursive interactions represented. In sum, high level visualizations created opportunities for perturbation—a precursor to deeper reflection and PV construction as "zooming in" occurs at the medium and fine grain sizes.

The medium grain: Noticing and interpreting the cadence of the class

At the medium grain size, teacher PV centered on the sequence of talk and cause/effect relationships between teacher and student discourse. Here, teachers got a sense for the flow of the class period as they scrolled through a timeline of student and teacher turns. Teachers also flagged specific points of interest within the lesson. For example, eight teachers highlighted specific exchanges where they were interested in the number of responses and/or questions that occurred within an exchange. Many requested more information about these exchanges in order to fully interpret how and why these sequences unfolded. This need for more information was a point of productive dissonance. With this view of classroom discourse, "zooming in" from the coarse grain, teachers noticed patterns of interaction. To further illustrate the kinds of interpretations made at the medium grain size, we present another extract from middle school instructor Sara.

After highlighting the point in the lesson where a video played, Sara scrolled before and after the video segment to explore student engagement pre- and post-video viewing. As Sara explored, she shared: "It's good that after that [the video played] there's a lot more student engagement...that [video] was a phenomenon. The purpose…is to get students asking questions… I can look at this and be like, 'it worked'...Because there's definitely way more students talking [after the video]." Here, Sara connects her noticings about student responses before and after an event (video viewing) to a pedagogical move (the introduction of a phenomenon). She attends to this visualization as a way to interpret if pedagogical moves were successful—with success defined here by the number of students making contributions. Sara uses evidence from the visualization ("more students talking") to support her interpretation. In sum, the medium grain afforded noticing and pedagogical reasoning around specific segments of classroom dialogue—attending to the sequential nature of interaction in ways not possible at the coarse grain level.

The fine grain: Attending to language and imagining alternative possibilities

Reflecting at the fine grain, PV construction included connection making across the noticing and interpretation moves that occurred at the coarse and medium grain sizes. Here, teachers reimagined specific pedagogical actions. Teachers were able to even further "zoom in" on the points of interest flagged at coarse and medium grain sizes—unpacking what happened and constructing narratives about *why* the dialogue unfolded in a turn-by-turn analysis.

For example, middle school math and science teacher Bill engaged in a reenactment of his practice as he reflected at the fine grain—reading aloud a sequence of his open-ended prompts and the student responses he received. Bill attended to one student response he received after a line of questioning posed to the whole class and noted: "Sure would be nice to have more than one opinion…I need to say, 'Is there another opinion?'" As Bill read, he echoed his noticing at the coarse grain (i.e., "there is less student talk than teacher talk"). At the fine grain this noticing was grounded in line-by-line interpretation—an affordance of the fine-grained visualization. Bill went on to consider alternatives to what unfolded in the episode he chose to explore in detail as he stated "I need to say, 'Is there another opinion?'" Here, Bill proposed a specific line of dialogue that may have shifted student participation. There was a kind of rehearsal as he verbalized possible moves—suggesting that the fine-grained level visualization can support the formulation of very specific facilitation moves.

Conclusions

As teachers moved across a trajectory of coarse to fine grain visualizations, their PV construction became increasingly nuanced. The flow of the visualizations functioned to put together the pieces of PV (*noticing, interpretation, and response).* As seen in the examples presented throughout the Findings, at the coarse grain, teachers generally noticed points of high-level dissonance ("I had no idea I talked that much!"). At the medium grain, these points of dissonance were positioned within the context of the "cadence of the classroom." As turn taking and the length and categorization of turns were visualized, teachers noticed specific points of interest and began to reason about what might have been happening. At the fine grain, these reasonings were confirmed, extended, or challenged, as teachers reviewed points of interest at the transcript level. Here, teachers also made the most fine-grained plans for shifts in future practice.

This work contributes to our understanding of how teachers reason with representations of their own practice. Further, the three grain sizes of representations of practice explored here, and the ways that teachers reflected with them, show promise for our emergent understanding of how PV construction occurs and can be scaffolded in personalized mediums that extend beyond more commonly used representations of practice (e.g., video and transcript).

References

Clarke, S. N., Resnick, L. B., & Rosé, C. P. (2015). Dialogic Instruction: A New Frontier. In L. Corno & E. M. Anderman (Eds.), *Handbook of Educational Psychology* (3rd ed., pp. 378-389). New York: Routledge.

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The Journal of the Learning Sciences*, *13*(1), 1-14.

Boekaerts, M., & Corno, L. (2005). Self-regulation in the classroom: A perspective on assessment and intervention. *Applied Psychology*, *54*(2), 199-231.

McNeill, K. L., & Knight, A. M. (2013). Teachers' pedagogical content knowledge of scientific argumentation: The impact of professional development on K–12 teachers. *Science Education*, *97*(6), 936- 972.

Michaels, S., O'Connor, M. C., Hall, M. W., & Resnick, L. B. (2010). *Accountable talk sourcebook: For classroom conversation that works*. Pittsburgh, PA: University of Pittsburgh Institute for Learning.

Potter, J. (2012). Discourse analysis and discursive psychology. In H. Cooper H. (Ed.), *APA handbook of research methods in psychology* (pp. 111-130). Washington: American Psychological Association Press.

Resnick, L. B., Asterhan, C. S. C., & Clarke, S. N. (2015). Introduction: Talk, Learning and Teaching. In L. B. Resnick, C. S. C. Asterhan, & S. N. Clarke (Eds.), *Socializing Intelligence through Academic Talk and Dialogue* (pp. 1-12). Washington, DC: American Educational Research Association.

Sherin, M. G. (2007). The development of teachers' professional vision in video clubs. In Goldman, R., Pea, R., Denny, S. (Eds.) *Video research in the learning sciences* (pp. 383-395). New York, NY: Routledge.

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. *Harvard Educational Review, 57*(1), 1-23.

Walkoe, J. D., & Luna, M. J. (2020). What we are missing in studies of teacher learning: A call for microgenetic, interactional analyses to examine teacher learning processes. *Journal of the Learning Sciences*, *29*(2), 285-307.

"It's Working - We're Bosses" – A Study of Contentious Moments of Learning, Identity and Power in the Context of a Coding Project

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Abstract: This study addresses how power issues are worked out in situ as youth engage in joint-meaning making and identity work in the context of a coding project at the crossroads of formal and informal science education. Based on an ethnographic case study of one team's forms of engagement in the coding project over the school year, we document shifts in participation and emergent relations with others, materials, and tools, and the manner these shifts are ethnically and politically laden moments of contentious moments of meaning making and becoming in STEM. We make evident how learner experiences and identity work are entangled with subtle ethnic, class, gender and linguistic differences, and in doing so, attend to power through a multilayered analysis of the coding project.

Problem

This study addresses how power issues are worked out in situ as youth engage in joint-meaning making and identity work in the context of a coding project at the crossroads of formal and informal science education. Building on work by Vossoughi et al. (2020), we are interested in documenting shifts in participation and emergent relations with others, materials, and tools, and the manner these shifts are ethnically and politically laden moments of contentious meaning making and becoming in STEM. We assume that learner experiences and identity work are entangled with subtle ethnic, class, gender and linguistic inequalities. We also build on the argument advanced by Philip and Gupta (2020), who note that shifts in activity systems make evident that "power is never fully deterministic" (p. 206). That is, "the intersectional nature of power allows students to position themselves and get positioned by others along multiple axes" (p. 206), a process that still needs to be better understood and documented. Work by Takeuchi (2020) offers an example of a careful multi-level analysis of second language learners in the math classroom and the manner the students are othered in interactions. The study makes evident how "the dynamics between multi-layered identities and learner experiences" (p. 1) are worked out in situ. In contrast, Hand, Penuel and Gutiérrez (2012) applied the notion of framing to study the manner race and power work out in learning environments. Building on these studies, we explore the following research question: What do conscientious moments of interactions reveal about relationality among actors, their histories, positionalities, and potential future selves? In doing so, we attend to the manner implicit assumptions reproduce yet also support transformations of selves in the making, rendering visible the manner learning, identity and power constitute one another. We focus on contentious moments in a girls-only team, as they pursued the construction of a house in which coded electrical circuits ensured that lighting was ecologically sound.

Theoretical grounding

Building on practice theory, we understand learning and identity as a dynamic process, continuously in the making (Holland et al., 1989; Lave & Wenger, 1991). Learning and identity are both jointly accomplished in light of an activity, tools, relationships, but also marked in important ways by the institutional and cultural contexts (Hand & Gresalfi, 2015). While our focus rests on the individuals and the manner learning and identity take shape through interactions over time, we see the contentious moments as also entangled with power which we understand as "co-constructed at multiple scales – historically and structurally at the macrolevel" (partnership between school and CO; institutional politics about language & STEM education), next to interactions and "bodies of individuals" (Philip & Gupta, 2020, p. 197). Through the explorative case study, we aim to bring multiple lenses and layers together to offer deeper insights into the complex power dynamics at play in science education.

Methods

An ethnographic case study was conducted, implying the filming of all meetings in the classroom, supplemented by fieldnotes and a journal. At the end of the school year, we conducted interviews with the teacher and the lead instructor from the ONG, and two years later, with some of the youth who participated.

Activity and Setting. The case is an enrichment activity that was co-animated by a high school science teacher and two instructors from the partner community organization or CO, implying the construction of an ecological house out of cardboard that integrates lights and electrical circuits, created with tools such as an Arduino card and C-code. The project aimed to engage first year high school students with technology in creative and critical ways

(Kafai & Burke, 2014). The one-year project first introduced students to different notions of coding and electrical circuits, and then encouraged them to mobilize these ways of knowing in their own creations of ecological efficient houses. The activity was part of the science curriculum and aligned with the five-year high school science curriculum. That particular high school also follows the five-year Intermediate Program of Education (PEI) associated with the main goals of the International Baccalaureate Program, preparing youth for a future as critical and contributing citizens, concerned with the well-being of humanity and the world, and therefore as committed to lifelong learning, with a particular concern for intercultural relations, globalization, and communication. The International Program now offered in a number of public high schools as an enriched track typically implies entrance exams and ongoing high academic standing, with a fast paced and demanding curriculum and heavy homework load. The school serves an ethnically highly diverse group of students, with the majority of them speaking at least three languages (Native tongue, plus English and French). Given the language charter that resulted in French being the official majority language of Quebec in 1977, all children are schooled in French with the exception of those who are part of the English minority, and to whom the English school system is available.

Data Collection and Analysis. We pursued a video-ethnography of the project, collecting fieldnotes of 17 of the 20 meetings during one academic school year (fall 2017 to spring 2018) and video data of 16 meetings (44 hours total). We then analyzed the work of teams over time, creating video logs and engaging in interaction analysis among our research team (Jordan & Henderson, 1995). In this paper we report on a team of three girls, Maude and Rose (13 years old), who self-identify as French Canadian, and Alexi, who was born in Romania (12 years old), and self-identifies as English Canadian. We pursued timeline interviews of Rose and Alexi in the fall of 2019. Analysis implied the identification of contentious moments of meaning making in the team, over time. We defined those moments as interesting moments, marked by disagreements and contestations of competing interpretations and ways of doing things with the tools provided. From that microgenetic analyses, we turned to the interview data to engage in a multi-layered reading of learning and identity work at play, in the moment, but also as sedimented into enduring identities over time. We made sense of those moments through attention to the manner they seemed entangled with ideologies about girls in science, positionings of second language learners and immigrants, and local meanings that circulate about academic success in a public high school, and effects of SES on academic achievement (Philip & Gupta, 2020). In many ways, our analysis entailed a going forth-and back between the micro interactions among the team and the larger layers of the project and educational structure and reality around it in light of the school system, language requirements and politics associated with them. At the same time, we also carefully attended to the body in action and considered emotions tied to positionings of each other, that transpired in this manner. As noted by Kristensen (2018), analysis can be understood through the metaphor of "peeling an onion" and in the end also implies a bricolage of multiple data sources and analyzed data points. We share a beginning of that bricolage here (Kincheloe & Berry, 2004).

Results

Data Point 1. Alexi caught our attention during the fall, as she worked with Nancy, who like her, had immigrated from Romania. We were struck by how easily and often they engaged in translanguaging, moving among French, English, and Romanian, as they coded and in turn assessed their code as the Led did not light up. The instructor eventually checked everything and noted that it was a problem with the connection and not the code. Note the languages at play as they are trying to figure it out together:

	Talk	Explanation
Alexi :	C'est que confusing, yeah	French & English; (looking at breadboard)
Nancy :	Ça trouve rien	French (examining the code)
Alexi :	C'est blanc depuis tantôt. On voit rien!	French [it's white since a while, we see nothing]
Instructor :	Quais, elle était mal branchée!	French [yes, error was in the connection]
Alexi:	We just have to wait for it to get like below 500	English (they check to see if the range they had chosen in the code was the problem)
Nancy:	Yeah	English
Alexi:	On voit toujours rien!	French (still nothing)
Instructor:	Oui, elle était mal branchée!	French (yes, error was in the connection)

Alexi then called out, "Agh, look, now it's green!" Alexi looked at her code and clapped her hands, calling over to Nancy who fiddled with breadboard "Nancy, we're bosses" and they gave each other a high five. They engaged in an interesting play with languages which seemed to be entangled with felt emotions tied to the project and the people they interacted with. They always switched to French when talking with the instructor, and thereby adhered to the language they had to speak in class by law. At the same time, whenever they looked at the camera and felt its presence, they switched to Romanian, and at one point even commented on that, noting "I wonder what they will do, use google translator?", referring to us, researchers, trying to make sense of their interactions. In the above exchange, Alexi switched to English, aligned with her self-identification as Canadian, and not 'Quebecoise' as the other two girls. English also surfaced naturally, when she was problem-solving (changing the range), when noting it worked, and in reference to themselves as "bosses" and maybe girls who can get the work done. That fluidity among languages is typical of youth like Alexi and Nancy, who grow up as multilinguals in Montreal (Lamarre, 2013). The two girls used their language repertoires to make sense of their coding project, despite local politics that sanction such work and portray French as the language of power within that province. The case makes evident that traditional boundaries among languages and using language as an identity marker just simply no longer hold up (Lamarre, 2013). When local politics do not get in the way, and when youth feel safe to dive into their language repertoires, they do so in ways that further develops their affinity and pride as multilanguage speakers. That contentious moment resulted in the authoring of themselves as "bosses" and embodiment of pride. Yet, the idea of multi-layered identity work and questioning about who actors are and can become in relation to one another took another turn for Alexi later in the school year, as she continued the project as a member of another team.

Data Point 2. Alexi's positioning in that team was quite different and tied up with language politics in other ways. Alexi was 12 years old at the time of the study and had lived in Quebec for 11 years. Alexi talked about her initial integration into the school system during the interview as follows:

> When I came here, I was sent to a private English daycare but they taught us French there already too, as they knew that most of us would have to pursue our education in the French school system. When I started Kindergarten, I was totally bilingual, but I always talked Romanian with my parents, while I talked English with my sister who needed to get better at it and practice it, and then most around me was in English, TV, the news, films, and more. The majority here is English (maybe referring here to Canada), but then there is also the French in Quebec. So if we talk of it globally, it's really English that is the majority and now, I consider myself 100% English, I think in English, I count in English, when I just discuss with somebody, I have to translate my thoughts.

In her new team, we got the impression that Alexi's immigration history and language skills were held against her by her peers, both of whom identified as French Canadian. They positioned Alexi as academically less able and not the kind of person who could become somebody in science or technology, yet did so in subtle ways. That led to many contentious moments of meaning making and identity work, as Alexi was actually an extremely competent coder. There were multiple instances when the others called out for help from the instructor, yet while waiting, Alexi took up the space and rapidly fixed the code. Alexi also continued to switch among French and English, English clearly being the language of power to which she resorted when she asserted her position as somebody who is competent and interested in science and technology. That became evident in a dialogue among the team when they measured the cardboard for their ecological house. It led to an argument about whether they should measure in inches or centimeters. For Alexi it seemed clear from the beginning how the board should be cut, and she intervened multiple times in the conversation, yet her suggestions were brushed aside. She even added in English at one point, "trust me, I'm the math person" which was immediately challenged by Rose, her team mate who came up with a better idea and positioned herself as the "misunderstood Genius." Shocked by that remark, Alexi sat back and then mumbled, again in English, "If anyone of us here is gonna end up being an engineer I think I'm most likely to." Rose tried to tame the argument by adding "do not worry" (in French).

Figure 1. The team struggling with the door they wanted to add to their designed Science Lab

Interview data confirms Alexi's interest in engineering and computing, whereas Rose shared her strong dislike for a career in the sciences. Alexi was not new to robotics or computing as her father is a programmer and taught her much about Java Script. She had fond memories of the coding project, as she thought about it during our interview in 2019, noting "each time we met, we learned something new in programming." She also described her groups' work as ambitious (see Figure 1), "we wanted to create a house with a code to open the door, which in the end never worked as we had just too many wires, and the code, technically it was flawless but in practice, given the wires, it worked one out of five times. I think in the end we managed to make it work." She recalls how stressful the project was given the evaluations their teacher developed, in line with the international school competency requirements. When asked about her future career aspirations, Alexi projected herself as pursuing a career in Aerospace Engineering. She continued, "I want to make spaceships" (in English, before continuing in French), "anything about space always fascinated me." She then passionately talked about events in the history of science that stood out for her, like going to mars, inventing the internet, and now thinking of the future, she shared a sort of science fiction story with us where "we should just ditch the earth and go somewhere else." She was imagining that half of the population should leave the earth, as we have come to its limits. If we would split in half, however, she imagined that "we could keep on living good lives." She continued, "the other half would find a planet that is colonizable, or we could move to Mars and colonize it, I really think this would be one of the best solutions" in light of the current problems tied to climate change and overpopulation on the planet. She continued, "my dream was always to do something really amusing and awesome so that one day, my name would be in a book that students at the University would use and learn with." Alexi was clearly ambitious and invested in some kind of future in STEM with which she strongly identified, in part due to her father's coaching. At the same time, her peers continuously challenged her positioning as a science savvy person. Interestingly, even Alexi's teacher who likes technology, was convinced, after twelve years of experience, that her female students were never too crazy about it. At the same time, the teacher shied away from programming, which in the end may have led to a lack of appreciation on her part of Alexi's skills and ambitions, even though some of them can also be read as problematic.

Conclusion and implication

Alexi's trajectory makes evident how moments of contentious practices, next to stories of participants' learning lives gathered through interviews, can make evident the manner power is worked out and constitutes learning and becoming. It resulted in embodied pathways and ethical trails of engagement that we problematize here as we believe they are consequential for Alexi and at the root of relational histories that continue to undermine equity and social justice in STEM. The study has implications for teacher education and educational practices, both formal and informal, that are committed to educational dignity and justice (Espinoza & Vossoughi, 2014).

References

Espinoza, M., & Vossoughi, S. (2014). Perceiving learning anew: Social interaction, dignity, and educational rights. *Harvard Educational Review, 84*, 285-313.

Hand, V. & Gresalfi, M. (2015). The joint accomplishment of identity. *Educational Psychologist,* 50(3),190-203.

Hand, V., Penuel, B., & K. D. Gutiérrez (2012). (Re)Framing educational possibility: Attending to power and equity in shaping access to and within learning opportunities. *Human Development, 55*, 250-268.

Holland, D., Lachicotte, W., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds.* Harvard University Press.

Kafai, Y. B., Burke, Q. (2014). *Connected code: Why children need to learn programming*. MIT.

Kincheloe, J. L., & Berry, K. S. (2004). *Rigour and complexity in educational research. Conceptualizing the bricolage.* Open University Press.

Kristensen, L. K. (2018). "Peeling an onion": layering as a methodology to promote embodied perspectives in video analysis. *Video Journal of Education and Pedagogy, 3*(3), 1-21.

Lamarre, P. (2013). Catching "Montréal on the move" and challenging the discourse of unilingualism in Québec. *Anthropologica, 55*(1), 41-56.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press.

Takeuchi, M. A. (2020). Geopolitical configuration of identities and learning: Othering through institutionalized categorization of "English Language Learners". *Cognition and Instruction.*

Vossoughi, S., Jackson, A., Chen, S., Roland, W., Escudé, M. (2020). Embodied pathways and ethical trails. Studying learning in and through relational histories. *Journal of the Learning Sciences*, 29(2), 183-223.

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The Unexamined Influence: An Object's Perceived Gender on Spatial Reasoning Skills in Girls

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Abstract: Explanations for gender differences in spatial visualization and mental rotation typically center on lack of experience or cognitive deficits of females. Our research offers an alternative explanation for these differences–one rooted in the materials used for mental rotation tasks, informed by sociocultural approaches and posthumanist perspectives. Combining a gender sorting task and a mental rotation assessment, this study shows that students–regardless of gender–perceive consistent gender differences of everyday objects. Their ability to mentally rotate each object is related to their gender and the objects' perceived gender. Females perform significantly higher on mental rotation tasks that involve objects that are perceived as feminine, matching scores of males. Yet, the stereotypical mental rotation differences between females and males are seen only on objects perceived as neither feminine nor masculine. The perceived gender of materials included in educational design may shape mental rotation ability.

Introduction

Spatial reasoning skills play an important role in STEM fields (e.g., Uttal et al., 2013). For example, scores on spatial assessments are significant predictors of future attainment of STEM degrees and entering STEM professions (Wai et al., 2009). Yet, these skills are subject to consistent gender disparities favoring males, especially in three-dimensional mental rotation (3DMR; Linn & Petersen, 1985; Voyer et at., 1995). Despite views and societal perceptions that facility with spatial information is an innate talent (e.g., Wai et al., 2009), spatial skills can be taught and improved (Uttal et al., 2013). Women and young girls especially are disproportionately impacted by a lack of opportunities to develop spatial skills due to the stereotype that men are naturally more talented in 3DMR (e.g., Muenks et al., 2020). Rather than considering innate abilities as a source of gender differences in spatial reasoning and, in particular, 3DMR, there seems to be something about who is being invited to engage that may shape students' opportunities to engage in 3DMR practice.

The current study considers the traditionally feminine as its starting point, rather than viewing an increase in girls' engagement with stereotypically masculine activities as the only solution to the 3DMR gender gap. To determine the relationship between gender, material, and mental rotation (MR) performance, we asked: *1) To what extent do students perceive gendered differences of everyday objects and does the gender identity of the respondent affect these outcomes? 2) To what extent does mental rotation of everyday objects vary in relation to students' gender identity and students' perceived gender of objects?* To answer these questions, we first introduced a gender sorting task and asked students (n=89) to sort everyday objects from very feminine to neither feminine nor masculine to very masculine. Then, to test whether students' ability to rotate objects varied by both the gender of the object and the gender of the students, we designed a MR assessment and administered it with another student group (n=51). Findings demonstrate that students perceive gender differences of everyday objects mostly consistently. Additionally, findings showed that MR ability is related to students' gender and objects' perceived gender: female students perform significantly higher on MR tasks that involve objects that are perceived as feminine, matching scores of their male peers. By contrast, stereotypical MR gender differences between females and males were seen in relation to objects that were perceived as neither feminine nor masculine. The results of the study offer an alternative explanation for gender differences and stereotyping in 3DMR tasks that is rooted in materials and not in the cognitive or psychological makeup of females. We argue that the perceived gender of objects included in educational design may shape MR ability.

Background: Mental rotation, gender, and materials

Mental rotation (MR) is an aspect of spatial visualization skills, which describes the ability to understand and imagine an object's spatial relationship to other objects (Linn & Petersen, 1985). These abilities involve the manipulation of visual information, which may include problems of navigation and calculation of shape, size, and fit (Gardner, 1993). MR, in particular, refers to imagining objects at different angles (Linn & Petersen, 1985). Typically considered a cognitive skill, MR is also regarded as a predictor for future career success and engagement with STEM fields (e.g., Humphreys et al., 1993; Wai et al., 2009). Assessments of MR are based on people perceiving two-dimensional images as abstractions of three-dimensional figures through a MR experiment (e.g., French et al., 1963). The Mental Rotation Test (MRT) was designed to measure an individual's MR ability with cube shaped items (Vandenberg & Kuse, 1978).

It was long considered that practice of spatial skills does not lead to long term improvement (e.g., Sims & Mayer, 2002). Thus, findings that boys outperform girls in MR assessments (e.g., Voyer et al., 1995, Linn & Petersen, 1985; Neuburger et al., 2011) can lead to highlight deficits over training effects and possible assessment bias. However, efforts to reduce inequities related to educational and career access have shown that repeatedly mentally rotating objects, including administration of assessments, can lead to improved performance (Uttal et al., 2013). The learnability of spatial visualization skills, especially MR, is hopeful in relation to gender differences and points to inquire to what extent aspects of instruction and gender play a part in MR assessment.

We take a perspective that understands gender as performance (Butler, 1990), we conceptualize gender as a construct that exists beyond humankind, but there are features of tools that send cues to individuals. The strong emphasis on contextual materiality resonates with recent studies that highlight the non-neutral role that a diversity of materials and representations play in producing what can be learned (e.g., Kuby et al., 2017; Peppler, Rowsell, & Keune, 2020). These lines of research suggest that materials and tools are non-neutral and play an active part in shaping domain knowledge (Keune, 2020). The gender associations of tools and material are increasingly important in terms of what people can learn and how people participate. With the present study, we aimed to understand how materials relate to MR ability for female and male students.

Methods

The research was conducted at a Midwestern charter school with two separate cohorts of students (ages 10-18). The gender sorting included 89 students (39 female, 48 male, and 2 gender non-binary) and the MRT assessment included 51 students (15 female, 33 male, and 3 gender non-binary).

The *gender sorting* prompted students to sort everyday objects (e.g., lemon, doll, hammer) based on a mutually exclusive spectrum of five gender categories (i.e., very feminine=5, somewhat feminine=4, neither feminine nor masculine=3, somewhat masculine=2, and very masculine=1). The scale enforced a gender binary also because the prevalent orientation within MR positions females at a deficit. The task had 32 objects, 30 everyday (e.g., dress, box, truck, etc.) and two building block objects from spatial visualization assessments (i.e., MRT and PSVT:R). To probe how students' perception of the objects' gender and students' gender identity related to students' MR scores, we administered a *modified MRT assessment* with the objects from gender sorting, 30 everyday objects and nine MRT items. Based on the original MRT assessment, items of our modified assessment showed the target object above four perspectives of the object, including two mirrored options and two correct rotations (Figure 1). To answer an item correctly, students had to select both correct rotations.

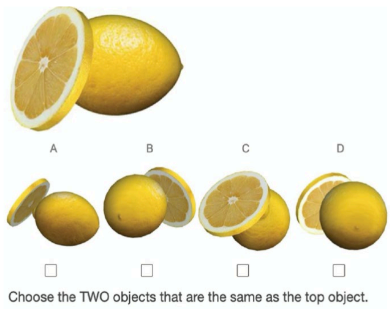


Figure 1. Modified MRT assessment item with everyday object.

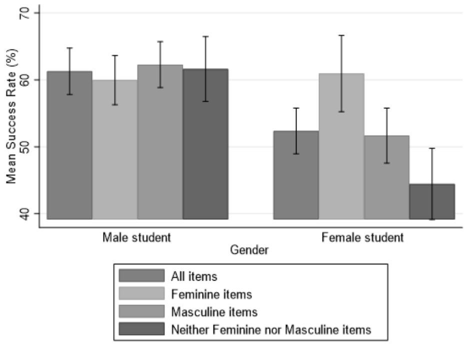
Data analysis

Using a two-sample t-test, we divided the participants in two groups based on their gender to test whether gender sorting was independent of students' gender for any of the 32 objects. For each object, if the mean sorting score by female students was different to that by male students, we rejected the null hypothesis of equal means between genders. A p-value of the two-sample t-test lower than 0.00156 (i.e., the Bonferroni-adjusted p-value of 0.05/32) meant that gender sorting varied based on student gender.

The success rate score for the MR assessments was represented with *four* variables (i.e., all, feminine, masculine, and neither feminine nor masculine items). We compared *different* success rates to test whether MR varied in relation to students' gender and students' perceived gender of objects. Specifically, we calculated Cohen's d and Hedges's g estimates to test the null hypothesis that the mean success rate score of male students was equal to the mean success rate score of female students. If we reject the null hypothesis, Cohen's d and Hedges's g estimates show the difference of means in terms of the pooled standard deviation of both gender groups. The expected effect size is between 0.40 and 0.75 (see Uttal et al., 2009 for a review).

Results

Taking all three conditions together, students performed a total of n=85-87 sortings per object on a scale from 1 (very masculine) to 5 (very feminine). Students sorted 16 objects as more feminine, 4 objects as neither feminine nor masculine, and 12 objects as more masculine. Overall, a two-sample t-test showed that none of the everyday objects was sorted differently in relation to the students' gender identity (i.e., p-value > 0.00156).



Note: the error bars represent the standard errors of each mean success rate score.
Figure 2. Mental rotation scores related to gender identity of respondents and perceived gender of assessment items.

Across all items, female students' MRT scores were lower than those of their male peers (see Figure 2). Where male students rotated on average 61.28% of items correctly, female students rotated 52.36% of items correctly. However, the difference between the average male and average female student scores was not statistically significant (p-value 0.12). Across all items, female students performed best on items with feminine objects. By contrast, male students performed best on items with masculine objects and worst on feminine objects. Nevertheless, the average score of female and male students for feminine objects was not statistically different (p-value 0.88). On feminine items, female students performed only slightly above their male peers on average. When objects are considered feminine, gender differences in MR scores disappear.

Most interestingly, female students' MR scores were significantly negatively affected when objects were neither feminine nor masculine (p-value 0.038). On average, on neither feminine nor masculine items, male students scored 61.62% correctly and female students only 44.44%. Male students outperformed female students between 65% and 67% of a pooled standard deviation for the mean success rate score of neither feminine nor masculine items (Table 1, column 4). While the absence of a control group may overestimate the effect size, this large effect is within the range that other studies with similar designs found (Uttal et al., 2013).

Overall, the effect size analysis presented that for objects that were sorted as neither feminine nor masculine, the overall gender difference in MR scores was consistent with the results typically found in MR assessments (Voyer et al., 2006). These results suggest that objects that seem gender neutral favor male students in MR assessment, reproducing gender differences.

Table 1: The effect size of MR scores comparing male and female students.

	All items	Feminine items	Masculine items	Neither feminine nor masculine items
Cohen's d	0.49	-0.05	0.57^{+}	0.67^{*}
Hedges's g	0.48	-0.05	0.56^{+}	0.65^{*}

Note: Bootstrap standard errors with 1000 repetitions: + p<0.10, * p<0.05, ** p<0.01, *** p<0.001

Discussion and implications

When asking students to sort everyday objects across students' perceived societal gender stereotypes, female and male students sorted the objects predominantly similarly across all object conditions. Regardless of gender identity, students categorized the gender of everyday objects consistently. The results suggest that students' gender identity did not largely affect students' perception of the genderedness of objects. These results further suggest that gender associations may be inherent to educational assessments and could risk introducing a bias.

The findings demonstrate that objects that students consider as neither masculine nor feminine can explain differences in MR scores related to student gender. Gender perception of objects seems to matter for how well a rotation task is performed. The results contribute to a possible explanation that gender differences are related to power and positionality of gendered objects rather than cognitive makeup. For example, where male students may consider masculine objects for them and, therefore, possible to rotate, female students may disassociate with these objects. The differences in students' scores are important because assessment designs may be based on false assumptions that gender neutral items eliminate gender-related assessment bias.

We see potential for considering everyday objects for the design of MR assessments. Especially feminine items seem promising for reducing possible gender differences in MR. This study considered gender on a binary scale, which reduces the wide spectrum of possible gender identities and gender perceptions. Thus, we consider it as important that future studies are conducted with a larger sample size of gender non-binary students and to consider ways to break out of gender binaries in the gender sorting and assessment results.

References

Butler, J. (1990). *Gender trouble: Feminism and the subversion of identity.* London: Routledge.

French, J. W., Ekstrom, R. B., & Price, L. A. (1963). *Manual for kit of reference tests for cognitive factors* (revised 1963). Educational Testing Service Princeton NJ.

Gardner, H. (1993). *Multiple Intelligences: The theory in practice.* New York: Basic Books.

Humphreys, L. G., Lubinski, D., & Yao, G. (1993). Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientist, or artist. *Journal of Applied Psychology*, 78(2), 250.

Keune, A. (2020). Fabric-based computing – (Re)examining the materiality of computer science learning through fiber crafts. [Doctoral dissertation, Indiana University]. ProQuest Dissertations Publishing.

Kuby, C. R., Spector, K., & Thiel, J. J. (Eds.). (2018). *Posthumanism and literacy education: Knowing/becoming/doing literacies.* Routledge.

Linn, M. C. & Petersen, A. C. (1985). Emergence and characterization of sex differences in spatial ability: A meta-analysis. *Child Development*, 56(6), 1479-1498.

Muenks, K., Peterson, E. G., Green, A. E., Kolvoord, R. A., & Uttal, D. H. (2020). Parents' Beliefs about High School Students' Spatial Abilities: Gender Differences and Associations with Parent Encouragement to Pursue a STEM Career and Students' STEM Career Intentions. *Sex Roles*, 82(9-10), 570-583.

Neuburger, S., Jansen, P., Heil, M., & Quaiser-Pohl, C. (2011). Gender differences in pre-adolescents' mental-rotation performance: Do they depend on grade and stimulus type?. *Personality and Individual Differences,* 50(8), 1238-1242.

Peppler, K., Rowsell, J., & Keune, A. (2020). Advancing posthumanist perspectives on technology- rich learning. *British Journal of Educational Technology,* 51(4), 1240-1245.

Sims, V. K. & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. *Applied Cognitive Psychology*, 16(1), 97-115.

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin*, 139(2), 352-402.

Vandenberg, S. G. & Kuse, A. R. (1978). Mental rotations, a group test of three-dimensional spatial visualization. *Perceptual and Motor Skills*, 47(2), 599-604.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117(2), 250–270.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology*, 101(4), 817.

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Concepts and Conceptual Practices in Teaching: Identifying Teachers' Functional Concerns in Inquiry-Based Mathematics Intervention Courses

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Abstract: This paper contributes empirical evidence for an understudied, rudimentary question of what teaching is *for teachers* by identifying the *functional concerns* (FCs) that arise for teachers during instruction. Using grounded theory's constant comparative method, video records of six teachers' enactments of two lessons in an inquiry-based mathematics intervention course were content logged and analyzed with thematic, descriptive narrative memos. These were then coded to emergently identify teachers' *conceptual practices* (CPs). Analysis of relationships between CPs illuminated four overarching FCs. Tellingly, the CP of building on student thinking was the only CP teachers enacted towards all four FCs. Better understanding what it means and what is needed to teach for inquiry in intervention courses can challenge back-to-basics approaches that cut off students' opportunities for meaningful learning.

Teachers make decisions every day that are consequential for students' learning. These decisions are big and small, conscious and unconscious. To support teachers in making decisions, researchers have developed tools for professional development (PD) and teacher education. For example, the Teaching for Robust Understanding (TRU) framework helps teachers reflect about dimensions of classroom activities that might serve as levers for change, helping them develop intentionality in decision-making (Schoenfeld, 2019) as a way to foster equity. Other resources for teachers' decision-making are action-based, such as Smith and Stein's (2008) description of 5 Practices for orchestrating whole class mathematical discussions. Both tools are most helpful for instructional decisions made in the planning stages of instruction. In-the-moment decisions are more difficult to influence (Pfister et al., 2015). Likely because frameworks like TRU and the 5 Practices provide *aspirational* visions of mathematics instruction that focus on ideal models, their descriptions do not quite capture the complexity of decision-making in teaching mathematics.

Currently, our theories of and designs for teacher learning are based more on aspirational, ideal types than on nuanced, evidence-based understandings of what teachers do, what motivates them, and how they learn (Kennedy, 2016). Thus, it is no surprise that teachers struggle to shift their practices, especially in courses that target students who have not been adequately supported in prior mathematics classes who also may not easily fit in the templates that aspirational frameworks offer. Teachers in all courses, but especially intervention courses, may struggle with teaching that aligns with reform frameworks, since few resources account for teachers' lived instructional experiences. Resources commonly provided to intervention teachers include rote curricula and recommendations to forego reform practices. This is likely partially due to the paucity of mathematics education research on students in intervention courses (Lambert & Tan, 2020). In addition, teachers can fall back on deficit perspectives and rote methods when they feel like students are struggling or like there is a mismatch between the difficulty of the mathematics problem and their students' current ability (Jackson et al., 2017; Horn, 2007).

Here, I develop a grounded framework of inquiry-based teaching in mathematics intervention classrooms by beginning with primary evidence of instruction in understudied classrooms — intervention classrooms. My research question is, *What is the main work of teaching, from a teacher's perspective, in an inquiry-based classroom for students who have academically struggled?* I articulate an evidence-based account of teachers' functional concerns.

Conceptual framework

Recently, teachers' decision-making has been described through a tripartite model of pedagogical judgement (Horn, 2020), including dimensions of pedagogical action, pedagogical reasoning, and pedagogical responsibility. *Pedagogical action* describes the choices teachers make, whether intentional or not. *Pedagogical reasoning* is the logic behind these actions—the same action may be done for many different reasons. *Pedagogical responsibility* involves teachers' sense of obligations to ethical principles or to situational constraints such as mandates from administration. Together, these constitute the pedagogical judgement that informs teachers' decision-making.

Teachers' *functional concerns* involve a practical sense of pedagogical responsibility. Functional concerns are pragmatic in that they focus on elements of instruction that are within teachers' control. For example, teachers might feel an obligation to support learners' retention and transfer of content, but they focus their attention—their concern—*in-the-moment* of teaching on creating coherent and relevant mathematics experiences.

In this way, learners' retention and transfer may be *goals* that emerge from teachers' sense of pedagogical responsibility, as distinguished from the phenomenon of interest here: teachers' *concerns*.

Scholars seek to shape teachers' concerns in practical ways. For example, the TRU framework helps teachers reflect on five dimensions of classroom practice that Schoenfeld (2019) describes as "necessary and sufficient to characterize powerful learning environments" (p. 3): cognitive demand; equitable access to content; agency, ownership, and identity; and formative assessment. While these five dimensions seem to characterize powerful learning environments, they do not explicate a theory of teacher learning that is grounded in teachers' daily work.

Theoretical framework

Pedagogical judgement can be identified in pedagogical activities (i.e., actions and the *meaning* behind them). Pedagogical activities constitute *conceptual practices* — "recurring patterns of purposeful activity that are distributed over people and technologies" (Hall & Horn, 2012, p. 241) in particular practices. I examine teachers' *enactment* of curriculum, with the curriculum functioning as a formal representational infrastructure (i.e., the technologies, ways of talking, and materials that support how people engage; Hall & Horn, 2012), in order to learn what concerns anchor teachers' decision-making. Instead of highly structuring teachers' concerns and conceptual practices, the representational infrastructure of the curriculum is a setting with constraints and affordances that teachers move through to address their functional concerns. Constellations of conceptual practices make up functional concerns.

Research design

The representational infrastructure for these six teachers was an inquiry-based intervention curriculum that foregrounded student exploration and sensemaking. The course was ungraded and emphasized big ideas in algebra, leveraging tools such as Desmos to support student collaboration on complex mathematical ideas.

Data collection

Data collection aimed to capture teachers' talk, gestures, and movement through the classroom. Data include Swivl (i.e., teacher tracking) video-records of observations of six teachers from different locations across the United States teaching the same two lessons, which were part of a larger year-long curriculum. Each lesson was followed by a video-recorded debrief with a curriculum coach. These debriefs focused on teachers reflecting on how the lesson went, with coaches acting as thought-partners rather than advisors.

Data analysis

To understand the work of teaching from teachers' perspectives, I used grounded theory's constant-comparative methods (Corbin & Strauss, 2014) and made close-to-data inferences about teachers' functional concerns in inquiry-based mathematics intervention classrooms by looking at what was *stable* and *variant* across six teachers' enactments of and reflections on two of the same lessons.

Phase 1: In the first round of analysis, I created time-indexed content logs (Derry et al., 2010) for classroom videos and teacher debriefs with their coaches. Then, I looked for recurring teacher actions and the outcomes of these actions that seemed to satisfy teachers (allowing me to infer meaning behind the actions), noting for example, the ways in which teachers organized and set norms for participation structures, cared for relationships between themselves and students and between students, and held themselves and students accountable for pacing. Phase 2: From the content logs of both debriefs and classroom videos, I generated descriptive, narrative memos (e.g., Cobb & Whitenack,1996; Powell et al., 2003) organized by themes for each lesson for each teacher. These themes (such as *emphasis on individual students' math history* and *modeling curiosity*) were not determined a priori, but rather were emergent from and closely tied to what became salient as I parsed each teacher's lessons and debriefs. Sometimes this process required going back to the video record to clarify or gain more nuance on a teacher's instruction. Phase 3: After identifying themes in each lesson for each teacher, the themes were compared and collapsed across into broad descriptive categories (Corbin & Strauss, 1990). These are *the conceptual practices of teaching* in this data. Phase 4: To better understand their dimensions and the boundaries between them, I examined the narrative memo coded under each theme for each conceptual practice and selected examples illustrating more and less productive realizations of the conceptual practice. I operationalized *productiveness* by determining whether the realizations elicited student sensemaking in classroom videos as described in the narrative memo. This process of defining each conceptual practice and selecting a spectrum of examples of each one in action uncovered how conceptual practices were both unique and related. This examination of the distinctness of each conceptual practice resulted in four clusters of conceptual practices, with each cluster representing a functional concern in teaching inquiry-based mathematics to learners with a history of academic struggle.

Conceptual Practices: In my constant comparative analysis of six teachers teaching the same two lessons at different points in the year, I identified 15 pedagogical activities that I theorize as conceptual practices of teaching inquiry-based mathematics to students who have previously struggled. These 15 conceptual practices (codes) represent the daily work of teaching; they are inferred meanings of what teachers do and say (activities, not actions). These conceptual practices are distinct in that they serve different purposes for each teacher (see list A-D in the Findings). Due to space limitations, the definitions are not included in this manuscript; the names of each conceptual practice meaningfully describe what they represent. While distinct, these conceptual practices are also related to each other, clustering together to support four functional concerns in teaching inquiry-based mathematics to students who have struggled.

Findings

The main work of teaching from a teacher's perspective in an inquiry-based classroom for students who have struggled involves 15 conceptual practices that cluster together to constitute four functional concerns in-the-moments of teaching.

Concepts and Concerns: The conceptual practices, or pedagogical activities of teaching, are thematically related and constitute functional concerns in teaching (concepts A-D below). They represent the job of teachers—their concerns or responsibilities—from teachers' perspectives.

A. **Mathematical Correctness & Completeness** (concept): *How can I make sure that student work is accurate, thorough, and finished?* (concern). Conceptual Practices: (1) Seeking final answers on a task or sub-task, (2) Navigating student uncertainty, (3) Assessing student progress, (4) Redirecting students' mathematical thinking, (5) Building on students' mathematical thinking
B. **Mathematical Coherence & Relevance** (concept): *How can I make sure that mathematics is meaningfully connected to students' prior knowledge and lives?* (concern). Conceptual Practices: (6) Generalizing mathematical strategies, (7) Connecting mathematics, (8) Connecting mathematics to everyday life, (9) Offering mathematical choices
C. **Student Motivation** (concept): *How can I make sure that students are interested enough to get started and to persevere through uncertainty and confusion?* (concern). Conceptual Practices: (10) Offering non-mathematical choices, (11) Attending to student confidence (high inference), (12) Caring for relationships (high inference)
D. **Student Access** (concept): *How can I make sure that students can get started on the task and that struggle stays productive?* (concern). Conceptual Practices: (13) Unpacking the task, (14) Setting participation norms, (15) Organizing materials and student bodies

These functional concerns are all mathematics teaching specific, but also differently emphasize concerns about mathematics or students. Figure 1 illustrates how conceptual practices work towards constituting multiple concepts, including overlap between more strongly mathematics- or student-centered concepts. In the list above, the conceptual practices are located under the concept they most heavily constituted in the data.

Notably, *Building on student thinking* is the only conceptual practice that contributed to all four concepts. "Building on student thinking" happens when teachers elicit student ideas as a primary way to support student learning, particularly by eliciting some students' ideas publicly. Positive instances of building on student thinking include asking students to share their thinking with the teacher or with each other and then pressing for connections or *why* explanations. A less desirable instance of building on student thinking is, for example, referencing student ideas while explaining complex mathematical concepts before allowing exploration. Because *Building on student thinking* contributed to all four concepts, professional learning around this conceptual practice could be a powerful way to support shifts in instruction.

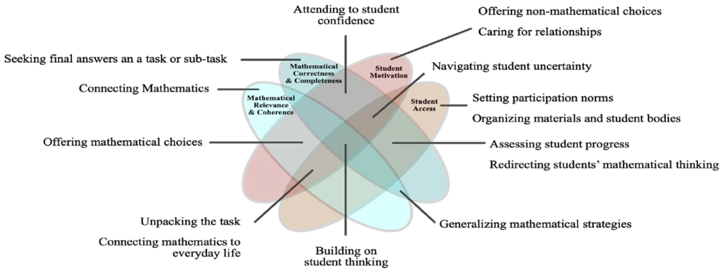

Figure 1. Relationship between concepts in terms of conceptual practices.

Implications

This paper contributes empirical evidence for an understudied, rudimentary question of what teaching is *for teachers* (Cohen, 2011) in reform-oriented intervention courses by identifying teachers enacted functional concerns. Too often, teachers experience PD as disconnected from teaching. PD around functional concerns may aid in supporting teachers to develop a practice of intentionality around instructional decisions that are often tacit, routine, and unconscious. For example, it may support teachers to develop a *professionalizing discourse* (Horn & Kane, 2019) in which they collectively work to develop shared meanings of concepts by pressing each other to explicitly connect, with detail, the particular contexts of their daily work with the functional concerns of teaching. This discourse centers teachers' meanings and concerns, making it more likely that PD fostering such discourse will make contact with what teachers actually do and care about, and, ultimately, influence classroom practice.

References

Cohen, D. K. (2011). *Teaching and its predicaments*. Harvard University Press.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., ... & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences*, *19*(1), 3-53.

Hall, R., & Horn, I. S. (2012). Talk and conceptual change at work: Adequate representation and epistemic stance in a comparative analysis of statistical consulting and teacher workgroups. *Mind, Culture, and Activity*, *19*(3), 240-258.

Hall, R., & Jurow, A. S. (2015). Changing concepts in activity: Descriptive and design studies of consequential learning in conceptual practices. *Educational Psychologist*, *50*(3), 173-189.

Horn, I. S. (2007). Fast kids, slow kids, lazy kids: Framing the mismatch problem in mathematics teachers' conversations. *The Journal of the Learning Sciences*, *16*(1), 37-79.

Horn, I. S. (2020). Supporting the development of pedagogical judgement. In G. M. Lloyd & O. Chapman (Eds.), *International handbook of mathematics teacher education, Volume 3: Participants in Mathematics Teacher Education* (2nd Edition, pp. 321-342). Brill Sense.

Horn, I. S., & Kane, B. D. (2019). What we mean when we talk about teaching: The limits of professional language and possibilities for professionalizing discourse in teachers' conversations. *Teachers College Record*, *121*(4), 1-32.

Jackson, K., Gibbons, L., & Sharpe, C. (2017). Teachers' views of students' mathematical capabilities: Challenges and possibilities for ambitious reform. *Teachers College Record, 119*, 1-43. doi:http://www.tcrecord.org

Kennedy, M. M. (2016). How does professional development improve teaching?. *Review of educational research*, *86*(4), 945-980.

Pfister, M., Opitz, E. M., & Pauli, C. (2015). Scaffolding for mathematics teaching in inclusive primary classrooms: A video study. *ZDM*, *47*(7), 1079-1092.

Schoenfeld, A. H. (2019). Reframing teacher knowledge: a research and development agenda. *ZDM*, 1-18.

Stein, M. K., Engle, R. A., Smith, M. S., & Hughes, E. K. (2008). Orchestrating productive mathematical discussions: Five practices for helping teachers move beyond show and tell. *Mathematical thinking and learning*, *10*(4), 313-340.

Corbin, J. & Strauss, A. (2014). *Basics of qualitative research. Grounded theory procedures and techniques* (Fourth edition). Sage Publications.

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Supporting Third Graders' Use of Subroutines in Programming through Play Versus Worked Examples

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Abstract: We conducted an in-depth analysis to better understand the role of playing versus analyzing worked examples when learning programming commands. Our findings, focused on two pairs of third graders, demonstrated that students did not use complex programming commands when only playing; whereas, when supported through analysis of worked examples, they did use subroutines. Both pairs started to identify repeating patterns in their code once they had a worked example where a subroutine was used to repeat a set of commands. Yet, having time to play before analyzing worked examples in programming contexts may provide subtle benefits, especially for more abstract commands such as subroutines. Unlike prior studies, our findings suggest that looping concepts can be taught within the concept of subroutines, even with young students.

Tangible programming devices are popular for introducing younger students how to program because students can see the direct results of the commands they program (e.g., Horn & Jacob, 2007). Depending on the type of device, students might program a robot (or other object) to make noises, light up, turn, and move forward or backward (e.g., Sullivan & Bers, 2016); all of these actions are easy to hear or see. However, some elements of programming, such as conditionals, loops, and subroutines, are still abstract in tangible forms because some of the steps or logic are not heard or seen in the same way. For example, Sullivan and Bers (2016) explored pre-kindergarten through second grade students' learning of programming involving KIBO robotic kits combined with a CHERP tangible programming language. At the end of the eight-week robotics curriculum, students struggled more with loop and conditional tasks than sequencing tasks.

There are several ways to help young students make sense of programming commands. One option, based on a constructionist philosophy, is to let students play and explore with the device, providing them with the opportunity to question and discover on their own (Monga et al., 2018). In a study where first and third graders played versus explained their program and goals while playing a tangible programming game, just playing the game supported students' (particularly females') improvement the most (Bofferding et al., 2020). On the other end of the spectrum, students could receive explicit instruction on commands and how to use them and then have targeted practice using the concepts. However, Lee et al. (2013) explored kindergarten students' social interactions through unstructured and structured programming curricula and did not find an impact of instruction on robotic skills and programming concepts. In the middle of the spectrum, students could use worked examples to reason about how a particular command works. In one case, worked-examples supported nine- to ten- year-old students' learning to program. (Joentausta & Hellas, 2018). To better understand such practices, we used an in-depth analysis of two pairs of third graders, unpacking their understanding of subroutines and programs depending on whether they engaged in playing or analyzing worked examples.

Play versus worked examples

If students have sufficient domain knowledge, play might be at least as good or even better than using worked examples (Tuovinen & Sweller, 1999). Playing that involves no explicit instruction would be helpful to learn programming (McCoy-Parker et al., 2017; Mitamura et al., 2012; Monga et al., 2018) by reducing extraneous cognitive load (Hawlitschek & Joeckel, 2017). However the benefits of play might differ based on the context; playing was more effective on first and fifth graders' creative scores on robot programming but less effective on their technical scores than explicit instruction (McCoy-Parker et al., 2017).

On the other hand, worked examples are guided instruction techniques which provide students with step-by-step problem-solving instructions used to teach problem-solving processes (Atkinson et al., 2000) and can help students focus on understanding, reasoning, and encoding (Ward & Sweller, 1990); they are appropriate to guide students to solutions for difficult problems (Pirolli & Anderson 1985) so that students do not waste time on unhelpful strategies. However, the design of worked examples is important (Sweller et al., 1998). Examples with errors (i.e., incorrect worked examples) support students to use more self-explanations when interpreting the concept, identifying errors, and correcting bugs (Zhi et al., 2018). Zhi and colleagues (2018) found that analyzing incorrect examples can effectively support older students' learning about loops; however, analyzing a mixture of correct and incorrect worked examples can be helpful for students who have sufficient prior knowledge (Große & Renkl, 2007).

Current study

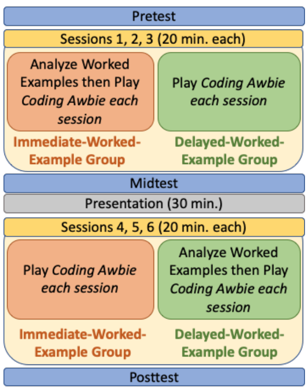
In this study, we used play and worked examples to help third graders understand and reason about programming commands, with an emphasis on abstract concepts related to subroutines and loops. Although worked examples can help middle school students learn more abstract programming commands (e.g., Zhi et al., 2018) and play can help younger students learn more concrete programming commands (e.g., Mitamura et al., 2012), our aim in this study was to identify the relative benefits of both methods for third grade students and determine when either method is most helpful. Therefore, a further aim was to gain clarity on whether analyzing worked examples was more beneficial during their initial exposure to programming or after given some time to play as we explored two research questions: How do students, depending on their prior experience playing the tangible programming game, interpret the worked examples and the meaning of the subroutine programming block? How do they use information from the worked examples in their pair and their own programming?

Methods

Setting, participants, study design, and materials

This study took place at a school in a midwestern district of the United States where approximately 45% of students qualified for free or reduced-price lunch. To elevate the voices of females in early programming, we selected two female pairs of third graders for this in-depth analysis (out of 26 students). We chose the two pairs from the same classroom and who both attempted to use the subroutine block the most in their sessions. Students Sheep7 and Sheep8 played during sessions 1-3 and analyzed worked examples in sessions 4-6. Students Sheep5 and Sheep6 analyzed worked examples in sessions 1-3 and played in sessions 4-6.

To examine the role of worked examples versus play, we employed a repeated-measures, between-groups design (see Figure 1). For this paper, we report on students' descriptions of the subroutine programming block as well as on their programs to move Awbie to a specific spot (on the posttest, they wrote a second version of their program using the subroutine block). Additionally, we report on an item where students explained a program involving grab and walk blocks repeated within a subroutine. Between the pretest and midtest, students worked in pairs to either play the programming game or analyze worked examples plus play, and students switched activity-foci between the midtest and posttest.



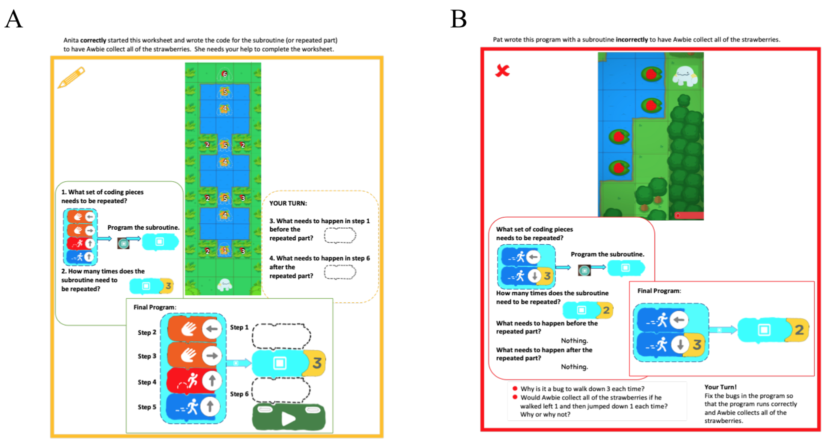


Figure 1. Study design.

Figure 2. Example (A) incomplete and (B) incorrect worked examples.

In the worked example sessions, students spent the first 5-8 minutes analyzing and answering questions about worked examples. In session 2 (or 5), students analyzed a correct, worked example to show how to use a subroutine block to repeat a set of grab and walk movements. Then they had to identify missing problem blocks in an incomplete worked example (see Figure 2A), and they found and fixed an error with a subroutine (see Figure 2B). In session 3 (or 6), students analyzed a correct worked example about using a warning block within a subroutine, and they fixed a worked example that incorrectly repeated a jump within a subroutine.

Analysis

Across subroutine items, we identified shifts in students' explanations (focusing on accuracy and conceptual understanding) and differences between the two pairs (i.e., the subroutine block can be programmed to do a set of commands or the subroutine can be repeated by adding numbers to the subroutine block or by making a subroutine of the subroutine). In order to characterize how pairs used the information from the worked examples, we identified the extent to which the pairs implemented subroutine ideas (and their effectiveness in doing so) within the sessions. Finally, at the individual level, we performed a similar analysis to the sessions using a programming item from the pretest, midtest, and posttest.

Findings

Overall, students showed a better understanding of subroutines after analyzing worked examples (see Table 1).

Table 1: Students interpretations and use of the subroutine on pretest, midtest, and posttest

Group:	**Pretest**	**Midtest**	**Posttest**
Intervention		**Explaining the Function of the Subroutine**	
-First	-------	Repeating (Sheep5, Sheep6)	Repeating (Sheep5, Sheep6)
-Second	Related to repeating (Sheep7)	-------	Can be programmed, involves repeating (Sheep7, Sheep8)
Intervention		**Programming the Character, Awbie**	
-First	-------	Correct (Sheep5, Sheep6)	Correct, recognized repeating pattern but did not program subroutine block (Sheep5, Sheep6)
-Second	Correct, not efficient (Sheep7); Debug (Sheep8)	Correct (Sheep7, Sheep8)	Correct, programmed subroutine with full program, did not have it repeat (Sheep7, Sheep8)

During sessions one to three, when analyzing the worked examples, Sheep5 and Sheep6 explained that the subroutine could repeat programmed commands by adding number blocks to the block; however, they did not explain that the subroutine block can be programmed to do a set of commands. They did not find the correct commands to complete the program in Figure 2A; but they were able to explain the problem with the program in Figure 2B. When they tried to fix an incorrect worked example that repeated a jump too many times within a subroutine. They explained the subroutine and fixed the bugs, although they created a new program that did not involve a subroutine. When playing, although the intervention-second group did not recognize repeating patterns, the intervention-first group started to recognize repeating patterns after analysis of the worked examples (which emphasized repeating patterns in the code). However, rather than programming the subroutine block with the part to repeat (*"walk right 1, walk down 1"*) and putting a number on the subroutine button, they placed the blocks to repeat after the subroutine button in the sequence of code. Sometimes they tried to use the subroutine button but forgot to program it first.

During sessions four to six, when analyzing the worked examples, Sheep7 and Sheep8 now explained that the subroutine could repeat programmed commands by adding number blocks to the block, and they mentioned they could repeat the programmed commands by using number blocks on the subroutine. Due to an implementation error, Sheep5 and Sheep6 reanalyzed one set of worked examples and, this time, identified the missing commands in Figure 2A, while Sheep7 and Sheep8 correctly identified the first missing command. They also fixed the subroutine with too many jumps by changing the code and not using the subroutine to do the new repeated part. When playing, both groups recognized repeating patterns and tried to use the subroutine block, but both groups forgot to program the subroutine block; instead, they put it at the end of the part they wanted to repeat. The intervention-second group eventually remembered to program the subroutine block and used it to *repeat jump right 1* three times, and they even put additional code after the block. By session six, they also used the subroutine to repeat by making a subroutine of the subroutine!

Discussion

Although this analysis focuses on two pairs of students, a limitation of this analysis, the results follow larger trends from our research for those students who used the subroutine in their programming. Using the worked examples was beneficial for helping students understand and use the subroutine block. Sheep5 and Sheep6 were better equipped to try using the subroutine block in their second and third sessions because they engaged with worked examples involving the subroutine block; whereas, Sheep7 and Sheep8 did not try using the subroutine block until they had their first worked example involving the subroutine block. This is particularly interesting because both pairs had been exposed to examples on the pretest and midtest that required them to interpret the action of the subroutine block; however, they only tried to use the block when they had a worked example with one. Although prior research suggested that students would have difficulty learning abstract programming concepts (Sullivan & Bers, 2016; Zhi et al., 2018), our results suggest that students might be less likely to learn these more complex programming commands through play only; they can learn more abstract programming concepts with the support of varied worked examples (Lee et al., 2013).

Based on this study, students who initially played made just as many gains as students who started with worked examples, and arguably, their use of the subroutine button was more complex than the students who started out with worked examples. Therefore, having some time to play before analyzing worked examples in programming contexts may serve some subtle benefits, especially for more abstract commands, an area that should be explored further. Lastly, unlike the previous studies that were teaching loops (Sullivan & Bers, 2016; Zhi et al., 2018), we taught the repeating idea within the concept of the subroutine. Our study showed that students developed an understanding about programming a set of commands and calling them back *while* developing reasoning about repeating a set of commands at the same time.

References

Atkinson, R. K., Derry, S. J., Renkl, A., & Wortham, D. (2000). Learning from examples: Instructional principles from the worked examples research. *Review of Educational Research*, *70*(2), 181-214.

Bofferding, L., Kocabas, S., Aqazade, M., Chen, L., & Haiduc, A. M. (2020, Apr 17 - 21) Exploring Practices to Support Commenting and Debugging in Early-Years Tangible Programming [Structured Poster Session]. AERA Annual Meeting, http://tinyurl.com/yyd7ayh4 (Conference Canceled)

Große, C. S., & Renkl, A. (2007). Finding and fixing errors in worked examples: Can this foster learning outcomes? *Learning and Instruction, 17*(6), 612-634.

Hawlitschek, A., & Joeckel, S. (2017). Increasing the effectiveness of digital educational games: The effects of a learning instruction on students' learning, motivation and cognitive load. *Computers in Human Behavior, 72*, 79-86.

Horn, M. S., & Jacob, R. J. (2007, April). Tangible programming in the classroom with tern. In *CHI'07 Extended Abstracts on Human Factors in Computing Systems* (pp. 1965-1970).

Joentausta, J., & Hellas, A. (2018, February). Subgoal labeled worked examples in K-3 education. In *Proceedings of the 49th ACM Technical Symposium on Computer Science Education* (pp. 616-621)

Lee, K. T., Sullivan, A., & Bers, M. U. (2013). Collaboration by design: Using robotics to foster social interaction in kindergarten. *Computers in the Schools, 30*(3), 271-281.

McCoy-Parker, K. S., Paull, L. N., Rule, A. C., & Montgomery, S. E. (2017). Challenging elementary learners with programmable robots during free play and direct instruction. *Journal of STEM Arts, Crafts, and Constructions, 2*(2), 100-129.

Mitamura, T., Suzuki, Y., & Oohori, T. (2012, October). Serious games for learning programming languages. In *2012 IEEE International Conference on Systems, Man, and Cybernetics (SMC)* (pp. 1812-1817).

Monga, M., Lodi, M., Malchiodi, D., Morpurgo, A., & Spieler, B. (2018). Learning to program in a constructionist way. In *Proceedings of Constructionism*, Vilnius, Lithuania. https://hal.inria.fr/hal-01913065

Pirolli, P. L., & Anderson, J. R. (1985). The role of learning from examples in the acquisition of recursive programming skills. *Canadian Journal of Psychology/Revue Canadienne de Psychologie, 39*(2), 240-272.

Sullivan, A., & Bers, M. U. (2016). Robotics in the early childhood classroom: Learning outcomes from an 8-week robotics curriculum in pre-kindergarten through second grade. *International Journal of Technology and Design Education, 26*(1), 3-20.

Sweller, J., Van Merrienboer, J. J., & Paas, F. G. (1998). Cognitive architecture and instructional design. *Educational Psychology Review, 10*(3), 251-296.

Tuovinen, J. E., & Sweller, J. (1999). A comparison of cognitive load associated with discovery learning and worked examples. *Journal of Educational Psychology*, *91*(2), 334-341.

Ward, M., & Sweller, J. (1990). Structuring effective worked examples. *Cognition and Instruction, 7*(1), 1-39.

Zhi, R., Lytle, N., & Price, T. W. (2018, February). Exploring instructional support design in an educational game for K-12 computing education. *In Proceedings of the 49th ACM Technical Symposium on Computer Science Education* (pp. 747-752).

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Multimodal Generalizing in a Mathematical Videogame

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Abstract: This study adapts and augments Ellis and colleagues' Relating, Forming, and Extending generalization framework by examining how multimodal generalizing emerges from a player's interaction with a mathematical videogame. We review the literature on generalizing, describe how embodied cognition (particularly physical gesture and digital actions) contribute to the field's understanding of generalizing, and describe the videogame. We then detail our multimodal evidence of generalizing during gameplay, and conclude that attending to physical gesture and digital action are a necessary component of examining multimodal generalizing.

Introduction

The bulk of research investigating students' mathematical generalizations has occurred in the domains of early algebra and algebra, and has relied heavily on patterning tasks (e.g., Rivera, 2010). Doerfler (2008) has noted, however, that the presentation of patterning tasks can have a strong regulating or even restrictive effect on students' generalizing. These tasks may provide figural cues and expected progressions that encourage a narrowly prescribed range of potential generalizations. In contrast, he argued for *'free'* generalization tasks that are not restricted by pre-given purposes and there is a need to better understand how students construct generalizations in more open-ended tasks or contexts, such as occurs during mathematical play (Williams-Pierce & Thevenow-Harrison, accepted). Simultaneously, we focus on investigating how generalizing itself may transform during novel and multimodal contexts. We do so by leveraging established research in embodied cognition, which recognizes evidence of mathematical learning contained in modalities other than speech (e.g., Williams-Pierce et al., 2017). In particular, we adapt and extend Ellis and colleagues' generalization taxonomy (Ellis, Tillema, Lockwood, & Moore, 2017; Ellis, Lockwood, Tillema, & Moore, under review) to the context of a mathematical video game designed to provoke mathematical play (Williams-Pierce, 2017a). Our research question was *How does generalizing emerge from playing a mathematical videogame?* Here, we share two different results: first, we contrast how *recursive embedding* (Lockwood & Reed, 2016; Ellis et al., 2017) appears in a different form in gameplay; and second, we examine how multimodal generalizing occurs by extending the data sources used to infer generalizing from primarily spoken language and written work to physical and digital gestures. We introduce generalizing and embodied cognition, our game and methods, give an illustrative example of how multimodal generalizing manifested in gameplay, then conclude with implications.

Theoretical frameworks: Generalizing and embodied cognition

We use the Relating, Forming, Extending (RFE) framework (Ellis et al., 2017; Ellis et al., under review), which draws on the multiple types of generalizing accounted for by Ellis' generalization taxonomy (2007a; 2007b). The RFE framework is built upon the results from 146 interviews with 93 participants in middle school through college in the domains of algebra, advanced algebra, trigonometry/pre-calculus, and combinatorics. These interviews incorporated a wide variety of problem types, including open-ended and complex problems that could afford a number of different viable generalizations, therefore responding to Doerfler's (2008) call to leverage more "free" generalization tasks unrestricted by pre-determined goals. Due to space restrictions, we describe solely the components of the RFE framework that appear in the Findings section, which is primarily Forming, with some Relating and Extending. Forming is the development of an initial, sometimes tentative generalization, and can encompass a number of different actions. *Isolating constancy* often occurs as a precursor to *identifying a regularity*, which can either be *extracted* (identifying a common feature across multiple observed cases) or *anticipated* (predicting that a feature will continue to future cases, even if this has not been observed). Students can also form generalizations through non-searching actions, such as *associating objects* (forming a relation of similarity between two or more mathematical objects), or by *establishing a way of operating* by forming novel mental operations that become the foundation for a generalization that can be applied to a broader domain. Once formed, extending is the use of a generalization, sometimes to a broader domain. When *continuing* a generalization, one does not alter it, but when *operating*, the student will alter the expression of the generalization in order to extend it to a new case. *Transforming* a generalization involves changing the generalization itself. The one part of relating that was particularly evident in our data was *recursive embedding*, which is the act of reflecting on prior activity and inserting that activity into one part of a new situation (see also Lockwood & Reed, 2016).

However, the RFE framework has relied primarily upon spoken and written language as evidence of generalizing, so we now introduce aspects of embodied cognition as a way to understand other types of evidence.

Gestures are a recently identified key component of mathematical communication and cognition (e.g., Alibali & Nathan, 2012; Williams-Pierce et al., 2017). The ways in which physical gesture accompanies spoken language in order to contribute unique information about mathematical reasoning is well-documented (e.g., Alibali & Nathan, 2012; Williams-Pierce et al., 2017). Alibali, Boncoddo, and Hostetter (2014) described gestures as "movements of the hands and body that are integrally connected with thinking, and often, with speaking" (p. 150). In particular, Hostetter & Alibali (2008) note that "The isomorphism between images and gestures is manifested in their frequent co-occurrence. Gestures often occur when speakers express information that evokes images" (p. 501). Consequently, embodied cognition – particularly gesture as simulated (digital) action – needs to be considered when examining multimodal generalizing, particularly with Doerfler's (2008) "free" generalization tasks that do not attempt to *a priori* constrain generalizing.

Context and methods

Rolly's Adventure (*RA*) represents multiplicative reasoning (Hackenberg, 2010) through quantities (e.g., Thompson, 1993), where players engage in cycles of mathematical hypotheses (Williams-Pierce & Thevenow-Harrison, accepted) about the underlying and implicit mathematical relationships within the game (Williams-Pierce, 2017a, 2017b). The artefacts and interactions are based solely upon the game and the participants' physical gestures - no other tools were provided or allowed. Participants directed their digital avatar to interact with the game, and regularly used physical gestures to supplement their spoken language. The goal of each puzzle in the game is to fill a digital hole with iterated and/or partitioned copies of a block, and the overall trajectory was designed to support generalizing across the puzzles as each puzzle becomes more difficult. In other words, players were introduced to new problematic situations that created new disequilibrium, causing the need to engage in continued generalizing to regain equilibrium. This approach, combined with the non-standard representations and interactions presented by *RA*, led to players perceiving and engaging the game as a "free" generalizing task, despite the designer's initial goal of evoking learning about multiplication of fractions. For more information about *RA*, see Williams-Pierce (2017a, 2017b) and Williams-Pierce & Thevenow-Harrison (accepted).

The data analyzed for this paper comes solely from the *RA* gameplay of one middle-school aged participant, Ike. Since *RA* is a console game, Ike sat about 10 feet from the television and held a controller. A video camera was positioned to capture their bodies and audio, and Roxio screen-capture software was used to capture their gameplay. During gameplay, the interviewer sought solely to understand Ike's thinking, and did not direct their learning through questions or evaluation, which allowed Ike to engage with the game as a "free" generalization task, rather than an activity with a single correct answer. After data collection, the video record of the participant's body and the screen capture of the gameplay were synced and transcribed to include spoken language, gestures, digital actions, and key gameplay points. We used MaxQDA, software for qualitative data analysis, to implement a mixture of emergent and *a priori* coding (Williams-Pierce, 2017b, Williams-Pierce, 2017a; Williams-Pierce & Thevenow-Harrison, accepted). Our holistic focus here is on multimodal generalizations, based upon the *a priori* RFE framework infused with embodied cognition.

Findings

Since *RA* has no explicit instructions, Ike begins play by activating various buttons and attending to the feedback and failure mechanisms. First, they activate the 1-button, and fail; then activate the 3-button, and fail; then they activate the only remaining button, the 2-button, and are successful. Although there is insufficient evidence of generalizing during this interaction, later patterns of engagement provide evidence that the establishment of a *regularity* occurs here. In other words, they learned in this puzzle that moving up the row of buttons causes a larger quantity of resulting blocks, whereas moving down the row of buttons results in a smaller quantity of blocks. Ike's uncovering of this (fairly trivial, but crucial) mathematical pattern in RA provides the foundation for their recursive embedding in future puzzles. As Ike continues playing RA, they quickly determine that filling the hole is the goal, and that there is some type of relationship - as yet unknown - between the buttons, the initial amount in the hole, and the resulting amount deposited. In other words, Ike engages in *continuing* and then *operating* on the *regularity* they noticed earlier: if they activate a button and the amount deposited in the hole is too little (or too much), then they need to move up (or down) a button. They then recursively embed this activity, as they have recognized that enacting the same digital actions in every new puzzle will lead to more information about the deeper, less trivial mathematical patterns within the game. Although this recursive embedding is fairly inefficient and mathematically trivial, it is fully reliable - it always works, even if it takes considerable time and failure.

As Ike continues recursively embedding their regularity, they begin to develop a powerful generalization, first in tandem with their recursive embedding then by itself. First, Ike begins searching for a more efficient gameplay strategy: Ike's frustration with slowness of *operating* on their *regularity*, combined with their developing awareness of the mathematical relationships within the game, has provoked them to seek a more efficient mathematical strategy. In particular, they are trying to identify another *regularity* in order to develop a *transformation* of their generalization that will work consistently across all the puzzles. After solving Puzzle 6 (shown in the right of Figure 1) with their recursive embedding, the researcher asks if they had expected that choice to be correct. Ike replies that they were not sure, because "the scale was a little different than earlier, because it was treating a larger amount of cubes [spreads their fingers vertically and gestures up into the air to indicate they mean the blocks initially present in the hole] as a smaller number." The interviewer asks them to clarify what they mean, and their explanation is illustrated as an enhanced transcript (Figure 1).

Line 1 verifies that Ike used recursive embedding to solve the puzzle when they state that they were not sure if their choice was correct, and that they considered the correct choice just as likely to be the button that was slightly less. When the interviewer prompts them to explain more about their thinking, Ike explains that there is probably a relationship between the buttons and the amount of gold blocks preset by the game (Lines 2-4). In a further explanation not included in Figure 1, Ike went on to say that when the game began, the numbers on the button were larger, because the resulting blocks that would come in were smaller. As the game progressed, however, the buttons began having smaller numbers, but the space that needed to be filled was about the same. Ike first used recursive embedding to solve the puzzle, and their musings afterwards indicated that they were seeking to further unpack and understand the game's underlying mathematical relationships. Later, although space constraints preclude us from including the data excerpts, Ike *searches for* and *identifies a regularity*, and uses that regularity to *establish a way of operating*, as they continue to use this regularity to guide their activity in following puzzles. As the game introduces other variations – such as an overfilled hole, modeling an improper fraction – Ike engages in *extending* in order to *continue* and then *operate* with this generalization.

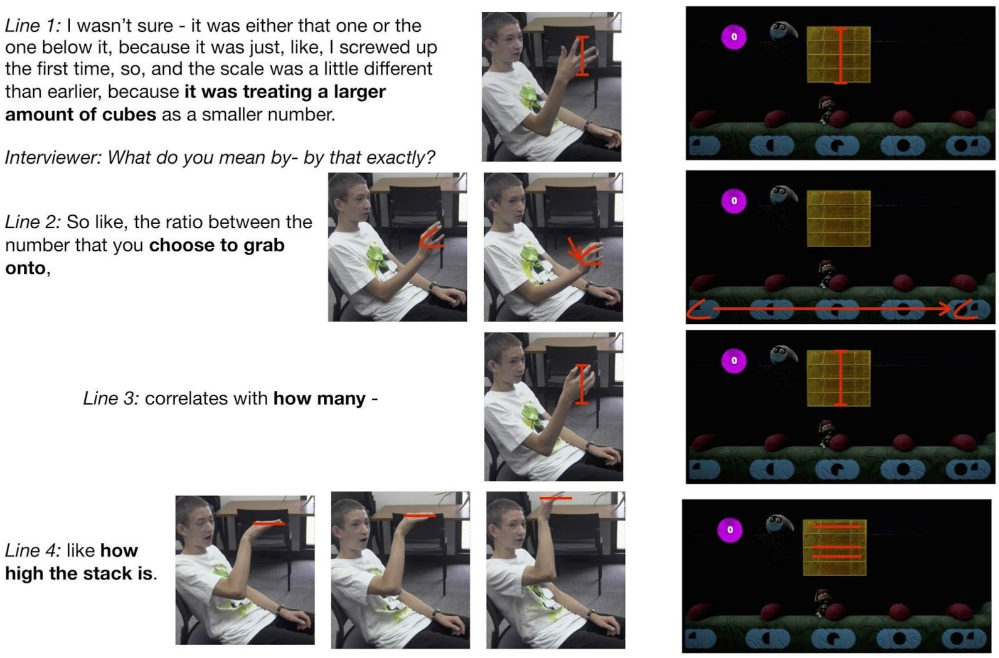

Figure 1: Ike's spoken language with gestures (left). Red maps gestures to the game structures.

Discussion and conclusion

Ellis and colleagues' generalizing framework is rich enough to navigate the distinct differences across context, participant interactions, and artefacts from their research to ours. We identified different ways in which generalizing was mediated in this digital context that directly influenced generalizations. In addition, we found that RA provoked recursive embedding of mathematical activity, as one puzzle provided the foundation for the next puzzle. In other words, we conducted the analysis with the understanding that there is some underlying experience that ties mathematical engagement together across the arc of gameplay and learning. We hypothesize in particular that such designed experiences are likely to increase recursive embedding and may provoke an intellectual need for structure (Harel, 2013) that leads to developing powerful generalizing opportunities. Such intellectual need plays a crucial role in motivating the development of sophisticated generalizations in non-linguistic learning contexts like *RA*, as recursive embedding becomes frustratingly inefficient.

We attended to two types of gestures: the simulated digital actions that result from the player's interaction with the game controller; and the player's physical representational gestures in order to identify which digital structures – and their mathematical counterparts – they are referring to in speech. There is an ebb and flow of different types of evidence during multimodal generalizing. For example, there is a shift in data types being used to support Ike's usage of recursive embedding, depending upon which context – digital or physical – they are primarily focused upon. During gameplay, evidence of recursive embedding can be seen through their spoken language paired with their avatar's digital action – e.g., activating a button, failing, then moving to activate another button. During pauses in gameplay, however, our analysis pairs the spoken language with Ike's physical and representational gestures – that is, how Ike is manifesting their simulated action in a moment when digital action is not occurring. We consider this to be an ebb and flow because although it is tempting to slice the data according to the different modalities – Ike playing the game vs. Ike not playing – each slice is in fact a new layer upon our understanding of Ike's generalizing, and looking at each modality separately disregards Ike's holistic experience. Consequently, we identify multimodal generalizing by threading through these different modalities, and consider physical and digital gestures necessary for investigating such generalizing.

Endnotes

(1) We use *they singular* pronouns to refer to Ike (a pseudonym), as we failed to identify appropriate pronouns for Ike in two important ways. First, we only asked the parent registering the youth participant rather than the youth themselves; and second, we conflated sex and gender by asking "What gender is your child?" We thank Damarin and Erchick (2010) for highlighting the need for *clarity* of such methodological issues in our field.

References

Alibali, M. W., Boncoddo, R., & Hostetter, A. (2014). Gesture in reasoning: An embodied perspective. In L. Shapiro (Ed.), *The Routledge Handbook of Embodied Cognition* (pp. 150–159). London: Routledge.

Damarin, S., & Erchick, D. B. (2010). Toward Clarifying the Meanings of Gender in Mathematics Education Research. *Journal for Research in Mathematics Education*, *41*(4), 310–323.

Ellis, A.B. (2007a). Connections between generalizing and justifying: Students' reasoning with linear relationships. *Journal for Research in Mathematics Education, 38*(3), 194 – 229.

Ellis, A.B. (2007b). A taxonomy for categorizing generalizations: Generalizing actions and reflection generalizations. *Journal of the Learning Sciences, 16*(2), 221 – 262.

Ellis, A.B., Tillema, E., Lockwood, E., & Moore, K. (2017). Generalization across domains: The relating-forming-extending framework. In E. Galindo & J. Newton (Eds.), *conference, North American chapter* (pp. 677-684). Indianapolis, IN: Hoosier Association of Mathematics Teacher Educators.

Ellis, A.B., Lockwood, E., Tillema, E., & Moore, K. (under review). Generalizing across multiple mathematical domains: Relating, Forming, and Extending.

Hostetter, A. B., & Alibali, M. W. (2008). Visible embodiment: Gestures as simulated action. *Psychonomic Bulletin & Review*, *15*(3), 495–514. https://doi.org/10.3758/PBR.15.3.495

Lockwood, E. & Reed, Z. (2016). Students' meanings of a (potentially) powerful tool for generalizing in combinatorics. In T. Fukawa-Connelly, K. Keene, & M. Zandieh (Eds.), *Proceedings of Research in Undergraduate Mathematics Education* (pp. 1-15). Pittsburgh, PA: West Virginia University.

Rivera, F. D. (2010). Visual templates in pattern generalization activity. *Educational Studies in Mathematics, 73*, 297–328.

Thompson, P. W. (1993). Quantitative reasoning, complexity, and additive structures. *Educational Studies in Mathematics*, *25*(3), 165–208.

Williams-Pierce, C. (2017a). *Designing provocative objects for mathematical play.* Paper presented at the 2017 American Educational Research Association Annual Meeting and Exhibition. San Antonio, TX.

Williams-Pierce, C. (2017b). *Fractions, mental operations, and a unique digital context.* In E. Galindo & J. Newton (Eds.), *Proceedings of the Psychology of Mathematics Education conference, North American chapter* (pp. 1349-1352). Indianapolis, IN: Hoosier Association of Mathematics Teacher Educators.

Williams-Pierce, C. (2019). Designing for mathematical play: Failure and feedback. *Information and Learning Sciences, 120*(9/10), 589-610. https://doi.org/10.1108/ILS-03-2019-0027

Williams-Pierce, C., & Thevenow-Harrison, J.T. (accepted). *Zones of mathematical play.* Submitted to the Journal of the Learning Sciences.

Williams-Pierce, C., Pier, E., Walkington, C., Clinton, V., Boncoddo, R. Nathan, M., & Alibali, M. (2017). What we say and how we do: Action, gesture, and language in proving. *Journal for Research in Mathematics Education*, *48*(3), 248-260.

Centering Praxis in Design-Based Research: Insights from an Informal STEM Research Practice Partnership

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Abstract: Design-based research, when taking place within research practice partnership, leads to an essential tension between the interventionist nature of educational design and a commitment to praxis. We encountered this tension within a DBR project to design a computational science exhibit within a science museum, and in this paper, we highlight how paying attention to praxis shifted our epistemological enframings and methodologies of our work. Moving away from a device-centered approach focused solely on the design of the exhibit, we show how listening carefully to museum facilitators led to the recognition of their hidden labor, and helped us to explicitly position the museum facilitators as co-designers.

Introduction and background

Design Based Research (DBR) acknowledges the intertwined nature of educational designs and practice and is expected to lead to contributions in both practice and theory (McKenney & Reeves, 2012). This paper addresses an essential tension at the heart of DBR: rather than focusing exclusively on the interventionist nature of educational design, DBR taking place within Research Practice Partnerships (RPPs) also demands attention to supporting longer-term relationships and understanding the roles and experiences of the researchers and practitioners working together for mutual benefit (Penuel et al., 2015). Our work arises from our lived-in experiences of the tension between these two foci within a multi-year RPP in a science museum, illustrating how the work of the facilitators drew our attention away from the materiality of the designed environment to the complexity of praxis causing a shift in the theoretical and analytical foci of the researchers. Failing to attend to relationships, hierarchies and the meaningful actions of all involved *as part of the design or reform activity*, leaves the status quo intact and constrains the possibilities for real and meaningful change in educational settings (Carlone & Webb, 2006). This is especially important given that informal STEM education scholars rarely focus on the *work* of museum facilitators, and the literature largely views facilitators through a deficit lens and as needing more training (Ji et al., 2016; Tran et al. 2019). The spectre of technocentrism (Papert, 1980) – the fallacy of referring all questions about technology to the technology itself, rather than inquiring about the socially, historically and institutionally constructed meanings and experience of technology – looms large in the field of computing education (Sengupta et al., 2021). This emphasizes device-level engagements (Rosner, 2018; see also Ames, 2019), orienting our attention primarily toward the software/hardware involved, rather than the complexity of the participants' experiences. In informal STEM education research, the emphasis on device-level engagements is evident in the form of a focus on the effectiveness of the designed technologies and exhibits (see for example, Horn et al., 2009), which obscures the complexity of the work of facilitation (Ozacar et al., 2020).

Given this background, our work seeks to identify and understand the work of facilitators in the design process as *mediated praxis* (Gutiérrez & Vossoughi, 2010), where "changes in practice necessarily involve changes in the ways we think about practice [and] individual shifts in thinking and participation influence (and are influenced by) changes in the activity itself." (p. 105). We ask the following **research question**: How did paying attention to the complexity of praxis shift our methodological approach and the underlying epistemological metaphors in design-based research in our work? We argue that *listening* (Schön, 1983) to facilitators' voices plays an essential role in the context of design in informal science centers and museums, and present an investigation of the epistemological and methodological shifts that result from centering their work and their voices in the context of a multi-year RPP. Our work illustrates how, by listening to the facilitators rather than continuing our own, initial, device-centered approach to design, we were able to identify the hidden labor of facilitators. Our work builds on Star and Ruhleder (1996), who argued that support systems or infrastructures that are locally relevant and develop over time are essential to the long-term sustainability of innovations, and that it is often in moments of conflict between or breakdown of these support systems - a phenomenon that they termed "infrastructuring" - that infrastructures become visible. We conclude the paper with a discussion of the epistemological and axiological implications of our methodological shift.

Context, data, and method

This paper reports an ongoing, multi-year RPP with a science museum around the design, visitor experience and facilitation of a public computing exhibit called *Hack the Flock*. At Hack the Flock, visitors can interact with a simulation of flocking, in which boids (bird-droids) continuously shift and flock around the screen, moving in relation to other moving boids according to three forces (Reynolds, 1987): alignment (trying to steer in the same direction as neighbors), cohesion (trying to move towards the centroid of the flock), and separation (trying to keep some distance between itself and other flockmates). Visitors can use the computer terminal to directly change those forces through changing the underlying code and parameters for color, shape, speed, and size, and images.

We collected data in multiple forms: a) field notes of researchers who participated as both facilitators and observers of visitors' interactions, b) video recordings of visitors' and facilitators' interactions with the visualization, code, and other elements of the exhibit, c) interviews with museum facilitators about their experiences with the exhibit, and d) video recordings of museum facilitators taking part in design meetings. Visitor interactions with the exhibit ranged in length from a few minutes to over an hour. We adopted interpretive and phenomenographic approaches for the analysis. Phenomenography focuses on identifying participants' enframing of situations, and an object or an event, in this view, must be interpreted in light of the "complex of the different ways it might be experienced" (Marton & Booth, 1996, p. 538). Our interpretive analysis (Thorne et al., 1996) relied on analytic frameworks to accommodate both participants' enframings as well as disciplinary enframings. In our context, disciplinary enframings included theoretical constructs such as device-level engagements and infrastructuring, and interpretive analysis involved inductively refining the match between our data and the conceptualizations implied by these constructs, which also guided how we selected the cases. Our findings illustrate the chronological shift in our stances from device-centeredness to a more praxis-centered approach, and illustrate how this resulted in us learning to value what we later termed *improvisational infrastructuring* through acknowledging and centering the complexity of praxis in DBR.

Findings

Recognizing infrastructuring

Prior to the installation, our stance was design-based researchers was device-centered, as our focus during the pilot testing phase (Nov 2016 – Jan 2018) was entirely focused on designing and improving software and hardware components of the exhibit based on a series of six user testing sessions, with minimal involvement of the facilitators. After the exhibit was installed in March 2018, collecting initial facilitation and visitor interaction data required the research team and administrators from the science museum to work together, and it was during this phase that we began to notice institutional constraints and expectations that facilitators had to navigate. This was our first encounter with *infrastructuring* (Star & Ruhleder, 1996), i.e., breakdowns in support systems around the exhibit. Firstly, a job requirement for museum facilitators at this science centre was that they were expected to roam around the galleries to help guests and they were not supposed to spend longer periods of time (beyond a few minutes at the most) at any one exhibit. Therefore, collecting video observations of facilitators and visitors working together meant that a facilitator had to be specifically stationed at the exhibit (requiring another facilitator to work and cover their typical duties, atypical for this science museum) and availability of facilitators was adversely affected by shrinking budgets and high turnover – a commonly noted issue in museum education (Moore et al. 2020). Furthermore, inconsistent training sessions meant that some facilitators who were scheduled to spend time at Hack the Flock (and were therefore eligible to consent to be part of the research) had never worked at Hack the Flock previously or received training from researchers or museum staff on the exhibit.

The infrastructuring that resulted from issues was quickly visible as data collection began. Facilitators generally did not like the exhibit, as facilitation was difficult due to lack of experience, time, and training. Some discomfort with the topic of coding and technical difficulties with the first exhibit iteration, such as needing to reset it if a visitor "broke" the code, compounded the negative viewpoint of the exhibit. In fact, before they were scheduled to spend blocks of time at the exhibit, some facilitators actively *avoided* facilitating the exhibit (Interview, Ashley, Jul 2019). Facilitators felt that they had been "thrown into" the exhibit without any training (Interview, Kaitlynn, Aug 2019), the physical interface was difficult to use (multiple facilitator interviews, Jul-Aug 2019), and had only been able to have a few good, extended interactions with visitors (multiple facilitator interviews, Jul-Aug 2019). Thus, their institutional regulations, coupled with negative personal experiences, oriented them away from Hack the Flock. And yet, even in our observations, it became increasingly clear that the most important factor shaping the quality of visitor experiences at Hack the Flock was not the exhibit itself, but the work that facilitators do to support it. We began to notice hidden work that facilitators did while at the exhibit, even in cases where the facilitators themselves had little or no prior experience in working with the exhibit and/or code. It was at this point that our research interests pivoted from exhibit redesign to the hidden work that facilitators were doing to make the exhibit "work" - an ontological innovation (DiSessa & Cobb, 2004) we later termed *facilitator infrastructuring*. This work was largely invisible to the researchers until they spent extended time in the field and strengthened relationships with the facilitators, and we describe this next.

Improvisational infrastructuring as hidden design work, and centering facilitator voice

The complexity of facilitator infrastructuring emerged from their interviews and observations of their interactions with visitors, and a common form of infrastructuring involved improvising in the moment to deal with challenging situations with visitors. For example, Janelle used experimentation – a strategy that she would usually use with other exhibits - when she could not remember the results of a particular code change, noting: "So I'll be like, with a kid when I forget, I just kind of experiment. So I'm like, let's see what happens when we do this. I was like, oh, what if we do the opposite?" (Interview, Jan 2019). Other strategies included selectively emphasizing certain aspects of the code over others, based on the facilitators' own conceptual difficulties with the computational representations and abstractions (e.g., difficulties with "breaking" the code unintentionally) (Interview, Jan 2019). While not voiced as design ideas, these comments provide insight into which aspects of the exhibit were used to draw visitors in or were well-understood by facilitators, and which were confusing. These insights could lead to changes in code order, better explanations of existing lines of code, or new additions to the exhibit that were more "visible" and "fun" for visitors. With continuous prompting from the PhD students, facilitators also offered new design ideas for the exhibit and its surrounding infrastructure based on their experiences facilitating at Hack the Flock. For example, facilitators mentioned wanting more images and a facilitation guide that would be full of explanations and images to help both visitors and facilitators be able to more deeply explore the exhibit.

More important than the design ideas, however, was the creation of a community of practice (Lave & Wenger, 1991) around Hack the Flock that showed promise of persisting even after the researchers had left. Facilitators began to self-organize around the exhibit, creating a sense of community and increasing feelings of ownership, both over the exhibit and in the research project more generally. They were eager to help each other learn about the exhibit, often teaching each other in lieu of formal training or depending on researchers or exhibit designers who were not always available to them: "Even if I can't remember, I can ask my teammates to help me out and we can… all teach each other." (Interview, Ashley, Aug 2019). Facilitators shared new code changes with visitors, the researchers, and other facilitators, both in-person and via institutional and social media, such as when Hilda (July, 2019) created her new "favourite colour" using RGB colour representation and told the researcher to write it down before running off to find another facilitator in the gallery to show off her creation.

Making space for facilitators as co-designers

During Dec 2019, our goal was to run multiple 1-hour design meetings specifically for facilitators so that they could collaboratively reflect on their experiences at Hack the Flock and brainstorm potential solutions to the challenges they voiced throughout the project. Our design meeting had two components: firstly, at the request of facilitators throughout the project, the researchers gave a review of the data they had collected so far, what analyses were ongoing, and what future research directions might look like. For the rest of the time, facilitators worked in small groups to brainstorm exhibit improvements, in which drew upon their extensive experience to make a wide variety of design suggestions, encompassing everything from hardware components and props to new ways of inviting visitors to engage with Hack the Flock. Some suggestions included using a prop from a previous exhibit that explained RGB colour representation; a touchscreen interface, creating challenge cards, easter eggs, competition modes, and ways to save and display work; an easier way to reset broken code; and incorporating explanations of real-world applications of computing (video recordings and written documents, design meetings, Dec 2019). Their understandings of the exhibit extended beyond its hardware and software and were grounded in the need for interaction between visitors and facilitators. These design meetings also provided a space where multiple perspectives on the exhibit could exist simultaneously, such as those from the researchers as well as those of the facilitators who had to work with it on a daily basis. As Jasmine (Video recording, facilitator design meeting, Dec 2019) explained, having the researchers explain why they had designed Hack the Flock to use text-based code in this way and what they were hoping to learn from the exhibit was something she could understand and respect. At the same time, she and other facilitators were having difficulties "jumping right in" to the exhibit with visitors. Understanding and acknowledging these different viewpoints meant that facilitators and researchers could then engage in joint work together to design solutions to problems that could align with both of them - finding new ways for visitors and facilitators to interact with the exhibit that would not compromise the epistemology of computing that researchers wanted to promote.

Discussion: Intertwined shifts in epistemology and methodology

Our findings showcase the ways in which the move away from device-centeredness led to space in which mediated praxis (Gutiérrez & Vossoughi, 2010) could take place, promoting "expansive forms of learning in which individual and collective zones of proximal developments coalesce" (p. 111) and causing both facilitators and researchers to "act a head taller than themselves", moving the current project and the RPP towards a new, future form. The implications for centring praxis are both epistemological and methodological, extending far beyond reductionist accounts of accommodating or negotiating institutional challenges, and bringing into light the hidden labor of practitioners who enliven the designers' innovations. The epistemological shift involved moving away from centring materiality of the exhibit and intentionality of designers to more deeply considering *who* takes part in design, especially given that it is the labor of the facilitators that enlivens the exhibit. From an axiological perspective, one could then reframe the iterative core of DBR in RPPs as an ongoing quest to reflect upon our own roles as researchers and designers in contexts of praxis, by continually seeking to center the hidden complexities of the *labor* that constitutes praxis rather than solely foregrounding designers' intentionalities.

References

Ames, M. G. (2019). *The charisma machine: The life, death, and legacy of one laptop per child*. MIT Press.

Ash, D. B., Lombana, J., & Alcala, L. (2012). Changing practices, changing identities as museum educators: From didactic telling to scaffolding in the zpd. In E. Davidsson & A. Jakobsson (Eds.), *Understanding interactions at science centers and museums: Approaching sociocultural perspectives* (pp. 23–44). SensePublishers.

Carlone, H. B., & Webb, S. M. (2006). On (not) overcoming our history of hierarchy: Complexities of university/school collaboration. *Science Education*, *90*(3), 544–568. https://doi.org/10.1002/sce.20123

DiSessa, A. A., & Cobb, P. (2004). Ontological innovation and the role of theory in design experiments. *The Journal of the Learning Sciences*, *13*(1), 77–103. https://doi.org/10.1207/s15327809jls1301

Gutiérrez, K. D., & Vossoughi, S. (2010). Lifting off the ground to return anew: Mediated praxis, transformative learning, and social design experiments. *Journal of Teacher Education*, *61*(1–2), 100–117.

Horn, M. S., Solovey, E. T., Crouser, R. J., & Jacob, R. J. (2009, April). Comparing the use of tangible and graphical programming languages for informal science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 975-984).

Ji, J., Anderson, D., & Wu, X. (2016). Motivational factors in career decisions made by Chinese science museum educators. *Adult Education Quarterly*, *66*(1), 21–38.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. In *Learning in Doing*. Cambridge University Press.

Marton, F., & Booth, S. (1996). The learner's experience of learning. *The handbook of education and human development*, 534-564.

McKenney, S., & Reeves, T. C. (2012). *Conducting educational design research*. Taylor and Francis.

Moore, S., Roche, J., Bell, L., & Neenan, E. E. (2020). Supporting facilitators of maker activities through reflective practice. *Journal of Museum Education*, *45*(1), 99–107.

Ozacar, B. H., Hladik, S., Shanahan, M. C., & Sengupta, P. (2020). Centering and decentering participation in public computing through co-operative action. Proceedings of the International Conference of the Learning Sciences.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books.

Penuel, W. R., Allen, A.-R., Coburn, C. E., & Farrell, C. (2015) Conceptualizing research-practice partnerships as joint work at boundaries. *Journal of Education for Students Placed at Risk, 20*(1-2), 182-197.

Reynolds, C. W. (1987). Flocks, herds and schools: A distributed behavioral model. *SIGGRAPH Comput. Graph.*, *21*(4), 25–34. https://doi.org/10.1145/37402.37406

Rosner, D. K. (2018). *Critical fabulations: Reworking the methods and margins of design.* MIT Press.

Schön, D. A. (1983). *The reflective practitioner: How professionals think in action*. Basic Books.

Sengupta, P., Dickes, A., & Farris, A. V. (2021). *Voicing code in STEM: A dialogical imagination*. MIT Press.

Sengupta, P., & Shanahan, M.-C. (2017). Boundary play and pivots in public computation: New directions in STEM education. *International Journal of Engineering Education*, *33*(3), 1124–1134.

Star, S. L., & Ruhleder, K. (1996). Steps toward an ecology of infrastructure: Design and access for large information spaces. *Information Systems Research*, *7*(1), 111–134.

Thorne, S., Kirkham, S. R., & MacDonald-Emes, J. (1997). Interpretive description: A noncategorical qualitative alternative for developing nursing knowledge. *Research in Nursing and Health*, *20*(2), 169–177.

Tran, L. U., Gupta, P., & Bader, D. (2019). Redefining professional learning for museum education. *Journal of Museum Education*, *44*(2), 135–146. https://doi.org/10.1080/10598650.2019.1586192

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Proposing a Framework for Analyzing Metadiscourse in Dialogic Science Classrooms

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Abstract: Classroom discussions have become a centerpiece of reform efforts in science classrooms, yet there are recurring challenges to understanding how teachers and students engage, and make sense of classroom discussion to support knowledge building. In this paper, we present a framework for analyzing the metadiscourse (MD) used during discussions, building on prior work on the use of MD in academic writing. We argue here that while other analytic systems for classroom dialogue rely primarily on a speaker's *propositional content*, the speaker's use of MD can also shed light on how teachers and students are positioning themselves and their ideas during discussion. We provide an overview of our framework, illustrate its application, and discuss implications for analyzing discussions in K-12 classrooms.

Challenges in the analysis of verbal discourse in science classrooms

In the United States and elsewhere, there has been an increasing focus on moving away from monologic, didactic science instruction and towards co-construction and knowledge building through classroom dialogue (e.g. Berland et al., 2016). In order to apprentice students into disciplinary practice, classroom talk must reflect the dialogic, interactive, and social work that scientific knowledge building requires. Researchers utilizing frame, conversation, and interaction analysis to analyze discussions point out that teachers and students interpret and engage in meaning-making talk differently, and that these differences directly influence students' participation in disciplinary practices (e.g. Russ, 2018). This body of work has revealed several challenges to understanding what it is that's going on when discussions take place during science instruction, especially in regarding students' agency and teacher's authority (e.g. Miller et al., 2018). This prior scholarship suggests that talking past one another, using different resources, epistemic commitments and goals is probably more prevalent than we think. Here, we argue that while metadiscourse (MD) plays a vital role in how teachers and students engage in sensemaking and knowledge building, it is often overlooked in analyses of such talk. We therefore propose an analytical framework for MD that can be applied to talk in highly dialogic science classrooms.

Metadiscourse (MD): Definition and function in written text

The framework we propose builds on existing scholarship in fields of Systemic Functional Linguistics on the use of MD in written text. MD is defined as "the interpersonal resources used to organize a discourse or writer's stance toward either its content or the reader" (Hyland, 2000, p.109). Given our focus on verbal text, our concern is with a *speaker* and their *audience*. In this context, MD is not the "substance" of the ideas that a speaker puts forward, but rather, the language that surrounds it that, intentionally or unintentionally, shapes the audience's sensemaking of the content proposed. Tang (2017) writes that MD "is always present in most conversations...its function is to assist the audience to connect, interpret, organize, and evaluate the content in the talk in a way preferred by the author or aligned with the social conventions and values of the discourse community" (p. 2). Hyland and Tse (2004) argue that MD 1) is distinct from propositional content; 2) refers to those aspects of the text that embody writer-reader interactions; and 3) distinguishes relations which are external to the text from those that are internal. In applying these frameworks to verbal text, we replace the emphasis on *writer* and *readers* with a *speaker* and *their audience*. These 3 principles suggest that in the context of verbal discourse, MD can signal a speaker's attitudes and commitments, and in turn, shape the way that knowledge building unfolds in a science classroom.

Significance: Analyzing the use of metadiscourse (MD) in verbal text

Although there is extant work on the use of MD in written text, research into MD in verbal talk is limited in science education. The exception to this is work by Tang (2017), who proposed an analytic framework based on an analysis of teacher talk in a classroom where content was delivered predominantly through direct instruction. Here, we build on this work and explore how MD is used in dialogic classrooms. Our framework advances methods for analyzing the role of non-propositional content in shaping sensemaking and knowledge building talk, thereby making visible the nuanced ways in which teachers and students co-construct scientific knowledge.

Methodological approach

Selection of classroom episodes for analysis
To develop our framework, we selected four episodes of classroom talk from a 3rd, 5th, and two 6th grade science lessons from reform-oriented curricula that focus on phenomenon-driven inquiry and co-constructing knowledge through discussions (Lawrence Hall of Science, 1993-2016; Kracjik et al, 2013). We selected these episodes because they had been previously identified as discourse that reflected shifts in how teachers and students positioned themselves, their ideas, and their goals (Ko & Elby, 2018; Richards et al., 2020). For each episode, we conducted a turn-by-turn analysis to characterize the MD in teacher and student talk. Four transcripts consisting of 35 minutes of classroom discussion were analyzed to develop this framework.

Development of the analytic scheme
The framework presented here has three levels of codes, *Type*, *Category*, and *Subcategory*. The definitions and examples of these codes were derived from two phases of analysis, described below.

<u>Phase 1: Developing consensus on the Types and Categories of MD (Level I and II)</u>
In the first phase, we used the MD markers identified in the field of Systemic Functional Linguistics (Hyland & Tse, 2004, and recently, Tang, 2017) as provisional codes (Saldaña, 2013). This scheme has 3 levels, moving from most general to most specific: 1) *Type*, 2) *Category*, and 3) *Subcategory* of MD. The authors examined an eight-minute episode from an elementary science classroom to identify potential MD markers, and then coded each marker as an Organizational or Interpretive MD, based on the function of the MD in the context of the whole group discussion. Due to the contingent nature of classroom talk, we referred to at least 5 turns of talk that preceded and followed each turn (Schaffer, 2017) to come to consensus. After exhausting the codes with this data set and reaching consensus on the preliminary definitions, we independently coded ~100 turns of talk and discussed our codes and resolved discrepancies to develop greater consensus around the *Types* of MD and their associated *Categories*. We then independently coded an additional 40 turns of talk; we made note of MD markers that were inconclusive, generated a set of issues that needed to be discussed, and refined the existing code definitions to be more reflective of how MD functions within verbal talk. We also compared our analysis with those MD markers that have been commonly identified in written text (e.g. https://textinspector.com/) in the same eight-minute episode. This comparison revealed that we uncovered a wide range of MD markers that were not identified in the existing literature. In other words, the general frameworks from existing literature could not adequately capture the range of MD used during dialogic whole group discussion. This first phase of analysis generated consensus around the two levels of codes (*Types* and *Categories*) and refined our codes and their definitions to more accurately reflect how MD is used in dialogic conversations in science classrooms.

<u>Phase 2: Developing consensus around Subcategories of MD (Levels III)</u>
In the second phase of analysis, we engaged in axial coding (Saldaña, 2013) to (1) reorganize and extend our existing *Type* and *Category* codes, and (2) reach code and meaning saturation for all *Subcategories* of MD. To do this, we located the turns of talk containing a high density of MD in 4 excerpts from the 4 selected lessons. From there, we sought to identify multiple examples of each *Subcategory* of MD. The axial coding was done independently, so that we could identify discrepancies, make note of questions, and develop a set of criteria for making coding decisions across classroom contexts and content areas. Two or more exemplars for each *Subcategory* in both teacher and student turns of talk were identified. We jointly and independently coded until we reached code saturation, and then coded independently to reach meaning saturation across the 4 excerpts. The axial coding resulted in an expansion of *Subcategories* of MD. Three of Tang's *Subcategories* were eliminated from our framework because we were not able to apply them to our classroom data. Of the 22 *Subcategories*, then, 15 were similar to the subcategories in Tang's framework while seven were new altogether. Finally, we pulled out a subset of *Category* and *Subcategory* codes and organized them as a third Type of MD—*Epistemic MD*, to more prominently feature the role of these types of MD in signaling both what counts as a resource and whose ideas are valued during knowledge-building. In summary, this two-phase process led to a refinement, consolidation and reorganization of pre-existing frameworks for analyzing MD to more closely approximate the use of MD by teachers and students in dialogic classrooms. These two phases of analysis resulted in 3 *Types*, 7 *Categories*, and 22 *Subcategories* of MD markers.

Findings: A framework for analyzing MD in science classroom talk
While the full analytical framework includes definitions of each *Type* and *Category*, describes the function of each *Subcategory*, and provides at least two examples from our data for all 22 possible code combinations, the

limitations of a proposal make presenting the full framework impractical. Therefore, in this section we first provide a summary of the analytical framework showing the 3 *Types*, 7 *Categories*, and 22 *Subcategories* of MD the framework captures (Table 1). We then show an application of the framework on two turns of classroom talk. The conference presentation will include the full analytical framework with definitions, functions, and examples of all the codes, as well as further applications of the framework across more extended excerpts of classroom talk.

Table 1: Summary of analytical framework for MD with 3 *Types*, 7 *Categories*, and 22 *Subcategories*

Types of Metadiscourse and Description	**Organizational MD:** Signals different parts of the talk to guide participants through the (verbal) text. Also signals ways of engaging in conversation.	**Epistemic MD:** Signals the resources recruited (who and what) in the knowledge building process.	**Interpretive MD:** Signals an expectation, attitude, or point of view toward the propositional content.
Categories (7) and Subcategories (22)	Text Connective: Topicalizer, Sequencer, Revoice/Restate Activity Connective: Actionizer, Stringer Frame Marker: Earlier Conversation, Future Conversation, Transition, Previous Activity, External Activity	Evidentials: Sensory Experience, Material Stuff, Scientists'/Canonical Knowledge, Personal Beliefs/ Ideas Agents: Collaborative/Collective, Individual	Engagement: Participation, Translation Stance: Qualifier, Importance, Challenge, Emoter

An illustration of our coding scheme in action

To illustrate our analytic flow, we use two turns of talk from our data to highlight instances of MD evident in the talk and reason through their functions. Henceforth, we use the following conventions to highlight the MD markers in each turn of talk: Organizational MD is **bolded** text, Epistemic MD is *italicized* text, and Interpretive MD is underlined text. We then elaborate on the rationale that warrants the codes we applied at each level.

Table 2: *Types*, *Categories*, and *Subcategories* of MD in two turns of talk from an EL science lesson

Turn of talk (Organizational, *Epistemic*, Interpretive)	**MD markers identified**	**Type**	**Category**	**Subcategory**
Teacher: Shhh, listen. Listen to **his ideas**, okay?	Shhh	Interpretive	Engagement	Participation
	his ideas	Organizational	Text Connective	Topicalizer
Student (Leo): Ricky, *he says*, "oh maybe they um, or maybe' *they put* like um batteries or energy *so it could* move up or down.	he says	Epistemic	Evidentials	Personal Beliefs/Ideas
	maybe; maybe	Interpretive	Stance	Qualifier (Hedge)
	they put	Epistemic	Evidentials	Sensory Experience
	so it could	Epistemic	Evidentials	Material Stuff

In these two turns of talk, we identified six instances of MD being used—two instances by the teacher and four others by a student (Leo). Prior to these turns, one student had put forth the idea that batteries or energy are what cause the red liquid to move inside a thermometer. As the conversation continued, the teacher uses MD to first signal how she wants the students to engage in the discussion—by being quiet (Shhh), and focused on Leo's proposal (**his ideas**). The first instance serves an interpretive purpose, because the MD marker indicates the forms of participation that are encouraged by the teacher at that moment, while the second instance serves an organizational one, because Leo's ideas now have become the focus of attention. In the next turn, Leo uses MD to make references to another student's (Ricky's) earlier idea (*he says*), indicating a sense of uncertainty about the idea (maybe; maybe). The MD *They put* indicates someone's tactile experience, and, *so it could* indicates how the source of energy (batteries or energy) functions (by moving the red liquid up or down). Three of these instances of MD signal the resources that Leo is building off of—Ricky's idea, the tactile experience of using a battery—to support a claim about why the liquid moves up and down in the thermometer.

Conclusion and implications: How this framework can be taken up to understand and support sense-making in science classrooms

In this study, we proposed a framework for analyzing MD markers in whole group discussions, with the goal of bolstering existing methods for detecting how teachers and students are participating in knowledge-building talk in science classrooms. While there are numerous frameworks that have been developed for analyzing science classroom talk, these existing systems rely heavily on the propositional content that is put forth by a speaker to make inferences about how teachers and students are framing the classroom activity. Yet we argue that MD also plays an important role in classroom talk and that we need to include it in the analyses of classroom discourse. MD markers can help participants determine, among other things, what propositional content to focus on, how to engage with each other and the propositional content, and what resources are at play in the knowledge-building talk. And although MD markers have been intensively studied and supported in written text, there have been few studies that have systematically identified MD in dialogic discussions, or considered the role of MD relative to existing discourse analysis frameworks. We see the analysis of MD markers as complementery to coding done at the level of consecutive turns or episodes, which together can lead to increasingly thick descriptions of classroom events. With additional applications and refinement, we see our framework as a rich contribution to analytic methods that can be used to elucidate how teachers and students take up the work of co-constructing knowledge.

References

Berland, L. K., Schwarz, C. V., Krist, C., Kenyon, L., Lo, A. S., & Reiser, B. J. (2016). Epistemologies in practice: Making scientific practices meaningful for students. *Journal of Research in Science Teaching*, *53*(7), 1082-1112.

Hyland, K. (2000). *Disciplinary discourses: Social interactions in academic writing.* London, England: Longman.

Hyland, K. (2004). Disciplinary interactions: Metadiscourse in L2 postgraduate writing. *Journal of Second Language Writing*, *13*(2), 133–151.

Hyland, K., & Tse, P. (2004). Metadiscourse in academic writing: A reappraisal. *Applied Linguistics*, *25*(2), 156–177.

Ko. M. & Elby, A (2018). Talking Past One Another: Looking for signs of Conversational Mismatch in One 6th grade Science Classroom In Kay, J. and Luckin, R. (Eds.). Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018, Volume 3, pg. 1477-1478. London, UK: International Society of the Learning Sciences.

Krajcik, J. S., Reiser, B. J., Sutherland, L. M. & Fortus, D., (2013) IQWST: Investigating and questioning our world through science and technology. Middle School Science Curriculum Materials. Sangari Active Science: Greenwich, CT.

Lawrence Hall of Science. (1998–2016). Full-option science system (FOSS). Nashua, NH: Delta Education.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the Next Generation Science Standards. *Journal of Research in Science Teaching*, *55*(7), 1053-1075.

Richards, J., Elby, A., Luna, M. J., Robertson, A., Levin, D., & Nyeggen, C. (2020). Reframing the
responsiveness challenge: A framing-anchored explanatory framework to account for irregularity in novice teachers' attention and responsiveness to student thinking. *Cognition and Instruction,* 38(2), 116-152.

Russ, R. S. (2018). Characterizing teacher attention to student thinking: A role for epistemological messages. *Journal of Research in Science Teaching*, *55*(1), 94-120.

Saldaña, J. (2013). *Qualitative data analysis: The coding manual for qualitative researchers.* London: Sage.

Tang, K.-S. (2017). Analyzing teachers' use of metadiscourse: The missing element in classroom discourse analysis. *Science Education*, *101*(4), 548–583.

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Review of Design Assessment in STEM and Design Education

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Abstract: What is assessed drives what is valued, taught, and learned by teachers and students. This paper reviews the approaches proposed for assessing student design (processes and outcomes) in STEM courses to help inform the increasing focus on design in STEM curricula. We began with the goal of reviewing such approaches across 17 prominent journals that address STEM and design education. Database searches resulted in 2101 raw hits and an ultimate sample of 27 articles, predominantly in engineering education. We performed a content analysis to identify key assessment foci. The majority (20) included a focus on performance of the design, and a substantial number included a focus on communication (15) and scoping (11). While less prevalent, divergent thinking (9), creativity (9), convergent thinking (8), and collaboration (8) were also broadly represented. Ethical considerations were not strongly represented in the reviewed assessments, although there were important exceptions.

Introduction

In STEM education, there is increased attention to "design," both as a disciplinary practice and a pedagogical approach. Given the interdisciplinary nature of design, research on design learning and assessment has been conducted in an array of disciplinary journals. Our goal was to identify peer-reviewed articles about design assessment and to analyze how educators assess students' design artifacts and practices in STEM and design education. We explored the following questions: (a) what aspects of the design process and/or outcomes are assessed, (b) what approaches are used to assess design, (c) at what granularity are the assessments conducted, (d) who is involved in the assessment process, and (e) what age groups of students are the focus. To evaluate the status of assessment of design in STEM education, we performed a systematized literature review (Grant & Booth, 2009) and content analysis across seventeen leading journals that address STEM and design education based on Journal Citation Reports (JCR), Scientific Journal Rankings (SJR), and h-index statistics.

Theoretical framing

The structure, content, and scope of assessment drive what is valued, taught, and learned by teachers and students (e.g., Entwhistle & Peterson, 2004; Jürges, Schneider, Senkbeil, & Carstensen, 2012). Because of the increasing role of design in STEM curricula it is therefore of great importance to review the approaches proposed for assessing design given its multifaceted nature. Design educators, recognizing the importance of and the challenges in assessing informed design practices, have developed instruments for assessing students' knowledge of and practices in design (Atman, Chimka, Bursic, & Nachtmann, 1999; Bailey & Szabo, 2007). In design education, assessment of design outcomes (products, artifacts, or systems) is also important. Design outcomes need to achieve high quality while attending to competing criteria and constraints. Purzer et al. (2016) introduce the concept of trade-off value when evaluating student design artifacts. One of the challenges student designers face is balancing competing design criteria such as feasibility and novelty (Oman, Tumer, Wood, & Seepersad, 2012; Shah, Woodward, & Smith, 2013). Studies show that undergraduate engineering students skew toward novelty in their first year in college, while the balance switches toward technical feasibility in the final years (Genco, Hölttä-Otto, & Seepersad, 2012). The purpose of this review is to better understand how assessment practices attend to these multifaceted aspects of design processes and design outcomes.

Methods and search criteria

We bounded our review to articles published between 2002 through August 2018. Given the common use of the terms "design" and "assessment" in research beyond the scope of our study, we identified 17 specific journals as opposed to a broad search within selected databases. We searched across four databases (i.e., ASC, ERC, ERIC, and AA) indexed the 17 specific journals we targeted. We used the following search terms and Boolean operators at the abstract and title level: (Design* OR Ideation OR Creativity) AND (Assess* OR Rubric OR Framework OR (Coding Scheme) OR Measure OR Metric OR Instrument OR Method). This scan resulted in 2101 raw hits across the 17 journals. Our team identified several inclusion criteria in iterative discussions, including the proposition, presentation, or validation of an assessment framework, or sufficient theoretical warranting (a full list of criteria will be included in the journal publication). Articles that straddled the borders of the inclusion criteria were reviewed at the abstract level by the group for a final decision. We then reviewed the main-text of each article and evaluated whether the assessment instruments therein were described in sufficient detail to meet the criteria. The literature search resulted in a sample of 27 articles: 23 from engineering education journals and 4 from a design journal. We performed a content analysis of the final 27 articles to identify key components of assessment.

Results and interpretations

In our inductive coding, categories arose around multiple aspects of design, including: (i) problem scoping, (ii) divergent thinking, (iii) creativity, (iv) design performance and functionality, (v) convergent thinking, (vi) collaboration, and (vii) communication. While these seven categories were generally distinct, the clearest distinctions involved design performance, communication, and collaboration, while the distinction between divergent thinking and creativity was the least clear in many cases. This is complicated by terminology that is often used interchangeably in the literature (e.g., originality and novelty).

Table 1: Coding Results By Article

	Totals/AVG		Acar (2004)	Azmy & Mokhtar (2017)	Bar-Eli (2013)	Bartholomew et al. (2018)	Berry & Carlson (2010)	Charyton & Merrill (2009)	Charyton et al. (2011)	Chiaradia, et al. (2017)	Dancz et al. (2017)	Davis et al. (2002)	Davis et al. (2010)	Demirkan & Afacan (2012)	Guzzomi et al. (2015)	Jaeger & Adair (2015)	Lans & Verkroost (2004)	Mccormack et al. (2015)	Oehlers (2006)	Ozaltin et al.(2015)	Reid & Cooney (2008)	Ringwood et al. (2005)	Sherrett et al. (2013)	Sluis-Thiescheffer et al. (2016)	Steiner et al. (2011)	Sung-Hee et al. (2015)	Thompson et al. (2013)	Watson et al. (2017)	Welch et al. (2009)
Design Focus																													
Scoping	11			1				1	1			1					1	1		1	1		1		1	1			
Divergent Think	9				1			1	1			1				1	1			1				1		1			
Creativity	9							1	1			1		1					1	1		1		1		1			
Convergent Think	8			1				1	1			1					1	1					1			1			
Performance	20			1	1	1		1	1	1	1	1			1	1	1	1	1	1	1	1	1		1	1		1	
Collaboration	8											1	1			1		1			1				1	1			1
Communication	15		1	1			1				1	1	1			1	1	1		1	1				1	1	1		1
Avg/Total Foci	*2.96*		*1*	*4*	*2*	*1*	*1*	*5*	*5*	*1*	*2*	*7*	*2*	*1*	*1*	*4*	*5*	*5*	*2*	*5*	*4*	*2*	*3*	*2*	*4*	*7*	*1*	*1*	*2*
Students																													
K12	1																							1					
Undergraduate	25		1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1	1
Graduate	1									1																			
Evaluators																													
Instructor/TA	25		1	1	1	1		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1		1
Peer	12		1	1			1			1			1		1	1		1			1	1			1	1			
Self	9		1				1					1	1			1		1			1				1	1			
External	9		1			1		1	1	1				1				1		1								1	
Avg/Total Evaluators	*2.04*		*4*	*2*	*1*	*2*	*2*	*2*	*2*	*3*	*1*	*2*	*3*	*2*	*2*	*3*	*1*	*4*	*1*	*2*	*3*	*2*	*1*	*1*	*3*	*3*	*1*	*1*	*1*

Most of the assessment approaches addressed multiple categories (2.96 out of 7 categories on average). Among the 27 articles, the majority (20) included a focus on assessing design performance, and a substantial number included a focus on assessing communication (15) followed by problem scoping (11). While less prevalent, divergent thinking (9), creativity (9), convergent thinking (8), and collaboration (8) were also broadly represented (Table 1). Notably, most articles assessed the performance or function of a final design outcome but the processes of design were not always assessed. We speculate the logistics of assessing a final design are often easier for instructors than assessing intangible or real-time aspects of the design process in the midst of running a class or perhaps the assessment of design processes is done in implicit ways with a formative intent. Undoubtedly, the processes of design are as important as final projects as argued in prior research (see Atman et al., 1999), but we recognize that the pragmatic realities of facilitating and teaching a class may challenge the bandwidth to conduct simultaneous real-time assessments of process. There is work underway to collect real-time process data digitally to automate assessment of process (e.g., Worsley & Blikstein, 2016; Xie et al., 2014), which may change the nature of assessment of design radically in the future, but these approaches are not yet scalable. These digital tools can help complement, extend, or add depth to what is currently feasible.

One major influence on assessment foci are professional engineering organizations, particularly the Accreditation Board for Engineering and Technology (ABET). Within the 2019-20 ABET definition of Engineering Design, we see a strong alignment with the aspects of design highlighted by our coding of the assessments in terms of problem scoping (e.g., identifying opportunities and developing requirements), creativity (e.g., creative decision-making processes), design performance and functionality (e.g., meeting needs and specifications), ideation (e.g., generating multiple solutions), convergent thinking (e.g., evaluating solutions against requirements). Collaboration (e.g., ability to function effectively on a team) and communication (e.g., ability to communicate ideas and technical information effectively with a range of audiences) are key ideas represented in the specified ABET criteria for student outcomes. Interestingly, creativity is not specified within the 2019-20 student outcome criteria, although it is included within the definition of engineering design. That said, historically creativity has been even less represented in the criteria and definitions.

Aspects of ABET that are less extensively represented in the reviewed assessments include conducting experiments, applying science and mathematics, and information literacy/life-long learning. Engineering ethics and ethical considerations seem to be the very least represented, although there are exceptions. Berry (2010), for example, focused heavily in their approach to Calibrated Peer Review on having the students write a social impact document using the IEEE Code of Ethics as the rubric. Other assessments may include some aspect of attending to ethical issues as part of the task but not as a major aspect of the assessment rubrics themselves. While beyond the scope of this review, we find such omissions troubling given the very real impacts design can have on people's lives. For example, designers can face heavy ideological and ethical dilemmas when engineering products that are used in warfare (Philip, Gupta, Elby, & Turpen, 2018) or to marginalize specific populations (Chellew, 2019). This seems to be an area for future growth in the assessments. While not an assessment of students' actual designs, the approach outlined by Christensen, Hjorth, Iversen, and Blikstein (2016) assesses students' stance toward inquiry in a way that attends to the complexity inherent in wicked problems in terms of social and ethical dimensions among others.

In terms of how assessment is conceptualized and operationalized, most articles described summative rather than formative assessment procedures. We surmise this stems from a combination of formative assessments often being less formal (e.g., undocumented verbal commentary from an instructor circulating among students), traditional preferences to summative assessments in STEM education, and an interest in supporting accreditation processes (e.g., ABET).

For demographics, we anticipated undergraduate education would be the predominant focus of the assessments but were surprised by the limited focus at the K-12 level given the increasing interest and emphasis in K-12 education on design, design thinking, and engineering. There are many excellent studies of K-12 student design that are not focused on "assessment" or where design-based learning uses design as a pedagogy and hence their assessment focuses on student learning of science concepts (e.g., Crismond, 2001; Hmelo, Holton, Kolodner, 2000; Kolodner et al., 2003.). In terms of evaluators, there was the integration of multiple types of assessor (2.04 on average). Instructors and TAs were involved in almost all of the assessments (25 of 27), but most (18) of the assessments also involved other people including peers (12), self-assessments (9), and external disciplinary experts (9).

In terms of approach, the assessments primarily depend on the application of rubrics. Some articles do not provide enough information about their rubrics to be reliably applied by others, but many of the articles engage in a high degree of granularity with highly descriptive rubrics. Some of the assessments leverage complex approaches and mathematics within the assessment to create a final numerical score with great precision, but this apparent precision is necessarily limited because the input numbers are based, at times, on highly subjective and underspecified criteria. Another group of the assessments are more subjective in their orientation from beginning to end. Sometimes this has the advantage of not artificially systematizing the process, but greater specification within the rubric criteria would likely most improve the rigor and reliability of the assessment processes we reviewed.

Educational importance of the study

The approaches used to assess design varied based on area of focus but mostly targeted undergraduate education. Among the 27 articles, the majority included a focus on performance assessment, and a substantial number included a focus on communication and problem scoping. While not as prevalent, divergent thinking, creativity, convergent thinking, and collaboration were also broadly represented. Engineering ethics and ethical considerations seem to be the very least represented, although there are exceptions. What is assessed greatly influences what is taught and learned, and careful attention to these less represented aspects of design will therefore be an important area for future development for assessment as design takes on an increasingly central role in STEM education.

References

Acar, B. S. (2004). Analysis of an assessment method for problem-based learning. *European Journal of Engineering Education, 29*(2), 231–240. https://doi.org/10.1080/0304379032000157213

Atman, C. J., Chimka, J. R., Bursic, K. M., & Nachtmann, H. L. (1999). A comparison of freshman and senior engineering design processes. *Design studies, 20*(2), 131-152.

Azmy, A., & Mokhtar, H. (2017). A Project-Based Framework for Teaching and Assessment of Design Modules. *International Journal of Engineering Education, 33*(2), 629-638.

Bailey, R., & Szabo, Z. (2007). Assessing engineering design process knowledge. International Journal of Engineering Education, 22(3), 508.

Berry, F. C., & Carlson, P. A. (2010). Assessing engineering design experiences using calibrated peer review. *International Journal of Engineering Education, 26*(6), 1503-1507.

Charyton, C., & Merrill, J. A. (2009). Assessing general creativity and creative engineering design in first year engineering students. *Journal of Engineering Education, 98*(2), 145-156. https://doi.org/10.1002/j.2168-9830.2009.tb01013.x

Chellew, C. (2019). Defending Suburbia. *Canadian Journal of Urban Research*, *28*(1), 19-33.

Christensen, K. S., Hjorth, M., Iversen, O. S., & Blikstein, P. (2016). Towards a formal assessment of design literacy: Analyzing K-12 students' stance towards inquiry. *Design Studies*, *46*, 125-151.

Davis, D. C., Gentili, K. L., Trevisan, M. S., & Calkins, D. E. (2002). Engineering Design Assessment Processes and Scoring Scales for Program Improvement and Accountability. *Journal of Engineering Education*, *91*(2), 211-221.

Entwistle, N., & Peterson, E. (2004). Conceptions of learning and knowledge in higher education: Relationships with study behaviour and influences of learning environments. *International Journal of Educational Resesearch, 41*(6), 407–428. https://doi.org/10.1016/j.ijer.2005.08.009

Genco, N., Hölttä-Otto, K., & Seepersad, C. C. (2012). An experimental investigation of the innovation capabilities of undergraduate engineering students. *Journal of Engineering Education*, *101*(1), 60-81.

Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information & Libraries Journal, 26*(2), 91-108. https://doi.org/10.1111/j.1471-1842.2009.00848.x

Hmelo, C.E., Holton, D.L., Kolodner, J.L. (2000). Designing to Learn about Complex Systems. Journal of the Learning Sciences, Vol. 9, No. 3, pp. 247 - 298.

Jürges, H., Schneider, K., Senkbeil, M., & Carstensen, C. H. (2012). Assessment drives learning: The effect of central exit exams on curricular knowledge and mathematical literacy. *Economics of Education Review*, *31*(1), 56-65. https://doi.org/10.1016/j.econedurev.2011.08.007

Kolodner, J.L., Camp, P.J., Crismond D., Fasse, B., Gray, J., Holbrook, J., Puntembakar, S., Ryan, M. (2003). Problem-Based Learning Meets Case-Based Reasoning in the Middle-School Science Classroom: Putting Learning by Design™ into Practice. Journal of the Learning Sciences, Vol.12, No 4, pp. 495 - 548.

Oman, S. K., Tumer, I. Y., Wood, K., & Seepersad, C. (2012). A comparison of creativity and innovation metrics and sample validation through in-class design projects. Research in Engineering Design, 24(1), 65–92.

Philip, T. M., Gupta, A., Elby, A., & Turpen, C. (2018). Why ideology matters for learning: A case of ideological convergence in an engineering ethics classroom discussion on drone warfare. *Journal of the Learning Sciences*, 1–41.

Purzer, S., Fila, N., & Nataraja, K. (2016). Evaluation of current assessment methods in engineering entrepreneurship education, *Advances in Engineering Education, 5*(1), 1-27.

Shah, J. J., Woodward, J., & Smith, S. M. (2013). Applied Tests of Design Skills—Part II: Visual Thinking. *Journal of Mechanical Design*, *135*(7), 071004. https://doi.org/10.1115/1.4024228

Worsley, M., & Blikstein, P. (2016). Reasoning Strategies in the Context of Engineering Design with Everyday Materials. *Journal of Pre-College Engineering Education Research, 6(*2), 57–74.

Xie, C., Zhang, Z., Nourian, S., Pallant, A., & Hazzard, E. (2014). A time series analysis method for assessing engineering design processes using a CAD tool. *International Journal of Engineering Education*, *30*(1), 218-230.

Contributions of a Situative Perspective on Motivation in the Learning Sciences: Theorizing Motivation for Youth Voice and Equity

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Abstract: While productive disciplinary engagement has remained a key construct in the learning sciences, there has been limited exploration regarding what motivates learning activities. Accordingly, little is understood about purportedly "disengaged" youth who do not readily take up normative practices in learning environments designed with productive disciplinary engagement as a goal. In an attempt to bridge this gap and promote reflection of "disengaged" youth, we argue for embracing the more recent situative perspective on motivation. Further, we propose that tensions between authority and accountability in science education be examined in relation to power, arguing that connecting the situative perspective on motivation should be paired with a youth voice lens. Future directions for research are discussed.

Introduction

Recent research in the learning sciences has highlighted the importance of understanding learners' productive disciplinary engagement as intertwined with questions of identity, power, and positionality (e.g. Adams-Wiggins, 2020; Agarwal & Sengupta-Irvin, 2019; Carlone, 2017; Nasir, 2011). Similarly, some motivation researchers have begun to take up the call for attention to power and positionality. This has been referred to as a *situative perspective on motivation* and it has been outlined using arguments directly from the learning sciences (Nolen & Ward, 2008; Nolen et al., 2015; Nolen, 2020a, 2020b). In the current paper, we interrogate points of convergence and divergence in the situative perspective on motivation and perspectives in the learning sciences that aim to address similar sets of phenomena, namely the relationship between identity and productive disciplinary engagement. We do this specifically with the goal of understanding how motivation can be explored within the learning sciences and developing additional tools to understand youth experiences in learning environments. Motivation is understood as conceptually related to cognitive engagement, but is meaningfully separable: high-quality motivation is insufficient without opportunities for engagement and opportunities to engage may not be taken up by a learner who is not motivated to engage (Blumenfeld et al., 2005). Accordingly, we rely on science education as a context for this discussion and focus on the experiences of youth seen as "disengaged", "unmotivated", or "disidentified". The present paper is intended to promote reflection on the experiences of youth who experience disconnection from learning environments designed to promote learners' productive disciplinary engagement and the youth whose access to science identities is questioned by other people in the classroom itself (Adams-Wiggins et al., 2020; Tierney, 2020). The following sections of this paper offer an introductory situative motivational analysis of the role of youth voice, specifically in connection with a key feature of learning environments: disciplinary authority.

We propose that a situative perspective on motivation provides multiple benefits to those in the learning sciences who want to understand the role of learners' interests, values, identities, and self-perceptions. First, by applying a situative theory of motivation to understanding learning in reform-oriented learning environments, we gain insights into an under-addressed flipside of productive disciplinary engagement in reform-oriented learning environments. In reform-oriented science learning environments, engagement in scientific practices like engaging in argument from evidence and constructing explanations become an important priority (NRC, 2012). While the learning sciences as a field is indeed defined by a focus on "explaining learning" (Kolodner, 2004), we argue that to explain learning we also need to better understand what is happening for youth in reform-oriented contexts who do not necessarily "jump on board" with these curricula and reflect resistance or what researchers typically understand as "low-quality motivation" or "low levels of engagement". In a benefit related to our concern with explaining and improving the experiences of youth who do not readily embody expected forms of engagement in reform-oriented learning environments, the situative perspective on motivation explicitly focuses on questions of power and positionality. A key part of improving these youths' experiences is rejecting deficit perspectives: deficit perspectives propose cultural deficiencies as an explanation for youth of color's behavior in school and promote individualist solutions to promote academic achievement (Valencia, 1997). As an alternative to deficit perspectives, recent arguments from Agarwal and Sengupta-Irvin (2019), Bang (2012), and McKinney de Royston and Sengupta-Irvin (2019) highlight how engagement, motivation, and identification with science as a discipline cannot be separated from the broader context of power relations in a given society. Considering the matter of broader power relations, youths' own perspectives are often missing from discussions of how to best facilitate learning; this is in tension with the goal of ensuring critiques of claims and accountability to disciplinary norms are present in science classrooms, where youth are asked to think like scientists (Engle & Conant, 2002; Ford, 2008).

Redefining labels: "Unmotivated" and "disengaged"

Before moving forward, we want to name limits of language around youth who are not participating in the ways we wish to see them participate. Typically, students are assigned labels such as "unmotivated" and "disengaged". On a larger scale, youth can then be given labels such as "at-risk" (Tierney, 2018). However, scholars have shown the ways in which definitions of success are created and perpetuated in schools (Baines, 2014; McDermott et al., 2006; Willis, 1981). These studies show how the definitions of success are embedded in the contexts and structures of the schools in which they exist; definitions of success do not exist in a vacuum. When considering students who are labeled as "unmotivated", "disengaged," or alienated in school (Dean, 1961; Galbo, 1980), students who are academically unsuccessful, students defined as "at-risk" (be it due to failing grades, drug use, etc.) (Vadeboncoeur & Portes, 2002), and students who are marginalized and disenfranchised (te Riele, 2006), it is important to contextualize these students' motivation and engagement within the specific school and classroom contexts in which this occurs. We approach our work recognizing the pervasive challenge of negative or outsider labels such as "at-risk", "unmotivated", and "disengaged". What often becomes deemphasized with these labels is the valued practices from which youth are "disengaging". Youth are "disengaged" and "unmotivated" for the prioritized tasks teachers present and youth are "at-risk" of not reaching the predetermined goals and definitions of success that exist in schools. However, even in reform-oriented learning environments, which are often student-centered and focused on equitable learning, labels of "disengaged" or "unmotivated" do not automatically lead to an interrogation of the tasks and communities youth are "disengaging" from to understand why and how to improve them. Instead, these labels become linked to the youth themselves, where, at best, youth are provided different learning environments or additional resources and, at worst, are discarded or fully assigned the onus of change (Raywid, 1999; te Riele, 2007; Tierney, 2018; Vadeboncoeur & Portes, 2002).

The relevance of a situative view on motivation in the learning sciences: Extending perspectives on disciplinary authority

Situative perspectives on motivation reconceptualize context such that individuals and contexts are not split in a dualistic fashion; further, identity and forms of participation are key components in any situative account of motivation (Nolen et al., 2015). Sociocultural perspectives on learning and participation, prevalent within the learning sciences as a field, explore the ways that learning and development are created through interactions between individuals and the contexts in which individuals participate (Wenger, 1998). Similarly, identity is not just an internal construct, but something created as individuals participate in the world. Within the learning sciences, engagement has often been used as a placeholder for motivation, a way to understand why individuals participate the way they do (Nasir & Hand, 2008; Nolen, Ward, & Horn, 2011). One result of focusing on a sociocultural definition of engagement is that it examines the processes that occur between individuals and their environments and not just processes that exist within individuals' heads, as is historically the case for motivation literature. In that way, a learning sciences perspective is that to increase engagement, educators should redesign the learning environment to better support engagement. Engagement is not owned solely by the individuals who are seen as disengaged.

Encouraging youth to think like scientists often produces unbalanced uptake of normative scientific practices among youth within a classroom, with those who successfully take up normative scientific practices acquiring *authority* and *ownership of ideas* as their perspectives are validated by teachers and peers (Cornelius & Herrenkohl, 2004). Yet, the youth we prioritize in the present discussion may not experience a sense of ownership or authority, as authority is itself negotiated on the basis of more than just correctness of ideas (Engle et al., 2014). We propose that a situative motivation perspective explicitly incorporating a youth voice lens would enable deepened investigation into how "unmotivated"/"disengaged" students see authority and accountability operating in their learning environments. A situative motivation perspective applying the lens of youth voice would consider these youths own pre-existing interests, goals, values, and expectations as relevant to how these youth negotiate opportunities for participation and whether they see authority as possible and worthwhile given their understanding of who in the classroom actually is positioned as sufficiently accountable to disciplinary norms as authority is negotiated. Further, in order to understand the conditions under which youth will see developing their own disciplinary as both possible and worth their time, we propose that a situative motivation perspective prioritizing youth voice should ask questions about how relevant curricular content is to the lives of "unmotivated"/"disengaged" students. Recent research related to constructs like critical science agency has already begun to consider this matter, but research on motivation in the learning sciences should address this directly, as well.

Conclusions

In sum, a synthesis of recent equity-oriented perspectives on productive disciplinary engagement with existing situative perspectives on motivation suggests an importance of youth voice in conceptualizing motivation in the learning sciences. Addressing the question of situated motivation in learning environments from a youth voice lens can provide important insights that should be integrated into the design process, ensuring these youth are not relegated to invisibility in the learning sciences literature. We argue that both educational psychology and the learning sciences stand to benefit from further elaborating the situative perspective on motivation through a youth voice lens. Further engagement with educational psychology's situative perspective on motivation can offer insights into the learning of youth who do not readily take up designers and teachers' intended forms of participation in reform-oriented learning environments; this contribution will be enhanced by an emphasis on youth voice. The situative perspective on motivation could be a powerful tool for understanding how individual youths' understandings interface with prescribed forms of participation in the activity systems where learning is intended to happen. A situative perspective oriented toward youth voice would intentionally examine youths' resistance and frustrations in addition to productive disciplinary engagement, seeking to understand what provides a sense of ownership and authority for youth on the margins of a science community. Recent research in inquiry science classrooms has already highlighted the unexpected ways that small group collaboration common in inquiry-based science classrooms can involve questioning competence and involves some youth deferring to peers perceived as highly competent rather than cognitively engaging (Adams-Wiggins et al., 2020). These kinds of hurdles to productive disciplinary engagement and identity-in-practice may not be visible in observational research unless verbally recognized by the youth during group talk. More studies are needed to explain the relationship between individual-level meaning-making about group-level activity and forms of engagement youth pursue in the classroom.

In line with relational and practice-oriented perspectives on identity typical in the learning sciences, a situative perspective on motivation could serve as an analytical tool for examining relationships between individual and group level processes: while traditional theories of motivation generally retain a split between the social and the cognitive, a situative perspective leaves room for understanding not only youths' *actions* as forms of engagement, but also youths' contextualized intentions, goal directedness, values, and construals regarding activity in the learning environment as important contributors to youths' pursuit of further forms of participation. Doing so, we aim to foster a conversation regarding how to both deepen the situative perspective on motivation in light of advances from learning sciences theory and empirical research as well as maintain an equity-oriented lens on learning to better promote the interests of youth who are often understood as "disengaged", "unmotivated", or "disidentified" (te Riele, 2007). We hope that by exploring situated motivation within the context of theories from the Learning Sciences that we can better attune to youths' motivations, specifically youth who are not motivated to complete situated tasks or participate in situated communities. We believe this information will support the iterative design of reform-oriented learning environments, while contributing to conversations around motivation and engagement within the Learning Sciences.

References

Adams-Wiggins, K. R. (2020). Whose meanings belong?: Marginality and the role of microexclusions in middle school inquiry science. *Learning, Culture and Social Interaction*, *24*, 100353. https://doi.org/-10.1016/j.lcsi.2019.100353

Adams-Wiggins, K. R., Myers, M. N., & Dancis, J. S. (2020). Negotiating status hierarchies in middle school inquiry science: Implications for marginal non-participation. *Instructional Science*, *48*, 427–451. https://doi.org/10.1007/s11251-020-09514-5

Agarwal, P., & Sengupta-Irving, T. (2019). Integrating power to advance the study of connective and productive disciplinary engagement in mathematics and science. *Cognition and Instruction*, *0*(0), 1–18. https://doi.org/10.1080/07370008.2019.1624544

Baines, A. (2014). *(Un)learning disability: Recognizing and changing restrictive views of student ability*. New York: Teachers College Press.

Blumenfeld, P. C., Kempler, T. M., & Krajcik, J. S. (2005). Motivation and cognitive engagement in learning environments. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 475–488). Cambridge University Press. https://doi.org/10.1017/CBO9780511816833.029

Cornelius, L. L., & Herrenkohl, L. R. (2004). Power in the classroom: How the classroom environment shapes students' relationships with each other and with concepts. *Cognition and Instruction*, *22*(4), 467–498.
Dean, D. G. (1961). Alienation: Its meaning and measurement. *American Sociological Review, 26,* 753–758.
Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399–483.
Engle, R. A., Langer-Osuna, J. M., & Royston, M. M. de. (2014). Toward a model of influence in persuasive discussions: Negotiating quality, authority, privilege, and access within a student-led argument. *Journal of the Learning Sciences*, *23*(2), 245–268. https://doi.org/10.1080/10508406.2014.883979
Ford, M. (2008). Disciplinary authority and accountability in scientific practice and learning. *Science Education*, *92*(3), 404–423. https://doi.org/10.1002/sce.20263
Galbo, J. J. (1980). It bears repeating: Adolescent alienation in secondary schools: A literature review. *High School Journal, 64*(1), 26–31.
Kolodner, J.L. (2004). The learning sciences: Past, present, and future. *Educational Technology: The Magazine for Managers of Change in Education, 44*(3), 37-42.
McDermott, R., Goldman, S., & Varenne, H. (2006). The cultural work of learning disabilities. *Educational Researcher, 35*(6), 12-17.
Nasir, N. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *Journal of the Learning Sciences, 17*(2), 143-179.
National Research Council (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas.* Committee on a Conceptual Framework for New K-12 Science Education Standards. Board on Science Education, Division of Behavioral and Social Sciences and Education. Washington, D.C.: The National Academies Press.
Nolen, S. B. (2020a). A situative turn in the conversation on motivation theories. *Contemporary Educational Psychology*, 101866. https://doi.org/10.1016/j.cedpsych.2020.101866
Nolen, S. B. (2020b). Challenging research norms in educational psychology. *Educational Psychologist*, *55*(4), 267–272. https://doi.org/10.1080/00461520.2020.1810043
Nolen, S. B., & Ward, C. J. (2008). Sociocultural and situative approaches to studying motivation. In *Advances in Motivation and Achievement* (Vol. 15, pp. 425–460). https://doi.org/10.1016/S0749-7423(08)150130
Nolen, S. B., Ward, C. J., & Horn, I. S. (2011). Motivation, engagement, and identity: Opening a conversation. In D. McInerney, R. Walker & G. A. D. Liem (Eds.), *Sociocultural theories of learning and motivation: looking back, looking forward*. Greenwich, CT: Information Age Press.
Raywid, M. (1999). History and issues of alternative schools. *Education Digest, 64*(9), 47-51.
Royston, M. M. de, & Sengupta-Irving, T. (2019). Another step forward: Engaging the political in learning. *Cognition and Instruction*, *37*(3), 277-284. https://doi.org/10.1080/07370008.2019.1624552
te Riele, K. (2006). Youth "At Risk": Further marginalizing the marginalized? *Journal of Education Policy, 21*(2), 129-145.
te Riele, K. (2007). Educational alternatives for marginalised youth. *The Australian Educational Researcher, 34*(3), 53-68.
Tierney, G. (2018). Alternative schools in the United States: How history, policy, and definitions of success define alternative schools and the youth who attend them. In McCluskey, G. & Mills, M. (Eds.) *International perspectives on alternative education: Policy and practice.* Institute of Education (IOE) Press, London.
Tierney, G. (2020). Ideational Resources and Alternative Definitions of Success: Reorienting to Education and Developing Identities in an Alternative High School. *The High School Journal*, *103*(4), 241–261. https://doi.org/10.1353/hsj.2020.0015
Vadeboncoeur, J. A. & Portes, P. R. (2002). Students "at risk": Exploring identity from a sociocultural perspective. In D. M. McInerney & S. Van Etten (Eds.), Research on sociocultural influences on motivation and learning, Vol. 2 (pp. 89-128). Greenwich, CT: Information Age Publishing.
Valencia, R. R. (1997). *The Evolution of Deficit Thinking: Educational Thought and Practice. The Stanford Series on Education and Public Policy.*
Wenger, E. (1999). *Communities of Practice: Learning, Meaning, and Identity*. Cambridge University Press.
Willis, P. (1981). *Learning to labor: How working class kids get working class jobs*. New York: Columbia University Press.

Investigating the Nature of Learners' Feedback Seeking Actions and its Role in the Development of Representational Competence

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Abstract: Feedback seeking actions are learner initiated dialogic actions aimed at attaining learning goals during an instructional activity. Nature of these actions are complex during representational problem solving as learners have to use or generate multiple representations for the purpose of seeking feedback. Our focus contrasts with the predominant approaches to develop learners' feedback and representational competences as they are unsustainable and undermine the need to develop learners' agency alongside those competences. Currently the question of under what conditions do individuals proactively seek feedback or when and how such actions contribute to specific learning is being investigated primarily in organizational studies. Therefore drawing from these studies, we adapt a well-established cost-value framework of feedback seeking by aligning it with the cultural historical activity theory. We then use this framework to examine how instructional conditions influence learners' feedback seeking actions and the role of such actions in developing their representational competence.

Rationale

Feedback in education is largely viewed as a teacher driven practice involving one-way transmission of performance related information to learners. However, an individual in an authentic context often faces multiple feedback sources, representations, tools and norms (Blunden, 2010; Nicol, 2013). Hence feedback occurs mostly as a result of dialogue with multiple community sources. And during complex tasks such feedback dialogue presents numerous opportunities for developing one's representational competence (Engeström, 2014; Rau, 2020). Here by representational competence, we refer to a range of abilities to work with multiple representations of real or imaginary phenomena for addressing one's thinking, communication and problem solving needs. The challenge of meeting one's diverse feedback needs or more specifically feedback seeking during complex tasks is manifold. It involves identifying potential feedback sources from the community, eliciting and judging feedback from them, using multiple representations or tools for fluently negotiating one's feedback needs; and responding to the different or sometimes conflicting feedback being received by considering each other's emotional, motivational and identity aspects and all the while being sensitive to both implicit and explicit community norms (Engeström, 2014; Nicol, 2013).

Understanding how employees navigate above challenges to accomplish various professional goals has been a major concern in organizational studies for decades. Meta-analytic review of these studies show that the employees' perceived cost-value estimates predominantly guide their actions such as timing, purpose, mode or amount of feedback seeking (Anseel et al., 2015). However, feedback seeking in these studies is currently conceptualized as preferences or choices for different feedback types and opportunities without examining the actual feedback seeking act. Hence reciprocal and iterative nature of feedback seeking dialogue is unaccounted for both in research and practice. Besides, the focus is also on how specific characteristics of a task, situation, feedback sources and self contribute to one's cost-value perceptions rather than on the complex interaction between them. This has left complexities arising due to cultural diversity in relation to feedback seeking poorly addressed. Our attempt at connecting and addressing these issues from both the domains led to the adaptation of the cost-value framework of feedback seeking using cultural historical activity theory as shown in figure 1.

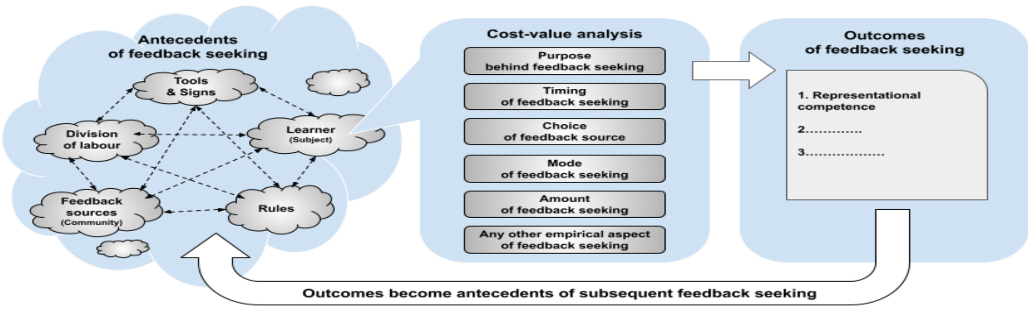

Figure 1. Conceptual framework for studying learners' feedback seeking actions.

As per our adaptation, the interaction between different factors tied to the instructional context referred under 'antecedents of feedback seeking' mediate the learner's (subject) perceptions of cost and value regarding their various feedback seeking actions listed under 'cost-value analysis'. The different factors tied to the instructional context include tools and signs or the representations made of them, both explicit and implicit norms or rules that learner and feedback sources (community) have to account for and the nature of cooperation or the division of labour between them (Engeström, 2014). Further, the interaction between these factors are both reciprocal and iterative at varying timescales and also depend on the outcomes of feedback seeking. However, in this paper we focus on the interactions occurring at a momentary timescale. Regarding outcomes of feedback seeking, while we acknowledge multiple other outcomes, our focus is specifically on learners' representational sensemaking and their use of representations for thinking, problem solving and communication. To clarify, here the terms 'cost' and 'value' are tied to human nature, where value refers to anything that satisfies a human want and cost is what an individual incurs to satisfy one's want. So cost-value perceptions can be of biological or cultural origins with cognitive, emotion, motivation and identity dimensions (Cropanzano & Mitchell, 2005; Engeström, 2014). Overall, our adaptation accounts for previously discussed issues and helps investigate how the interactions between learner and factors tied to instructional and cultural context impact the development of learner agency towards specific competences. Accordingly, our research questions are: How does the interaction between factors tied to the instructional and cultural context influence learners' cost-value perceptions regarding their different feedback seeking actions? and When and how do learners' feedback seeking actions contribute to the development of their representational competence?

Method

We gave students a representational problem pertaining to the synthesis of an important medicinal drug called 'Warfarin' used to treat blood clots and then examined their feedback seeking actions which emerged during the problem solving. The given problem requires students to employ major forms of representational reasoning like analogical reasoning with representations and thought experimentation or mental simulation with representations (Nersessian, 1999) . Participants have to interpret complex symbolic representations of chemical reaction steps, then determine the spatial arrangement of the intermediate structure formed based on their choice of catalyst and finally predict the expected drug's spatial arrangement by applying stereochemistry concepts. Here the expected medicinal drug's spatial arrangement is most crucial as its therapeutic effectiveness is tied to it. Nature and complexity of the given problem meant that participants would experience numerous challenges nudging them to build molecular models or sketch multi perspective diagrams for exchanging feedback.

We adopt a single case-study approach as it helps us answer the explanatory question of how the interactions between learners and the factors tied to the instructional context influence their feedback seeking actions by providing rich descriptions and insightful explanations. Our case consisted of two male undergraduate chemistry students identified through convenience sampling. They had completed an introductory stereochemistry course. The representational problem was an hour long activity designed such that the participants could either work individually or choose to collaborate as and when needed. This ensured that there was no external compulsion on them to collaborate. Data was collected through video recording of the participants' interaction with each other and the researcher. Data analysis was done using a microgenetic method in which high density observations are made spanning the event's timescale (Chinn & Sherin, 2014). To arrive at the key inferences, we employed competitive argumentation with two other colleagues where a sample data was independently analysed to answer specific questions followed by an open invitation to contest or justify each other's answers. The unit of analysis is an episode of proactive feedback seeking by any participant. By proactive we mean that the decisions such as the timing of feedback seeking and others referred to in the framework were all made by the learners themselves. One episode is distinguished from another by considering the change in the purpose for which the feedback is sought. For identifying instructional factors influencing feedback seeking actions, we examined by going back and forth a few seconds before and after the episode.

Findings

For demonstrating framework's analytical affordances, we present here two feedback seeking episodes. One is Episode-A tied to the analogical reasoning and another is Episode-B tied to the thought experimentation. Episode-A emerged when both participants S1 and S2 were mapping 2D representations of chemical reaction steps with 3D molecular models for arriving at the intermediate structure formed by the catalyst. It started with S1's feedback seeking which appeared as a question to S2. All subsequent conversations within this episode were tied to the S1's initial question. Here feedback occurred as a result of dialogue between S1 and S2 with 14 conversational turns lasting for about 3.33 minutes with an utterance count of 79 and 232 words respectively. On S1's choice of feedback source and timing of feedback seeking when Episode-A started, we observed that it was based on S1's estimate of cost and value associated with sourcing of feedback information from peer or researcher as opposed to generating it by drawing from one's own internal resources and/or working with the available tools and representations. Factors contributing to S1's perceived cost-value estimates were identified by accounting for cognitive, emotion, motivation and identity aspects of participants every moment. For instance, consider the following observations before S1 started seeking feedback.

Alternating one's gaze between the reaction mechanism and the molecular model being held in one hand, S1 utters "*correct, correct"* to oneself and continues with alternation of gaze. After a moment, S1 holds his forehead with the other hand and his facial expression changes from one being calm to one indicating discomfort and difficulty. Then while still looking at the reaction mechanism, S1 asks S2 with a fleeting but embarrassed smile "*DPEN* (catalyst) *what does it do bro?*" without looking up at S2. S2 had started humming a tune while examining the reaction mechanism just a few seconds before S1's question. The researcher was busy sorting worksheets. S2 was also seen picking up models and placing them closer to oneself while uttering "*correct".* Immediately after S1's question, S2 responds with a fleeting smile embodied with a sense of pride.

Above observations suggest that the choice of feedback source and timing of feedback seeking is dependent on both the internal state of S1 and when actually feedback availability cues emerge with the feedback sources in an instructional context. Actions of S2 such as self-directed utterances, humming tune and gestures embodied with emotions cued the feedback availability to S1. Also the likely emotions experienced by S1 due to difficulty in solving the task signalled the high cost in continuing to rely upon self as a source of feedback. S1's embarrassed fleeting smile and S2's fleeting smile embodied with pride shows the influence of prevailing cultural norms where ignorance or lack of competence is often treated with shame whereas showcasing one's competence is encouraged with explicit recognition. Hence for S1, to seek feedback from external sources involved the cost of threat to one's identity as it could reveal one's lack of competence to them. This further depends on the S1's perceived relational and identity aspects shared with the feedback sources. Thus seeking external feedback by incurring such costs, points to S1's motivation towards the learning activity.

Similar to Episode-A, the choice of feedback source and the timing of feedback seeking in Episode-B was preceded by the emergence of feedback availability and non-availability cues. But these cues were much more explicit in the form of their think-aloud. Before Episode-B started, S2 was observed uttering *"I don't know why I need to draw a Newman diagram?".* A few seconds later this was followed by S1's uttering "*Okay now I am understanding what it is*". Immediately S2 approaches S1 and the resulting dialogue lasts for around 16.56 minutes. Thus even when multiple peers are present these actions could occur as a result of cost-value analysis considering both feedback availability and non-availability cues emerging dynamically amongst them.

Further, for Episode-A we traced the emergence of feedback availability and non-availability cues in S2 and S1 respectively to the sequence of their interactions with artefacts such as different molecular models and sketches before and during feedback seeking. We observed that by the time S1 sought feedback, S2 had already referred to different individual molecular models which together constitute the intermediate structure. On the other hand, S1 was seen trying to make sense of the task by referring to just one model tied to intermediate structure. This shows us how subtle differences in interaction with artefacts contribute to the emergence of S1's perceived cost in continuing to rely upon self as a feedback source and S2's perceived value in providing feedback as it adds to both one's self image and problem solving goals. This discussion also holds for how S1's interactions with artefacts influenced the purpose for which he sought feedback. In addition, we observed that throughout feedback seeking, S1 incurs cost in terms of continuously monitoring and judging the feedback received against one's requirement for its relevance, specificity and accuracy. Based on such evaluation S1 seeks further elaboration, clarification while also contesting, verifying and confirming. Anticipation of such costs during the dialogue was observed to influence decisions like whether or not to continue seeking feedback with S2. Also varying time gaps between conversational turns were observed to be crucial for S1 to monitor, judge and construct a response to the feedback received. This was mutually negotiated through monitoring each other's verbal utterings, voice tone, facial expressions and gestures. All these are key features of 'feedback as dialogue' notion by which learners' unique and diverse feedback needs are met.

Regarding the amount of feedback seeking, although at surface it appears to be largely influenced by the complexity of subtasks, the characteristics of feedback source and feedback seeker are equally significant. For instance, the Episode-B which emerged during the subtask requiring mental simulation with representations lasted for about 16.56 minutes with 70 conversational turns in total. This is almost five times larger in terms of time spent and the number of conversational turns than Episode-A which emerged during subtask requiring just analogical reasoning. Here when we examined the nature of reciprocal exchanges between S1 and S2, it became evident that the amount of feedback seeking is equally shaped by the individual characteristics. If S1's perceived proficiency of S2 is low, then cost associated with feedback received like the need to monitor, judge and verify will be high. And actual proficiency of S2 will determine whether or not feedback provided will be justified or the mode of provision will be adapted to persuade the seeker. For instance, initially S2 starts providing feedback by mostly pointing at models or the reaction mechanism but later builds a complex intermediate structure with multiple models to convey one's feedback. It is during the feedback provision that the source comes to realize the cost associated with providing feedback and the value of using multiple representations in conveying one's feedback. An experienced or more proficient feedback source like an instructor might anticipate this much early thus reducing the cost associated with feedback seeking for learners and hence the amount of feedback seeking.

Another key aspect contributing to perceived cost-value estimates of learners and feedback sources regarding their feedback seeking and provision is how they cooperate or negotiate division of labour. For instance, in Episode-A while providing feedback, S2 encounters a situation where division of labour could be of help. Task involves identifying and distinguishing similar looking molecular models while trying to build an intermediate structure. S2 assigns this task to S1 and assignment of this task comes in the form of a question. But S1 redirects the task to S2 as he is holding the model and it is easier to apply chemical naming conventions by holding one. S2 instead goes on to check previous sketches of catalyst without expressing any emotion tied to disappointment or bitterness. Then S1 reassigns the task to himself and rules out that the model is not the one they were looking for. S2 does the same for another model and confirms that model as the required one. Both S1 and S2 based on momentary need, judge whether to allocate, distribute or redirect tasks to each other based on their cost-value estimates of what it requires to perform the task. In Episode-B, such instances were predictably high but they were also fraught with negative emotions such as irritation and frustration. So task complexity means that how participants mutually assign, redirect or reassign specific tasks while being sensitive to each other's emotions and motivation has potential to increase or decrease cost associated with feedback dialogue.

Our examination of factors contributing to the participants' perceived cost-value estimates regarding their modes of feedback seeking and feedback provision revealed the relationship between feedback seeking and the use of multiple representations. Consider the following observation from Episode B. Initially the mode of feedback seeking and the provision involved just the verbal exchange but then the participant seeking feedback did not get convinced with the feedback received. So he kept probing the feedback provider verbally. As a result, the peer providing feedback adapts one's mode of feedback provision. He first uses the model to convey one's feedback and later sketches the 2D diagram to convey the same recognising that the former did not serve the purpose. The participant seeking feedback still not satisfied with the feedback received, builds a model to convey one's reason for not being convinced and then goes on to elicit more feedback. And these transitions were fraught with emotions such as irritation and frustration. This suggests that affordances of specific feedback seeking strategies and representations can vary depending on the contextual factors such as characteristics of learner, feedback sources, available artefacts and specific task elements. Hence it is during the feedback dialogue that learners encounter opportunities to confirm or iteratively revise their cost-value estimates of different feedback seeking strategies and representations for thinking, communicating and problem solving.

References

Anseel, F., Beatty, A. S., Shen, W., Lievens, F., & Sackett, P. R. (2015). How Are We Doing After 30 Years? A Meta-Analytic Review of the Antecedents and Outcomes of Feedback-Seeking Behavior. *Journal of Management*, *41*(1), 318–348. https://doi.org/10/5x3

Blunden, A. (2010). *An interdisciplinary theory of activity*. Brill.

Chinn, C. A., & Sherin, B. L. (2014). Microgenetic Methods. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (2nd ed., pp. 171–190). Cambridge University Press.

Cropanzano, R., & Mitchell, M. S. (2005). Social Exchange Theory: An Interdisciplinary Review. *Journal of Management*, *31*(6), 874–900. https://doi.org/10/cjtkx7

Engeström, Y. (Ed.). (2014). The Emergence of Learning Activity as a Historical Form of Human Learning. In *Learning by Expanding: An Activity-Theoretical Approach to Developmental Research* (2nd ed., pp. 25–108). Cambridge University Press; Cambridge Core.

Nersessian, N. J. (1999). Model-Based Reasoning in Conceptual Change. In L. Magnani, N. J. Nersessian, & P. Thagard (Eds.), *Model-Based Reasoning in Scientific Discovery* (pp. 5–22). Springer US.

Nicol, D. (2013). Resituating feedback from the reactive to the proactive. *Feedback in Higher and Professional Education*, 34–49.

Rau, M. A. (2020). Cognitive and Socio-Cultural Theories on Competencies and Practices Involved in Learning with Multiple External Representations. In P. Van Meter, A. List, D. Lombardi, & P. Kendeou (Eds.), *Handbook of Learning from Multiple Representations and Perspectives* (1st ed., pp. 17–32). Routledge.

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Analysis of Co-designed Biology Units Integrated with Computational Thinking Activities

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Abstract: To support student learning of Computational Thinking (CT) in disciplinary contexts, it is important that teachers have agency and ownership in the design process of creating curricula. We conducted a 4-week-long summer institute for teachers to co-design CT-integrated high school science units. Our approach to CT integration into Science and Mathematics contexts is based on a *taxonomy-of-practices* of CT in Science and Mathematics professional contexts. The co-design teams in our summer institute used a version of this taxonomy to create CT-integrated lessons. In this paper, we analyze two co-designed biology units to characterize CT integration in these lessons using the new taxonomy. The results illustrate various types of activities and questions developed as a way to promote student engagement in CT practices in the disciplinary context. Findings yield implications for CT integration in disciplinary contexts as well as co-design of CT-integrated units based on a *taxonomy-of-practices*.

Keywords: computational thinking, practices, taxonomy, co-design, science education

Introduction

As computing becomes ubiquitous in science, technology, engineering, and mathematics (STEM) fields and society, researchers and educators have argued that it is crucial to build foundational Computational Thinking (CT) and literacy skills in K-12 settings (Wing, 2006; Grover & Pea, 2013; Wilensky et al., 2014). In our work, we integrate computational thinking (CT) into mathematics and core science courses because: (1) Unlike elective computer science courses offered in high school, the integration of CT into science courses ensures all students engage in CT and build computational literacy, addressing issues of underrepresentation and self-selection in computing fields (Wilensky et al., 2014); (2) The integration of CT into science and mathematics can support deeper learning of the science content (e.g., Levy & Wilensky, 2009); (3) With such integration, students can learn authentic disciplinary practices recommended by the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013; Dabholkar et al., 2020).

Inviting teachers to be design partners of new units has increased teacher ownership of curricular changes and supported appropriate pedagogical shifts (Kyza & Georgiou, 2014). In order to design CT-integrated curricular units, we partnered with high school science and mathematics teachers. We conducted a 4-week-long summer institute to co-design units with newly designed computational tools and pedagogical activities to support learning. Our co-design approach foregrounded teachers' views on how the curriculum aligns with learning objectives, teaching strategies, and expectations for student learning (Severance et al., 2016). In this paper, we analyze two co-designed biology units to characterize CT integration in a disciplinary context.

Theoretical framework

Prior work defined a taxonomy of CT practices in the context of science and math that includes modeling and simulation, data, problem solving, and systems thinking practices (Weintrop et al., 2016). Our team has used this *taxonomy-of-practices* to design and co-design CT-integrated science and math units over the past several years, resulting in several important outcomes for student learning (e.g., Arastoopour Irgens et al., 2020) and teacher learning and attitudes (Peel et al., 2020; Wu et al., 2020). Based on our experiences, a new version of the *taxonomy-of-practices* (ToP 2.0) is currently in development that represents a wider set of CT practices that we feel the original taxonomy did not include or did not give enough attention to (Peel et al., 2021). An initial beta version of the new taxonomy was piloted in this project. There are six practice categories in the CT-ToP2.0-beta: *computational modeling and simulation, computational data, computational visualization, algorithms, computational problem-solving,* and *programming*. The CT-ToP2.0-beta was used as a framework to integrate in science and mathematics curricular units. This paper uses the CT-ToP2.0-beta to frame our analysis of two co-designed biology units. The following research question guided the analysis: *How were CT practices integrated into co-designed biology units?*

Research and co-design context

Our team worked with 11 teachers in summer 2020 during a 4-week summer institute. Due to COVID-19 regulations, the summer institute was held remotely. Teachers learned about CT integration and pedagogy by engaging as learners in the first week of the summer institute. The following three weeks were used to co-design new CT-integrated science and math units. Each teacher, or pair of teachers, partnered with a member of the research team to co-design CT-integrated units and computational tools to support student engagement in CT practices and learning of science/math content. Teachers read a Google Slides presentation that introduced them to the CT practices. They were then asked to read a document with descriptions and curricular examples of each practice category.

CT-STEM website and Biology units

The curricular units developed in the summer institute are hosted on a website that facilitates curricular design and use in classrooms (https://ct-stem.northwestern.edu). Each curricular unit consists of several lessons, and each lesson has multiple pages containing questions that prompt student engagement. Lesson pages can include embedded computational tools (Figure 1). For example, Figure 1A shows a computational model embedded in the lesson titled: *How do the instructions to make proteins work?* The students are asked to explore the model and note the observations they find interesting. The follow-up questions on the subsequent pages provide scaffolding to support student learning of specific biological aspects regarding the process of DNA replication and transcription.

A B

Figure 1. A screenshot of embedded computational models in lessons in CT-STEM website

The two co-designed biology units that we analyze in this paper were about the Central Dogma and Covid-19 transmission. The Central Dogma unit, of the lead-co-designer teacher Ms. Kate (pseudonym), has computational activities that engage students in learning about Central Dogma. The second biology unit about Covid-19 transmission, of the lead-co-designer teacher Ms. Sara (pseudonym), is designed for student to use computational models for learning about transmission of COVID-19, focusing on the infectiousness of the virus and behavior of people.

Methods

We created a codebook to code questions in the lessons for taxonomy 2.0-beta categories. It contains the explanations and examples of each code. We coded 272 questions from 16 lessons in the two biology units. If a question prompted students to engage in multiple categories of practices, it was coded positive for all the categories. Author 1, 2, and 3 were involved in coding. Cohen's *Kappa* was used to determine interrater reliability. *Kappa* > 0.75 was considered as a cut-off. To characterize the units in terms of CT practice integration, we calculated percentage integration for each of the practices. To further characterize the how the practices were integrated in the lessons, we calculated the extent of integration (density) and presence of different types of CT practices (variety) for each page. We calculated Density and Variety scores using the following formulas: Density = total number of practice codes / total number of questions; Variety = practice categories coded / total number of practice categories.

Analysis and findings

In this section, we first present analysis of the units in terms of integration of CT practices. Then we discuss a page that has high density and variety of CT practices as an illustrative example of CT integration.

CT practices integration

Computational modeling and simulation practices were most prominently integrated in the lessons (Figure 2). *Computational visualization practices* and *Computational data practices* have more than 10% integration. Though this claim needs to be substantiated on the basis of student responses to the questions, we expect that minimum of 10% integration is needed for each category to provide adequate exposure. We used density and variety scores to identify high CT integration pages, one of which is discussed below to illustrate integration of the CT practices.

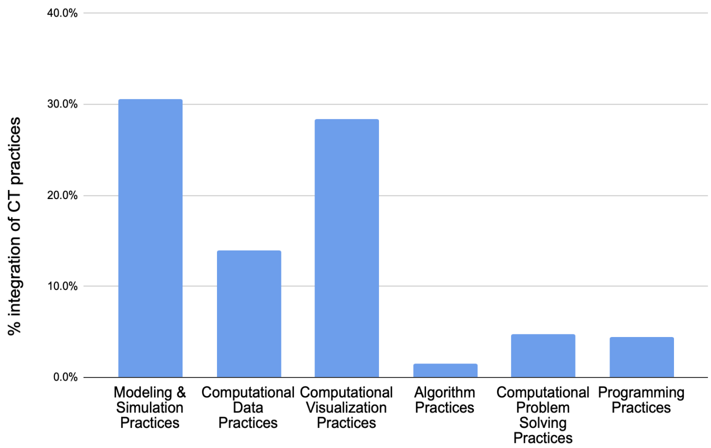

Figure 2. Percentage integration of CT practices in the biology units

An illustrative example of CT integration

We used density and variety metrics to identify pages that have high CT integration. We present qualitative analysis of CT integration in Page 3, 4 and 5 of lesson 5, of the Central Dogma unit (density score > 1 and variety score => 0.5) to illustrate how CT-ToP2.0 -beta practices were integrated. Lesson 5 was designed for students to understand the underlying biological processes that result in differences in hair color. In this lesson, students use a computational model built in NetLogo (Wilensky, 1999) (See Figure 1A). It is a test tube model of DNA replication and transcription. In this model, students can add appropriate 'ingredients' computationally and observe the outcomes. After students were asked to explore the model and make observations, to understand the processes and the functions of various macromolecules (e.g., DNA polymerase). Kate and her team designed these questions for students to use a *computational visualization* of a manipulable process in a scaffolded manner to engage in *computational modeling and simulation*. The model shows percentages of bases on the old DNA strand and the new strand. The questions ask students to make qualitative observations and collect qualitative data regarding the process of DNA replications. On the next page, students are asked to more systematically engage in *computational data practices* by performing trials and collecting data to identify a pattern regarding DNA replication (Chargaff's law).

On page 6, students are asked *to make RNA based on a DNA template.* This requires students to think about how to use a computational tool by providing appropriate inputs to generate a desired output. This requires them to engage in *computational problem solving practices*. This page has a model that has an intentionally placed bug. After students engage in *computational problem solving*, they are asked to identify a bug in the model. They are asked to engage in *programming practices* by modifying the program to fix the bug.

Discussion and implications

Integration of CT practices in disciplinary contexts serves two reciprocal purposes: (1) CT practices can have pedagogical value for learning the disciplinary content; (2) Disciplinary contexts can provide rich ways to engage in CT practices. Different levels of engagement in CT practices in disciplinary contexts can be thought of as a spectrum of sophistication. In disciplinary contexts less sophisticated practices, such as changing model parameters and observing the effects, are of pedagogical value whereas the disciplinary context provides ways for engaging in more sophisticated practices, such as understanding algorithmic logic in a model and modifying it. The example activities discussed in the results section demonstrate the co-design team's intentions of engaging students across the full range of sophistication to support the learning of key disciplinary ideas regarding DNA replication and RNA synthesis and then using the context to engage students in understanding programming and debugging.

The co-design approach for CT integration into these units was predominantly based on co-designing computational models and then using those models to engage in other CT activities. It is possible that the practices more prominently present in the lessons are due to the nature of the computational tool, NetLogo (Wilensky, 1999), that was used for CT integration. NetLogo is a highly effective modeling platform that allows easy creation of computational visualization of phenomena, performing multiple experimental trials and collecting data. In addition, the NetLogo code can be easily accessed, read and manipulated to debug and extend computational models. These affordances of the NetLogo environment open possibilities for integration of the full range of CT practices at all levels of sophistication. However, we anticipate that such wholistic intertwining of CT practices with a model-centered CT integration approach would require more intentionality in the co-design process. Even though new practices such as algorithm and programming practices were not present in high density, the addition of these practices in the taxonomy possibly resulted in the design of activities about understanding and modifying the code and writing algorithms for understanding computational aspects of biological processes. Our other work has demonstrated that sophistication and variety in CT integration can increase through the co-design experience of teachers over a couple of years (Peel et al., 2020). We anticipate more variety and sophistication in future units designed by these teachers.

References

Arastoopour Irgens, G., Dabholkar, S., Bain, C., Woods, P., Hall, K., Swanson, H., . . . Wilensky, U. (2020). Modeling and Measuring High School Students' Computational Thinking Practices in Science. Journal of Science Education and Technology, 29(1), 137-161.

Dabholkar, S., Arastoopour Irgens, G., Horn, M., & Wilensky, U. (2020). Students' epistemic connections between science inquiry practices and disciplinary ideas in a computational science unit. Proceedings of the International Conference for the Learning Sciences (ICLS 2020), Nashville, USA: ISLS

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. Educational researcher, 42(1), 38-43.

Kyza, E. A. & Georgiou, Y. (2014). Developing in-service science teachers' ownership of the PROFILES pedagogical framework through a technology-supported participatory design approach to professional development. Science Education International, 25(2), 55-77.

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education. Journal of Science Education and Technology, 29(1), 1-8.

Papert, S., & Harel, I. (1991). Situating constructionism. Constructionism, 36(2), 1-11.

Peel, A., Dabholkar, S., Anton, G., Wu, S., Wilensky, U., & Horn, M. (2020). A Case Study of Teacher Professional Growth Through Co-design and Implementation of Computationally Enriched Biology Units. Proceedings of the International Conference for the Learning Sciences (ICLS 2020), Nashville, USA: ISLS

Peel, A., Dabholkar, S., Wu, S., Horn, M.S., Wilensky, U. (2021). An Evolving Definition of Computational Thinking in Science and Mathematics Classrooms. 2021 International Conference of Computational Thinking Education and STEM (CTE-STEM) Proceedings.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. Journal of Science Education and Technology, 25(1), 127-147.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Wilensky, U., Brady, C. E., & Horn, M. S. (2014). Fostering computational literacy in science classrooms. Communications of the ACM, 57(8), 24-28.

Wing, J. M. (2006). Computational thinking. Communications of the ACM, 49(3), 33-35.

Wu, S., Peel, A., Bain, C., Anton, G., Horn, M., & Wilensky, U. (2020). Workshops and Codesign Can Help Teachers Integrate Computational Thinking into Their K-12 STEM Classes. Paper submitted to the Fourth International Conference on Computational Thinking Education 2020, Honk Kong, China.

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Pre-Service Teachers' Argumentations in the Context of Assessment

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Abstract: In this article, we introduce a conception of diagnostic argumentation skills and define three relevant facets, namely justification, disconfirmation and transparency. We present initial investigations in the three facets' (co-)occurrences in diagnostic argumentation and their relation with the accuracy of diagnostic decisions in the context of teacher education. For this purpose, we analyze data of 118 pre-service teachers, who were learning with simulated cases concerned with the topic of students' clinical problems. We interpret the results as justification, disconfirmation and transparency being three distinct facets of diagnostic argumentation skills. We also assume that justification may relate to cross-domain transferable argumentation skills, while disconfirmation and transparency are rather context-specific aspects of diagnostic argumentation, relating to standards in diagnosing. Moreover, we discuss the type of reasoning and prior processing of the case as potential explanation for a correlation found between justification in diagnostic argumentation and the accuracy of diagnostic decisions.

Pre-service teachers' diagnostic argumentation and diagnostic accuracy

Skills of diagnostic reasoning and argumentation are relevant in many disciplines (Heitzmann et al., 2019). In this article, we outline a conception of diagnostic argumentation skills and define three relevant facets, namely justification, disconfirmation and transparency. Furthermore, we present initial empirical investigations concerning their (co-)occurrences in diagnostic argumentation and their relation with the accuracy of diagnostic decisions in the context of teacher education.

The learning of diagnostic skills is a matter of professionalization within various disciplines (Heitzmann et al., 2019). Beyond medicine and medical education, also other disciplines like teacher education emphasize the role of diagnosing as "a process of goal-oriented collection and integration of case-specific information [aiming] to reduce uncertainty in order to make […] decisions", but use other terminology like *assessment* (Heitzmann et al., 2019, p. 4). Teachers need to diagnose students' performance, progress, and among other learning prerequisites, initially identify learning difficulties such as dyslexia or even behavioral disorders like ADHD (Praetorius et al., 2013; Reinke et al., 2011). Indeed, higher education programs in teaching and other disciplines increasingly acknowledge the relevance of diagnostic skills (Heitzmann et al., 2019). Simultaneously, research places a stronger emphasis on the facilitation of diagnostic skills, e.g., by exploring the effects of simulation-based learning on facilitating diagnostic skills (Chernikova et al., 2019). Advancing the understanding of the nature and relation of diagnostic skills is an essential foundation for learning and researching diagnostic skills.

Diagnostic skills reflect the application of professional diagnostic knowledge, e.g., in terms of effective diagnostic action and accurate diagnostic decisions (Heitzmann et al., 2019). Effective diagnostic action is researched e.g., in terms of epistemic activities like generating hypotheses, generating and evaluating evidence, and drawing conclusions (Fischer et al., 2014). However, research and education generally refer to the accuracy of diagnostic decisions as main indicator of diagnostic skills (e.g., Praetorius et al., 2013). The literature suggests that reasoning processes, which are underlying diagnostic action and diagnostic decision-making, can be either of fast and intuitive or of slow and reflective nature (Mercier & Heintz, 2013). While reflective inferences are conscious and explicable, intuitive inferences are less accessible for explication (Mercier & Heintz, 2013). Nonetheless, communicating diagnostic considerations, activities and decisions is crucial in various situations like collaborative diagnosing or verbalized post-hoc argumentation, e.g., when writing a report. In such situations, diagnostic reasoning is ideally explicated in the form of coherently interrelated arguments (Walton, 1990). We broadly subsume such instances of interrelated diagnostic arguments as *diagnostic argumentation*. Moreover, we assume that diagnostic argumentation does pursue different epistemic aims: Diagnostic argumentation may for example aim for sense-making during diagnostic action as well as for articulating or persuasively presenting diagnostic decisions (Berland & Reiser, 2008; Chinn, Rinehart, & Buckland, 2014). So far, research investigating verbal outcomes in diagnosing mostly focused on justificatory accuracy, e.g., in verbalized sense-making during the diagnostic process (e.g., Braun et al., 2018) or in articulating diagnostic decisions (e.g., Praetorius et al., 2013).

In our research, we build on the broader literature on scientific argumentation, which pointed out that beyond accuracy there are other, especially structural features contributing to an argumentation's persuasiveness (e.g., Hitchcock, 2005). It is not clear however, if structural features of diagnostic argumentation necessarily correlate with the accuracy of diagnostic decisions or if they reflect distinct diagnostic skills. Qualitative findings indicated that formal aspects of presenting arguments about diagnostic decisions may not necessarily correlate with accurate diagnostic decisions; instead, structural features of diagnostic argumentation may rather depend on additional skills (Braun et al., 2018), like cross-domain argumentation skills (Hetmanek et al., 2018). In addition, diagnostic argumentation may be a matter of internalized standards that are specific to the context of diagnosing (Bauer et al., 2020; Chinn, Rinehart, & Buckland, 2014). We conclude that further research is needed to investigate the nature of diagnostic argumentation and its distinction from other diagnostic skills, particularly accurate diagnostic decision-making. For this purpose, we outline a conception of diagnostic argumentation skills in the following and define three relevant facets, namely justification, disconfirmation and transparency.

The majority of studies considering argumentation structure refer to Toulmin´s argumentation scheme (2003). This model especially highlights the role of *justification*, since any claim requires some grounding to build a complete argument. Transferred to the context of diagnostic argumentation, diagnoses are comparable to claims that need to be justified with evidence. Moreover, the Toulmin scheme (2003) emphasizes the role of rebutting counterarguments and competing claims in supporting an overall conclusion. This rationale functionally resembles the scientific approach of *disconfirmation*: In the case of two competing hypotheses, a finding of evidence disconfirming one hypothesis supports in turn the other hypothesis. Disconfirmation is particularly relevant in cases that involve uncertainty, e.g., due to an incomplete data basis, thus requiring probabilistic reasoning (Kind & Osborne, 2017). Simultaneously, rejecting relevant differential diagnoses supports the plausibility of a diagnostic conclusion, especially in diagnosing cases that involve ambiguous evidence. Furthermore, elaborating on scientific argumentation and standards in science, other major themes are the reliability of processes and the evaluation of evidence in reference to methodology and data sources (Chinn, Rinehart, & Buckland, 2014; Fischer et al., 2014). Accordingly, *transparency* with respect to the processes is considered essential in underlining the quality of the presented evidence and conclusions (Vazire, 2017). In diagnostic argumentation, this is achieved by describing the processes undertaken to generate evidence.

We assume that justification, disconfirmation and transparency are three relevant facets of diagnostic argumentation. It is not clear however, if they are correlated, reflecting an overall diagnostic argumentation skill, or if they are distinct diagnostic argumentation skills. Therefore, to approach this issue, we explore how justification, disconfirmation and transparency (co-)occur in diagnostic argumentation (RQ1). Moreover, referring to the question of distinguishing diagnostic argumentation from diagnostic decision-making, we investigate, how justification, disconfirmation and transparency in diagnostic argumentation relate to diagnostic accuracy (RQ2).

Methods

We recruited 118 pre-service teachers to participate in a study that evaluated a simulation-based learning environment concerned with the topic of students' clinical problems that we developed for a teacher education program. The participants processed eight simulated cases of primary and secondary students displaying behavior that might indicate a disorder in the spectrum of either ADHD or dyslexia. Doing so, they could access several informational sources such as samples of the student's written exercises and school certificates, reports of observations from inside and outside of the classroom, conversations with the respective student, the parents, and other teachers. Participants had two tasks per case: (A) they had to make a diagnosis by indicating whether the simulated student might have a clinical problem and if so, which one it might be; (B) we asked the participants to write an argumentation about their conclusion and their approach in reasoning about the case. The data collection was computer-based and took place in a laboratory setting. We introduced participants to the aims and procedure of the study and familiarized them with the simulation-based learning environment. After giving informed consent to participate in the study, they answered a pretest that took around 35 minutes. Afterwards they entered the learning phase, consisting of the eight simulated cases. Time on task for all cases was M = 51.8 minutes (SD = 16.5). After four cases, participants took a break of ten minutes before continuing with solving cases five to eight. Subsequently, they answered a posttest, which took again around 35 minutes.

The data sources used for the analyses presented in this paper are the diagnoses (A) and the diagnostic argumentations (B) from six of the eight cases. We coded diagnostic accuracy of all the written diagnoses (A) as accurate (1 point), partially accurate (0.5 point) or inaccurate (0 points). Two raters coded 12.5% of the diagnoses, resulting in an inter-rater reliability of Cohen's κ = .80. The internal consistency across the six cases was rather low (McDonald's ω = .37). For further analyses, we calculated a sum score of the points achieved in terms of diagnostic accuracy with a possible range from 0 to 6 points.

Afterwards, we coded diagnostic argumentations (B) in two independent rounds of coding. First, we segmented and coded all argumentations in terms of the four epistemic activities *generating hypotheses, generating evidence, evaluating evidence* and *drawing conclusions*. Four raters coded 15% of the data in parallel before dividing the rest of the data. Subsequent to the initial coding, we decided to include *generating hypotheses* into *drawing conclusions*, resulting in a merged category of *drawing conclusions* (Krippendorff's $a_U = .62$) and the two additional coding categories *generating evidence* (Krippendorff's $a_U = .56$) and *evaluating evidence* (Krippendorff's $a_U = .75$). In a second round, we coded the diagnostic argumentations of six cases regarding the content dimension of *differential diagnoses*. 15% was double coded resulting in an overall inter-rater reliability of Cohen's $\kappa = .92$. We operationalized *justification* in diagnostic argumentation as one or more co-occurrences of evaluating evidence and drawing conclusions within a temporal context of two sentences. Moreover, we considered *disconfirmation* in diagnostic argumentation to apply if the argumentation included at least two differential diagnoses. Thirdly, we defined *transparency* in diagnostic argumentation as at least one explication of generating evidence. Internal consistencies across six cases was satisfactory, with McDonald's $\omega = .60$ for justification, McDonald's $\omega = .60$ for disconfirmation, and McDonald's $\omega = .71$ for transparency. For all three variables, we calculated again sum scores with a possible range from 0 to 6 points.

To explore both research questions, we used Pearson's correlation analysis, including the variables justification, disconfirmation, transparency, and diagnostic accuracy. The alpha level was defined as $\alpha = .05$.

Results

To explore, how justification, disconfirmation and transparency (co-)occur in diagnostic argumentation (RQ1), we report descriptive results and a Pearson correlation analysis. Across the six cases, participants put most emphasis on justification, which we found on average in around two thirds of their diagnostic argumentations ($M = 3.83$; $SD = 1.58$). Moreover, we found that participants hardly applied disconfirmation, which only occurred in around a quarter of the diagnostic argumentations ($M = 1.52$; $SD = 1.41$). We found transparency in around half of the diagnostic argumentations ($M = 2.67$; $SD = 1.81$), which is considerably less frequent than justification but more frequent than disconfirmation. Pearson correlation analysis indicated that justification and disconfirmation may be related, since the correlation was significant with a large effect ($r = .568$, $p < .01$). In contrast, transparency was not significantly correlated with justification ($r = .055$, $p = .55$) or disconfirmation ($r = .025$, $p = .79$).

To investigate, how justification, disconfirmation and transparency in diagnostic argumentation relate to diagnostic accuracy (RQ2), we report again a Pearson correlation analysis. Participants' average diagnostic accuracy was $M = 4.41$ (maximum of 6 achievable points; $SD = .94$). We found diagnostic accuracy and justification to correlate significantly, with a small effect ($r = .284$, $p < .01$). However, there were no significant correlations between diagnostic accuracy and disconfirmation ($r = .105$, $p = .26$) as well as transparency ($r = .059$, $p = .53$), indicating that diagnostic accuracy discriminated between justification and disconfirmation.

Discussion

Exploring the (co-)occurrences of justification, disconfirmation and transparency in diagnostic argumentation (RQ1), we found that pre-service teachers rather applied justification in their diagnostic argumentations than disconfirmation and transparency. Since there was no specific instruction that prompted students to emphasize justification in particular, we interpret that justification is less specific to the context of diagnosing, but may relate to a more generalizable skill level like cross-domain transferable argumentation skills (Hetmanek et al., 2018). Compared to justification, especially disconfirmation but also transparency were less prevalent in diagnostic argumentations. We suggest considering them as more specific argumentation skills (Hetmanek et al., 2018) that relate to standards in diagnosing or even broader standards of science (Chinn, Rinehart, & Buckland, 2014). Previous research has issued that such diagnostic standards may be insufficiently taught in teacher education (Bauer et al., 2020). Moreover, despite the finding of justification correlating highly with disconfirmation, we also found that diagnostic accuracy correlated only with justification but not with disconfirmation, thus discriminating between the two facets. Overall, we interpret that justification, disconfirmation and transparency seem to be rather independent diagnostic argumentation skills. In contrast to disconfirmation and transparency, justification significantly correlated with diagnostic accuracy (RQ2). Since the effect was only small, we still consider justification in diagnostic argumentation and the accuracy in diagnostic decision-making as two different skills. We assume that the correlation may be explained by reflective inferences made during the prior processing of the case (Mercier & Heintz, 2013): Reflective inferences are a conscious and explicable type of reasoning, which may facilitate both justification in diagnostic argumentation and accuracy in diagnostic decision-making.

Some methodological remarks seem relevant for our interpretation: Inter-rater reliabilities of generating evidence and drawing conclusions are rather low. However, the initial coding reflects the simultaneous segmentation and coding of individual epistemic activities; hence, we consider the agreement as sufficient for the combined task. Moreover, for our operationalization, we did not use the initially coded individual epistemic activities, but abstracted their overall presence or absence, on the level of diagnostic argumentations. Thus, we suppose that the actual agreement on the analyzed level of diagnostic argumentations is most likely superior to the agreement presented. A second limitation consists in the low internal consistency of diagnostic accuracy. This issue is in line with other studies suggesting that the accuracy of diagnostic-decision-making is comparably content-specific and thus, internal consistency of diagnostic accuracy only increases across a large number of cases (Monteiro et al., 2020).

Based on our initial considerations and results presented in this paper, we suggest that justification, disconfirmation and transparency represent three distinct facets of diagnostic argumentation skills. We derive the assumption that justification relates to cross-domain transferable argumentation skills, while disconfirmation and transparency are rather context-specific aspects of diagnostic argumentation. We also assume that reflective inferences made during the processing of the case may facilitate both justification in diagnostic argumentation and accuracy in diagnostic decision-making. Justification in diagnostic argumentation and accuracy of diagnostic decision-making seem to be distinct outcomes, reflecting different diagnostic skills. Therefore, as a matter of further professionalization, research and learning programs interested in diagnosing may consider diagnostic argumentation skills as relevant outcomes and distinguish them from established indicators for diagnostic skills, like accurate diagnostic decisions.

References

Bauer, E., Fischer, F., Kiesewetter, J., Shaffer, D. W., Fischer, M. R., Zottmann, J. M., & Sailer, M. (2020). Diagnostic Activities and Diagnostic Practices in Medical Education and Teacher Education: An Interdisciplinary Comparison. *Frontiers in Psychology*, *11*(562665).

Berland, L. K., & Reiser, B. J. (2008). Making sense of argumentation and explanation. *Science education*, *93*(1), 26-55.

Braun, L. T., Lenzer, B., Kiesewetter, J., Fischer, M. R., & Schmidmaier, R. (2018). How case representations of medical students change during case processing–results of a qualitative study. *GMS journal for medical education*, *35*(3).

Chernikova, O., Heitzmann, N., Fink, M. C., Timothy, V., Seidel, T., & Fischer, F. (2020). Facilitating diagnostic competences in higher education - A meta-analysis in medical and teacher education.

Chinn, C. A., Rinehart, R. W., & Buckland, L. A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. *Processing inaccurate information: Theoretical and applied perspectives from cognitive science and the educational sciences*, 425-453.

Fischer, F., Kollar, I., Ufer, S., Sodian, B., Hussmann, H., Pekrun, R., ... & Strijbos, J. W. (2014). Scientific Reasoning and Argumentation: Advancing an Interdisciplinary Research Agenda in Education. *Frontline Learning Research*, *2*(3), 28-45.

Heitzmann, N., Seidel, T., Opitz, A., Hetmanek, A., Wecker, C., Fischer, M., ... & Stürmer, K. (2019). Facilitating Diagnostic Competences in Simulations: A Conceptual Framework and a Research Agenda for Medical and Teacher Education. *Frontline Learning Research*, *7*(4), 1-24.

Hetmanek, A., Engelmann, K., Opitz, A., & Fischer, F. (2018). Beyond intelligence and domain knowledge: Scientific reasoning and argumentation as a set of cross-domain skills. *Scientific reasoning and argumentation: The roles of domain-specific and domain-general knowledge.* New York: Routledge.

Hitchcock, D. (2005). Good reasoning on the Toulmin model. *Argumentation*, *19*(3), 373-391.

Kind, P. E. R., & Osborne, J. (2017). Styles of scientific reasoning: a cultural rationale for science education?. *Science Education*, *101*(1), 8-31.

Mercier, H., & Heintz, C. (2014). Scientists' argumentative reasoning. *Topoi*, *33*(2), 513-524.

Monteiro, S. D., Sherbino, J., Schmidt, H., Mamede, S., Ilgen, J., & Norman, G. (2020). It's the destination: diagnostic accuracy and reasoning. *Advances in Health Sciences Education*, *25*(1), 19-29.

Praetorius, A. K., Berner, V. D., Zeinz, H., Scheunpflug, A., & Dresel, M. (2013). Judgment confidence and judgment accuracy of teachers in judging self-concepts of students. *The Journal of Educational Research*, *106*(1), 64-76.

Reinke, W. M., Stormont, M., Herman, K. C., Puri, R., & Goel, N. (2011). Supporting children's mental health in schools: Teacher perceptions of needs, roles, and barriers. *School Psychology Quarterly*, *26*(1), 1.

Toulmin, S. E. (2003). *The uses of argument*. Cambridge university press.

Vazire, S. (2017). Quality uncertainty erodes trust in science. *Collabra: Psychology*, *3*(1).

Walton, D. N. (1990). What is reasoning? What is an argument?. *The Journal of Philosophy*, *87*(8), 399-419.

Former Students' Perspectives on the Value of Computing Education Programs

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Abstract: One of the major efforts in computing education research is to broaden participation, especially involving women and people of color. This work presents the perspectives of women of color who participated in programs that were meant to encourage them to engage with computing, to understand what they valued. These insights could inform the design of future computing education programs.

Introduction

As broadening participation in computing (BPC) movements across the U.S. strive to democratize computing education, it is important to make explicit the values embedded in computing programs and to examine their impacts on learners, especially those from underrepresented backgrounds in computing (Santo, et al, 2015). Computing education programs highly value continued participation and persistence in computing, which tends to focus on students' reported career interest (Weidler-Lewis, et al, 2017). However, existing research argues that disciplinary views of participation and persistence are narrow and overlook the positive impacts on learners who may not choose to participate in computing in formalized ways, such as pursuing a computing major or career (Weidler-Lewis, et al, 2017). In this work, we examine participation and persistence in computing as a form of *social practice*; we investigate how BPC program participants make meaning out of their computing education experiences in ways that extend beyond formalized academic and career pursuits. In particular, we analyze how former BPC program participants articulate the perceived value of their participation and how they continue to apply the knowledge and skills they gained to different aspects of their lives.

We used photo elicitation interviews with a series of prompts designed to address the following research question: *How do former participants of BPC programs perceive the value of their experiences?* We conducted interviews with 12 women who participated in BPC programs in high school. Our data analysis was theoretically informed by the concept of "figured worlds," defined as "... a socially and culturally constructed realm of interpretation in which particular characters and *actors* are recognized, significance is assigned to certain *acts*, and particular *outcomes* are valued over others" (Holland et al., pg 52, 1998, emphasis added). Our findings show that while half of the participants did not pursue degrees or careers in computing, the programs did have lasting impacts on the significance they assigned to computing, including viewing computing as an avenue for personal development, relationship-building, and helping others. To illustrate this, we draw on the stories of three participants and detail their personal reflections on the programs they were involved in.

Background: Broadening participation in computing

Despite efforts to broaden participation in computing, disparities in participation among underrepresented minorities continue to persist across all educational levels (Code.org, et al, 2020). Scholars have examined numerous factors that contribute to these disparities, including the detrimental impact of racialized and gendered stereotypes (Margolis & Fisher, 2002) on learner interest and unequal access to rigorous CS education opportunities (Margolis, et al., 2017). In an effort to address these disparities, researchers advocate for early exposure to computing and propose programmatic efforts at the primary and secondary level that provide opportunities for students from underrepresented backgrounds to gain computing skills. However, despite an increase in available BPC programs, the upstream effects of these efforts have been slow and particular groups, such as women of color, continue to be vastly underrepresented in computing careers (Code.org, et al, 2020). While we acknowledge the importance of continuing to work toward increasing the number of underrepresented minorities in computing careers, we also urge researchers and educators to broaden their understanding of *what it means to participate* in computing. We present a more expansive view of participation and persistence in computing that is grounded in how former BPC program participants reflect and make meaning of their computing education experiences.

Conceptual framework: Figured worlds

We employ "figured worlds" to understand multiple aspects of participants' experiences. A *figured world* consists of actors who perform acts, with values ascribed to certain outcomes of participation. The "roles" that are played by participants in a figured world are not necessarily static, such as a student/teacher role, rather are "figured" by participants as they interact with one another over time (Urrieta, 2007). Understanding the actors, acts, and outcomes that are valued and reproduced within a figured world of computing created by BPC programs could be important for informing how value is placed on actors, acts, and outcomes within the dominant or broader figured worlds of computing (Perez, 2020). Drawing attention to how the aspects of the physical environment play a role in figured worlds (Hdlaik, et al, 2020; Sengupta & Shanahan, 2017), the photo elicitation method was chosen so participants can (re)present acts, actors, and outcomes of their figured worlds of computing.

Methods

We conducted photo elicitation interviews where participants were asked to bring photos (original or found) that (re)presented aspects of their "figured world" of computing, such as actors ("Who participates in computing?") and practices ("What do people who participate in computing do?"). In total there are 12, hour-long, semi-structured photo-elicitation interviews with women from different BPC programs (Table 1). Interviews were conducted virtually and were recorded with the consent of the participants. Future work in this area will include analyzing the photos in combination with the interview transcripts to more holistically analyze their figured worlds of computing and how that might inform future design of computing learning environments.

Table 1: Program information

Program	# participants interviewed	Program Location	Participant Demographics	Program Details
A	7	Texas	Asian: 1; White: 2; Latina: 2; White/Asian/Middle Eastern/North African: 1; Undisclosed: 1	5 days a week/7 weeks over the summer; taught Scratch, HTML/CSS, Python
B	3	Georgia	Black: 1; Black/Latina: 1; White/Asian/Native American/Pacitic Islander: 1	1 week over the summer, weekly during school year; taught Java, Alice
C	2	Arizona	Latina: 1; Undisclosed: 1	Weekly over the school year; taught Scratch, Computer Literacy

The initial open coding of the interviews employed a holistic coding scheme (Saldaña, 2009) which is consistent with a constructivist grounded approach to analyzing data (Charmaz, 2017). The analysis generated 46 child codes that were grouped thematically into 8 larger themes. For the purposes of this paper, we focus on reporting the analysis of codes that exemplify overall themes related to the social aspects of the learning environment.

Analysis

Personal development: Becoming a leader in the program

Miranda is a Latina who participated in Program C in 2009, following a short advertisement about the program in her math class. She and her friend both signed up as something to do and she described participating in the program as an accident, and that she was not planning on going to college when she first enrolled. Despite framing her participation as an accident, she ended up participating as a student for 2 years and as an assistant for the program for 2 more years while in college. She is currently an elementary English teacher. However, when reflecting on the program, she describes how she leads professional development sessions for other teachers on using technology in the classroom, creates videos, and integrates Scratch into her English curriculum, all choices or activities she credits to her participation in Program C during high school.

Her active role as a trainer for other teachers and view of herself as someone who is capable of experimenting with visual programming in the classroom aligns with the description of herself as a "leader" in the program. When reflecting on her role in the program, Miranda said, “We would all help each other... but also it was different in the sense that maybe I started just feeling more of a leader. I was more outspoken. I was presenting more or volunteering to present more.” Within a figured world, learners “figure” who they are through the activities they perform and through social relationships with others (Urrieta, 2007). The role that Miranda played was not fixed; she became “more outspoken” and volunteered to “present more.” Thus, through her increased participation, Miranda begins to see herself in a “different” light, as someone who is capable of leading and making significant contributions. She was able to develop leadership skills based on the way that the program allowed her to show her expertise and help others.

The leadership skills she developed in the program persisted into her career and she continues to grow and share her expertise on using technology in the classroom. Yet, these forms of participation and persistence can be overlooked when focusing on just an interest in a computing career. People engaged in teaching computing or using computational tools can count as part of the wider computing community, depending on how it “is defined and by whom” (Weidler-Lewis et al., 2017).

Relationship building: Making friends

Angelica is a Latina who participated in Program B in 2017. She is currently a third-year undergraduate student who recently switched majors from computer science (CS) to business. In her reflections, Angelica identified making friends and bonding over the experience of learning to program together as important outcomes of her participation. She described being drawn to computing education programs in high school because she viewed them as places where she was able to meet up with friends and develop new connections. The connections she made while participating in Program B were instrumental in her transition to college life: “I'm still friends with [friends from program], we all go to [university], so we still [hang out]. Less last year, but especially freshman year, we would get meals together and hang out. I think most of us were all engineering at that point, but I would be able to study together and just make those connections that I definitely wouldn't have had otherwise.”

The relationships she built through her participation in computing outlasted her decision to major in CS. Although she decided to change majors, she describes still valuing the opportunity to make friends and try out computing: “deep down I always kind of knew it really wasn't the thing for me, but I also just wanted to try it out. Because that's kind of badass…” Given her social nature, part of why the CS major did not resonate with Angelica was how little it showed the opportunity to interact with others as part of a possible career.

In a figured world, learners will attach significance to some acts and not others. Although Angelica was learning to program (which is a key academic outcome), she attached more significance to developing friendships. In her figured world of computing, the social acts of making "new connections" and "study[ing] together" were program outcomes that she personally valued. Importantly, the social outcomes were carried on beyond the program and into her broader educational experiences in college.

Helping others: Teaching with empathy

Deidre is a Black woman who participated in Program C in 2016. She is a fourth year student majoring in CS. Deidre’s experience in the program inspired her to not only pursue CS, but also to come back to the program as a mentor. She describes her decision to mentor other students as motivated by “being in a position to help someone else.” After majoring in CS for a year, she described understanding that there are computing concepts that others can get “caught up on” or struggle to understand. She expressed a desire to “help someone else through it” and to offer words of encouragement such as, "I know it feels this way right now. I felt that way a couple of months ago. But we can sort of work through it." Mentoring served a dual purpose for Deidre; she was able to identify her own knowledge gaps by “reflect[ing] on the things you still don’t understand,” as well as help others who were struggling to learn computing concepts.

As learners construct figured worlds through interactional experiences, they assign significance to particular acts or practices (Urrieta, 2007). BPC programs may narrowly assign significance to computing by primarily focusing on the field as an economically valuable career pathway. Yet, prior research identifies honoring and integrating communal values as crucial to promoting a sense of belonging among students underrepresented in computing (Lewis et al, 2017). Deidre’s reflections reveal that computing had *social* significance that aligned with her values of community-building and “being able to help someone else” with empathy and encouragement. The ability to go back and be a mentor for the program that supported her own educational trajectory in computing aligned with her values and was a personally meaningful outcome of her participation.

Conclusion

The narratives shared by women of color in this study suggest that they valued the social outcomes of participating in a BPC program, including viewing computing as an avenue for personal development, an opportunity to build lasting relationships with others, and a chance to help teach others with patience and empathy. The participants constructed a figured world of computing where social relations and interpersonal interactions were an integral aspect of what it meant to participate and persist in computing. Importantly, all of the participants in this study learned to code, but how they articulated the perceived value of their participation went beyond the mastery of computing knowledge and skills and was equally important to their experience. They viewed other participants as significant actors in the learning environment, valued the relationship-building opportunities presented in the process of struggling and learning together, and assigned communal significance to computing in ways that were closely related to helping others.

What could this mean for BPC programs, specifically those that seek to engage participants from groups that are underrepresented in computing? One thing to consider is how to move beyond an evaluative emphasis on students' interest in a computing degree or career after participation. Based on our findings, even those that did not pursue a computing degree or career still gained lasting experiences that influenced their careers and relationships. Our findings suggest that a more expansive understanding of participation and persistence in computing should include a consideration of learners' personal development and their ability or willingness to engage others in computing, at the very least. Secondly, when designing programs we could aim to create spaces that highlight multiple pathways for participating in computing, including using computational tools in non-computing careers, mentoring and teaching others to code, pursuing computing as a form of enjoyment and hobby, and using computational tools to serve communities and promote social justice.

References

Charmaz, K. (2017). The Power of Constructivist Grounded Theory for Critical Inquiry. Qualitative Inquiry, 23(1), 34–45.

Hladik, S., Shanahan, M., & Sengupta, P. (2020). Improvisational Infrastructuring by Facilitators in Public Computing. In Gresalfi, M. and Horn, I. S. (Eds.), The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 2 (pp. 807-808).

Holland, D., Lachicotte Jr., W. S., Skinner, D., & Cain, C. (1998). Identity and Agency in Cultural Worlds. Harvard University Press.

Lewis, C. M., Bruno, P., Raygoza, J., & Wang, J. (2019). Alignment of Goals and Perceptions of Computing Predicts Students' Sense of Belonging in Computing.Proceedings of the International Computer Science Education Research Workshop. Toronto, Canada.

Margolis, J., Estrella, R., Goode, J., Holme, J. J., & Nao, K. (2017). Stuck in the shallow end: Education, race, and computing. MIT press.

Margolis, J., & Fisher, A. (2002). *Unlocking the clubhouse: Women in computing.* The MIT Press.

Perez, M. (2020). Understanding Students' Computational Perspectives and Figured Worlds of Computing. In Proceedings of the 2020 ACM Conference on International Computing Education Research (ICER '20). Association for Computing Machinery, New York, NY, USA, 326–327. DOI:https://doi.org/10.1145/3372782.3407103

Saldaña, J. (2009). The Coding Manual for Qualitative Researchers. Sage Publications, Inc.

Santo, R., Vogel, S., & Ching, D. (2019). CS for What? Diverse Visions of Computer Science Education in Practice. New York, NY: CSforALL.

Sengupta, P. & Shanahan, M.-C. (2017). Boundary play and pivots in public computation: New directions in STEM education. International Journal of Engineering Education, 33(3), 1124–1134.

Code.org, CSTA, & ECEP Alliance. (2020). 2020 State of Computer Science Education: Illuminating Disparities. Retrieved from https://advocacy.code.org/stateofcs

Urrieta, L. (2007). Figured Worlds and Education: An Introduction to the Special Issue. *Urban Rev* 39, 107–116. https://doi-org.proxy.lib.umich.edu/10.1007/s11256-007-0051-0

Weidler-Lewis, J., Dubow, W., & Kaminsky, A. (2017). Defining a Discipline or Shaping a Community: Constraints on Broadening Participation in Computing. 627-632.

Examining How Youth Build Comparative Models in Storytelling with Large, Complex Data and Visualization Tools

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Abstract: While building comparisons is a common data science practice, youth's comparative logic in storytelling with large data and visualization tools has yet to be fully investigated. We present two cases of comparative modeling with socioeconomic data, one where youth constructed a story about a community that suffered a historic flood and another in which youth told stories about personal family migration histories. Our analysis revealed similar and different ways of youth engaging in counterfactual reasoning in their comparisons. Students in the flood project compared actual and imagined economic data trends to show how a particular community fared after the flood, and the student in the family migration project compared actual data trends across cities to consider an imagined personal experience (how she might have grown up). We discuss how youth approached differences in their comparisons in order to connect to local or personal experiences and critique distributions of power.

Introduction

In this paper, we closely examine how youth build comparisons for storytelling with large, complex data and visualization tools. Storytelling with data is a data science activity that is increasingly common across disciplines and industries and has become a necessary critical data literacy practice for democratic participation. Likewise, learning to build models for telling explanatory stories about social and scientific issues is important for youth to learn as well. While establishing comparisons is a central aspect of storytelling and modeling with data, it has not been the focus of recent data science education studies. We seek to understand how youth approach comparisons in their stories in order to support the construction of sound models with unwieldy data, the development of insights from these data and visualizations, and appropriate fit between their models and their stories.

Accordingly, we present a case study comparison that unpacks the nature of youth's comparative modeling with data visualization tools in two different contexts, one in which youth explored their family migration histories and the other in which youth told the story of a community that was severely impacted by a devastating flood. We describe the youth's comparative logic and practices in storytelling with dynamic data visualization tools across cases by analyzing how they leveraged the dynamic data visualization tools to tell their story as well as the temporal and spatial dimensions of the comparisons they established. We conclude with a discussion of how our findings contribute to future learning designs, including how to scaffold learners in building comparative models and facilitate learners' connections to the data through rich, meaningful storytelling contexts.

Theoretical framework

We take an approach to youth storytelling with data that closely aligns with earlier studies of spatial analysis and modeling by both STEM professionals (e.g., Hall et al., 2010) and youth (e.g., Hall et al., 2014) in the Learning Sciences. We view learning as changes in knowledge and action that results in shifts in understanding and participation in the activity (Lave, 1996). This approach considers how individuals coordinate tools and resources for sensemaking in order to develop disciplinary knowledge and understanding of spatial and data representations. Our work also draws on recent studies of how individuals utilize data visualization tools for community storytelling in CSCL and Learning Sciences (e.g., Wilkerson & Laina, 2019; Pfannuch et al., 2010; Radinsky, 2020; Van Wart et al., 2020). These studies identify comparative reasoning as an important activity for storytelling with data and for learning to model aggregate data more generally. Collectively, these works offer insight into the comparative practices of building stories with data: (a) Participants typically established comparisons between two data points or datasets or between data trends and personal experience; (b) participants struggled with making fair comparisons because of sampling and measurement challenges; and (c) comparisons emphasize differences across entities rather than similarities or associations (e.g., covariation) in the data patterns. These studies also highlight the complex relations between data, context, and uncertainty (Wilkerson & Laina, 2019; Rubin, 2020) that data modelers and storytellers need to navigate. However, this research has not deeply explored the dimensions of comparisons and their explanatory value for students' storytelling activities.

Methods

Just as comparative case studies of professionals at work (Hall et al., 2010) have been used to find new insights into how individuals learn to engage in spatial analysis and modeling, we similarly selected case studies to illuminate how youth build comparisons that serve as the basis for their stories. The first case study (introduced in Kahn et al., 2016) comes from a 2-week residential summer human geography course for rising ninth and 10th graders at a private university. As part of the class's culminating project to produce an "untold" placed-based digital story (Hall et al., 2020), one group of four teenage youth told the story of a community's particularly difficult recovery after a flood. The students compared neighborhoods, which differed in racial demographic and socioeconomic status, using US census data in Social Explorer and connected the data to oral histories and artifacts from local library archives as well as multimedia (i.e., recordings of students' field trip visits to parts of the city that were flooded). The second case (introduced in Kahn, 2020) comes from a 2-day workshop in a city public library in which middle and high school youth told stories about personal family migration histories using demographic and socioeconomic data that could speak to larger trends driving migration. In this case, an 11-year-old girl told the story of why her parents moved from Brooklyn to Greenville, comparing the two cities on various indicators with Social Explorer maps. All activities in both cases (the program and workshop) were video recorded.

We selected these two cases because (a) the stories told with data both involved a series of comparative models situated in a compelling storytelling context; (b) both cases presented comparisons that relied on counterfactual reasoning, a form of conditional reasoning in which one imagines "how the world would have been" if an antecedent condition or event happened, even though it did not actually occur (Lewis, 1973); and (c) they used the same dynamic data visualization tool, Social Explorer. Social Explorer accesses hundreds of open demographic and socioeconomic datasets from 1750 onwards and permits users to juxtapose places across the same time or different times in multiple visual ways (i.e., a single data map using a time slider, side-by-side map comparisons). We compared these two cases using interaction analysis methods (Jordan & Henderson, 1995) of video records to analyze participants' discourse and tool use in building and presenting their comparisons. We also examined their artifacts (data map comparisons made in Social Explorer with accompanying text in slides). The current analysis focused on final presentations. We looked for similarities and differences across students' presented comparisons.

Findings

Across the two cases, we found that students built comparisons that organized time and space in complex ways and engaged in reasoning about differences about socioeconomic conditions that the comparisons showed. For both cases, the presentation of stories with data involved counterfactual reasoning. Below we present each case by highlighting key patterns and differences that emerged.

Case study 1: Actual and imagined data trends over time and across communities

Darla, Brayden, Lydia, and David (all participant and city names are pseudonyms) examined imagined and actual data trends over time and across multiple geographic scales to create comparative models and reason about factors that could contribute to the differences they found. In their presentation, the group began by describing a picture of the city's downtown district during the flood, which occurred in 2010. Then they pulled up a swipe map using the time slider that zoomed into the county revealing variation across census tracts, which they used to represent city neighborhoods (Figure 1). The left side of the slider showed the population of *Age 18-64 for whom poverty status is determined (living in poverty)* in 2009 and the right side represented the same indicator in 2011. The students moved the slider back and forth to demonstrate that poverty increased in the county in 2011, after the flood.

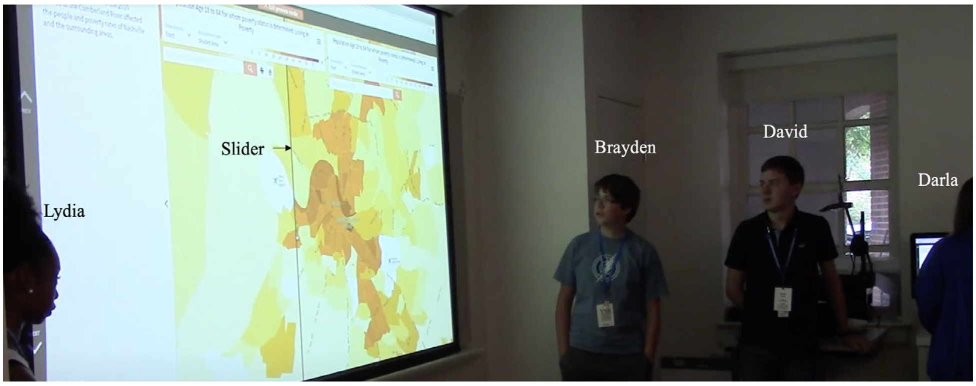

Figure 1. Darla explained the map by dragging the slider. The model compared poverty rates in 2009 and 2011.

Darla: And one thing we thought of was that maybe it's just a coincidence that this happened. So we checked around (*zooming out, first to a regional scale*) in some other places, to see if it affected them too...but---yeah pretty much everything stayed the same (*moving time slider left and right*) except for the areas affected by the flood (*points to an orange area on the screen*)

Then, Darla zoomed out to a regional and national level, shifting the slider back and forth, to show that this economic shift was only experienced locally. They were employing counterfactual reasoning here. If the increase in poverty rates was not unusual, they expected to see it in many other states. Zooming out served to highlight (Goodwin, 1994) comparisons that the students used to rule out other rival (Yin, 2000) causal explanations.

Subsequently, students zoomed into a neighborhood comparison (one predominantly white, more affluent; the other predominantly African American, less affluent) by showing bar graphs displaying small changes in unemployment and poverty in 2009 and 2011 overlaid on the map. Poverty increased in the year after the flood for the more affluent neighborhood (from 4% to 10%) but remained unchanged and high for the less affluent neighborhood (from 10% to 11%). The group pointed out that two neighborhoods did not start from the same place prior to the flood in terms of unemployment and poverty. They then explained that while both neighborhoods faced significant damage from the flood, the less affluent, African American community received less news media attention and consequently fewer allocated resources from the city. The series of comparisons the students presented collectively explained and supported this critique of the distribution of power and access to resources in the city.

Case study 2: Actual data trends across cities to imagine personal experience

In her final data story, Camille described how her family moved from Atlanta to New York for better job opportunities and then to Greenville, where she was born, for a variety of reasons: the New York Blackout of 2003, safety concerns, and lifestyle preferences. Camille built a series of Social Explorer side-by-side map comparisons, selecting the indicator *Total violent and property crimes* (in 2010) to represent safety concerns and the indicators *Owner-occupied housing units: less than $500k* (in 2006), *Workers 16 years and over: car, truck, or van* (in2006), and *Workers 16 years and over: public transportation* (in 2006) to represent "lifestyle." Her comparisons of county level data showed that Brooklyn had lower crime, a higher percentage of houses worth less than $500k, a higher percentage of people using private transportation, and a lower percentage of people using public transportation compared with Greenville. Camille used the datasets from the years after her family moved and she was born to build the counterfactual narrative of what her life would be like if they stayed in New York. As she explained in the narrative, "If my parents had stayed in New York, I would have had to take public transportation, and we probably wouldn't have had a house like we have now because it would cost too much to own a house in New York." With actual data trends across cities, Camille considered how she might have grown up as compared to her current lived experience (i.e., getting around town by car and living in a house as opposed to renting an apartment).

Discussion and conclusion

In these two cases, the "what would have happened" logic of the counterfactual was powerful for students to connect to personal or community experiences. We view the counterfactual as a humanistic, empathetic, and situated approach to the data (Wilkerson & Polman, 2020). However, youth need to be supported in systematically considering other variables that could drive the changes they see. Educators should also ensure that students build reasonable comparisons with georeferenced data, which may entail comparing places at the same geographic scale and/or understanding their scale choices (e.g., the flood group used a national scale [US states] to rule out causal explanations and looked across census tracts [neighborhood scale] to reason about differences in poverty rates). There may also need to be discussions of how to interpret singular data points from large, aggregated data, which are typically averages for a geographic area in choropleth maps, or how to analyze a trend across multiple data points.

Notably, students in both cases tried to highlight and reason about differences between communities but in different ways. The flood group focused on economic change over time in two communities in order to tell the story of one community's unjust treatment in the aftermath of the flood, which they had initially learned about from other contextual sources (i.e., library archives). Camille tried to understand differences between two cities in order to imagine how her day-to-day experiences might have been different. In both cases, youth tried to reason about differences in the data at the level of lived experience, whether their own lived experiences or that of others that had been shared with them. Furthermore, while we found that youth were more interested in telling stories about bigger differences, which aligns with other studies of youth data modeling, when they focused on smaller differences, they were able to add critical nuance to support their story (i.e., the flood group noted the small change in one neighborhood's poverty rate was related to its pre-flood poverty rate). We suggest that students may need more encouragement from instructors to consider similarities and smaller differences, which would include looking for patterns and arranging/connecting multiple comparisons in a meaningful way for effective storytelling. Moreover, students' use of spatial counterfactuals demonstrated that they were capable of learning and interested in participating in these complex kinds of comparative modeling and reasoning practices. Future studies should more deeply examine how to leverage lived and imagined experiences in comparative modeling and how a comparison might serve a counter-story (as in the flood case).

References

Goodwin, C. (1994). Professional vision. *American Anthropologist*. 96(3), 606-633.

Hall, R., & Leander, K. (2010, June–July). Scaling practices of spatial analysis and modeling. Symposium presented at the 9th International Conference of the Learning Sciences, Chicago, IL.

Hall, R., Ma, J. Y., & Nemirovsky, R. (2014). Rescaling bodies in/as representational instruments in GPS drawing. In V.R. Lee (Ed.), *Learning technologies and the body: Integration and implementation in formal and informal learning environments* (pp. 112-131). Routledge.

Hall, R., Shapiro, B. R., Hostetler, A., Lubbock, H., Owens, D., Daw, C., & Fisher, D. (2020). Here-and-then: Learning by making places with digital spatial story lines. C*ognition and Instruction*, 1-26.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The Journal of the Learning Sciences*, 4(1), 39-103.

Kahn, J. (2020). Learning at the intersection of self and society: The family geobiography as a context for data science education. *Journal of the Learning Sciences*, 29(1), 57-80.

Kahn, J., Hall, R., & Pearman, F. A. (2016, April). Telling the city with big data. In R. Hall (Chair), Re-inscribing the city in design studies of critical steam conceptual practice. Symposium conducted at the American Education Research Association 2016 Annual Meeting, Washington D.C..

Lave, J. (1996). The practice of learning: The problem with "context." In S. Chaiklin & J. Lave (Eds.) Understanding practice: Perspectives on activity and context (pp. 3-32). Cambridge University Press.

Lewis, D. K. (1973). *Counterfactuals*. Harvard University Press.

Pfannkuch, M., Regan, M., Wild, C., & Horton, N. J. (2010). Telling data stories: Essential dialogues for comparative reasoning. *Journal of Statistics Education*, 18(1).

Radinsky, J. (2020). Mobilities of data narratives. *Cognition and Instruction*, 38(3), 374-406.

Rubin, A. (2020). Learning to reason with data: How did we get here and what do we know?. *Journal of the Learning Sciences*, 29(1), 154-164.

Van Wart, S., Lanouette, K., & Parikh, T. S. (2020). Scripts and counterscripts in community-based data science: Participatory digital mapping and the pursuit of a third space. *Journal of the Learning Sciences*, 29(1), 127-153.

Wilkerson, M. H., & Laina, V. (2018). Middle school students' reasoning about data and context through storytelling with repurposed local data. *ZDM*, 50(7), 1223-1235.

Wilkerson, M. H., & Polman, J. L. (2020). Situating data science: Exploring how relationships to data shape learning. *Journal of the Learning Sciences*, 29(1), 1-10.

Yin, R. K. (2000). Rival Explanations as an Alternative to Reforms as "Experiments." In L. Bickman (ed.), *Validity and social experimentation: Donald Campbell's legacy* (pp. 241-268). Sage Publications.

Challenges and Opportunities in Teaching and Learning Data Literacy through Art

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Abstract: Achieving data literacy is challenging when schools narrowly focus on statistical reasoning rather than on meaning- and inference-making. Without attention to the social contexts of data, learners can fail to develop a critical stance toward data, to understand the nature and production of data, the questions that it can answer, and the ways that data can be used to inform and misinform. We explore art as an accessible and personally relevant approach to developing middle school students' data literacy. We designed and implemented a 2-week long arts-integrated unit in a grade 7 classroom. Interviews with two teachers and two students following the unit, and analysis of students' artworks and pre/post survey responses, reveal opportunities and challenges at the intersection of data science and art. We discuss pedagogical considerations for other interdisciplinary approaches to data literacy.

Art as an approach to data science

It is essential that young people become data literate. With public and private institutions increasingly amassing personal data, learners must be able to think critically about the sources, representations, and claims being made about data. This reasoning includes an ability to understand the nature of data and how to extract meaning from data patterns, as well as to make critical inferences about data based on context, and the extent to which evidence from the data supports a claim (Makar & Rubin, 2018). Cultivating data literacy is challenging because school mathematics tends to narrowly focus on statistical reasoning, and to present data as objective and devoid of context (Franklin et al., 2015).

We explore an approach to broadening participation in data science by integrating art and mathematics in a middle school classroom-based unit. This project builds on existing efforts to tie school-based data literacy instruction more closely to personal and social contexts (e.g. Kahn, 2020) by incorporating an interdisciplinary focus on art (c.f. Lupi & Posavec, 2016). Interdisciplinary approaches to mathematics and data literacy can be valuable for engaging students who are disengaged in mathematics and can support deeper data literacy learning (Stornaiuolo, 2020). It allows learning through the making process through which learners can engage in meaningful reflection (Turkle & Papert, 1990). Moreover, *data art* is a distinct art form that engages audiences with both emotional and intellectual properties of data (D'Ignazio & Klein, 2020; Hall, 2008). In negotiating these priorities, the artist represents the situated nature of data, a fundamental principle of critical perspectives.

We explore a form of data-driven art-making, in which learners identify a message to convey, reflect on the different perspectives and complexities involved in a data set, and determine how to use materials to communicate that message to evoke a desired reaction from an audience. As students engage in asking questions, gathering and interpreting data, and communicating an evidence-based claim or argument to inform or persuade, our conjecture is that an arts-based approach will encourage a critical perspective on data that is often absent from mathematics alone. Such a perspective would involve connecting data to context, identifying patterns in data at an aggregate, and weighing the warrant of the data for supporting arguments or claims (Makar & Rubin, 2018).

To examine the opportunities and challenges in students engaging in art-making for data literacy, we designed and implemented a unit, and asked: (1) *What value do teachers perceive in an arts-integrated approach to data science?* and (2) *How does this approach engage students with data?* By understanding teachers' goals and students' experiences, we can better design similar interdisciplinary activities that are feasible for the classroom.

Methods: Context, participants, and data

To explore the value of an arts-integrated approach to supporting data literacy, we co-designed and implemented a unit with two teachers, one art teacher (Kelly, female) and one math teacher (Bruce, male)) and their 25 seventh grade students. Kelly and Bruce teach at the same private school in the United States, in which their administration encourages interdisciplinary connections between subjects. Kelly and Bruce identified the theme of social interaction, which they felt would interest their students. The two-week unit was presented as a way for the students to explore the theme using both data and art through two activities: (1) a data drawing, which involved students collecting, organizing, and visualizing data using hand-made drawings to reveal patterns about their everyday social experiences (e.g., the number of times they heard the word "pandemic;" number of conversations they had and with whom); and (2) a data sculpture, which involved students using materials found in their homes to communicate a pattern found in their exploration of data on teens' use of social media. For this activity, we provided students with a tool (bit.ly/sm-pew) to explore an existing data set on teens' use of social media (Pew Research Center, 2015). This tool allowed students to explore the responses to survey questions (e.g., "Does social media make you feel better connected to your friends' feelings?") and group the data based on characteristics (e.g., gender, age, race/ethnicity, etc.). Because of the COVID-19 related school shutdown, students completed the activities asynchronously from their homes, sharing photographs of their artwork with peers, and responding to reflective prompts using the Web-based Inquiry Science Environment (WISE, wise.berkeley.edu). To support students' navigation through the unit, teachers corresponded with students via email and Google Classroom, and facilitated optional virtual synchronous check-in sessions once per week.

Our data consist of (1) a post-unit group interview with two students (whom we name Ariel (female) and Yamil (male)), which asked them to reflect on their experiences during the unit and to elaborate on the decisions they made in creating their artwork; (2) individual post-implementation interviews with each teacher, in which we ask them to reflect on how the unit met or failed to meet their learning goals, and on notable observations of student learning; (3) student artifacts (artwork, artist statements, and written reflections on their processes); (4) responses to a pre and post survey that probed students' engagement and self-perceived competencies in math and art, and their abilities to critique existing data-based art; and (5) researchers' reflections on our experiences co-designing the unit over the several months prior to its implementation, and in supporting teachers throughout its implementation. Three researchers conducted a thematic analysis of the data using an open coding approach to develop descriptive categories, and refining these through discussion and re-reading of transcripts (Saldaña, 2015). To answer RQ1, we describe the key themes that emerged from our analysis focusing mostly on the interviews with the teachers. To answer RQ2, we use our multiple data sources to construct narratives of students' experiences. For the purposes of this paper, we focus on students' data sculptures.

Findings

RQ1 What value do teachers find in an arts-integrated approach to data science?

The teachers indicated three main benefits from implementing an arts-integrated approach to data science with their students. First, it enabled students to contextualize ideas in the real world, increasing their awareness of the applications of art and math. Kelly noted that she "liked showing students why people create art (…) that it's more than just being an artist." She stated that a valuable part of the activity was showing students that "art can also help us understand concepts in other fields," and that data-based artists "exist and (...) this is an option for them instead of doing the graphs and the bar charts, you could make it more expressive (...) you can kind of go further with your statistics." Similarly, Bruce wanted students to use mathematical tools to accomplish a meaningful and practical goal, "not only are they working with the numbers, but they're taking that information and then doing something else with it, with the hope that it'll you know stick in their brain a little bit." Additionally, an arts-based approach was seen as important for students to recognize the real-world implications of data. Kelly observed that the activities allowed students to see "the overall story of the numbers, they were looking at. It wasn't just 90% of this or 40% of this. They saw: 'OK, so real people. So I'm going to tell the story of the person.' So that (...) puts a narrative into their math class."

Second, the teachers chose this curriculum to provide students with opportunities to use art and math to pursue their own interests. For example, Bruce appreciated that students "had to come up with their own question, and (...) find a topic they like to learn." He also noted that although the activity was less math-focused than he would typically assign, it was especially appropriate for asynchronous learning. Students "were able to do something that they might enjoy for school work" while incorporating diverse materials, connecting to "a lot of different topics and com[ing] up with their own ideas." Kelly also noted the ways that students seemed to build personal relevance, "I think [the topic choices] were very relevant to them because you know you can see in some of their storytelling, you know it sounds like they were kind of talking about their own experience".

Third, the curriculum provided new ways for students to work with data, demonstrate their understanding, and facilitate assessment of students' learning. Bruce noted that these types of interdisciplinary approaches provide him with an opportunity to promote inclusivity by helping him "make things, both the information and the assessment of what they've learned, kind of accessible to as many students as I can." By providing many options he hopes learners can “find their comfort zone.” The unit also provided new ways to assess learning, particularly how and whether students were able to transfer knowledge across contexts. He could see that the students were “not just regurgitating information exactly the way it was taught to them. They were shown some examples of how to read this data, what they could do with it, and they proved that they were able to do independent thinking with that by doing different types of projects that we didn't show them. (...) they have to be able to make inferences about the data (...) and the project was a good way to assess that.”

RQ2 How did students engage with data through art?

Ariel. Ariel’s pre and post-survey responses showed she developed a new awareness of the relationship between data and art. By the end of the unit, she expressed a belief that the quality of data-driven art resides in “how much [it] can show the meaning of a graph...” Ariel began the data sculpture project by exploring the Pew data set. She was intrigued by how frequently teens’ used the internet, a finding based on a graph titled “overall, how often do you use the internet?” From this discovery, she attempts to answer “how the internet can be impactful on the minds of teenagers.” She then misrepresented the data by making a claim grounded in her own perceptions of teens’ internet use: “social media appear to affect different people in different ways by finding what they are interested in, attracting them into that subject, and making you lost into the world of social media.” Using this statement, she mapped variables onto different visual attributes (Figure 1, left) to contrast teens who do and do not use the internet.

Ariel used the colors and arrangement of crayons, scissors, and hair elastics to symbolize the attitude differences she perceived between the two groups. The open scissors and scattered arrangement of objects in one pile represents the “open-mindedness,” imagination, and inclination toward “drama” that she perceived in teens who use the internet. Meanwhile the circular shape of the hair elastics and the square arrangement of crayons in the second pile represent people “circling around a topic,” who avoid the internet, and whom she presumes are more “organized, more ordinary (…) [and who] focus on educational stuff.” Kelly admired Ariel’s use of symbolism, and was surprised at how it differed from Ariel’s typically conventional artwork.

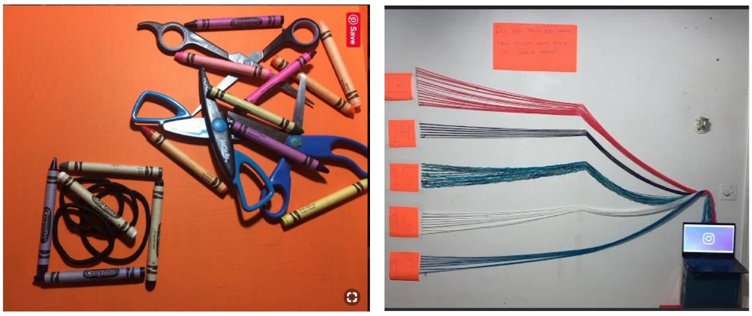

Figure 1. Data sculptures from Ariel (left) on the impacts of the internet, and Yamil (right) showing teens who “disagree” with the statement “Do you think age impacts how much teens share on social media?” by age.

Yamil. Based on his pre-test, Yamil had difficulty evaluating the quality of data, and making accurate claims based on graphical representations of data. He began his data sculpture by seeking relationships in the Pew data that he believed would be interesting to a wide audience (pre-teens and parents). He chose to communicate the relationship between young people’s age and their attitudes toward sharing personal information on social media. He first tried using clay to represent this relationship, but when he could not accurately scale his sculptures to the data, he abandoned this medium in favor of yarn. He pinned the yarn to a wall, distinguishing age groups by the yarn’s color, and mapping the number of strands to the number who disagreed with the claim.

Kelly, who shared that Yamil was one of the more creative students, noted surprise at the resemblance of his artwork to a canonical graph. At the same time, Yamil had misinterpreted the data set in multiple ways. His title, “Younger age group reveal more personal information on social media,” suggests that Yamil believed the data to be about how much information teens share, rather than teens’ perceptions of how much others share on social media. Moreover, the decisions he made for practical reasons seemed to have led to misrepresenting the data. More specifically, instead of showing each of the 1,060 survey respondents, Yamil transformed and filtered the available data, reinterpreting the Likert scale as a binary yes/no question, and representing only the respondents who disagreed with the focal statement. By representing only a fraction of the sample and using sums rather than percentages, he overlooked the fact that 80% of 13-year olds actually believe that people share too much personal information. It seemed that Yamil’s expectation that “older kids know more” (as in, they know better than to share personal information online) prevented him from recognizing his misinterpretation.

Discussion and significance

In exploring how teachers and students experienced an arts-based approach to data literacy, we found that students generated unique questions, negotiated relationships between data and materials, and made claims that attempted to go beyond the data. Ariel conveyed meaning through the color, shape, and organization of materials, while Yamil used an unconventional material (yarn) to construct a conventional representational form. Both students ultimately drew on personal beliefs rather than on the data as evidence to support their claims, a difficulty identified by Hug & McNeill (2008). By examining their process, artifacts, and reflections, we identify opportunities to better support students' informal inferences through art-making.

First, while Kelly and Bruce both highlighted the chance for students to pursue their interests through this unit as an opportunity, students struggled to communicate personal perspectives that were also grounded in data. Ariel and Yamil incorrectly interpreted data when pursuing questions that were personally interesting to them, rather than develop new questions, answerable with the data available. This shows the difficulties of working with data as an artistic material, that is, in negotiating its affordances and constraints for communicating a perspective to an audience. The mandated asynchronous format limited the discussion that teachers would have facilitated to address such issues. To scaffold students' sense-making, future iterations might incorporate tools and routines of authentic artistic practice, such as with tools such as peer and public (Soep, 2005), wherein students can iterate on their ideas, examine their biases, and test their artistic choices.

A second challenge was in defining data art. Yamil made a functional data art sculpture, offering his audience a tool for discovery by attempting to represent the data objectively. Ariel, on the other hand, made an expressive data art sculpture, connecting her audience to the topic through a feeling or concept. Both students showed difficulties in making and communicating informal inferences about data, either being unable to go beyond the data or using data as little more than inspiration. It is essential to support reflection on how choices about data skew toward either extreme, and to support students in iterating toward the center. In future, we will find ways for students to create personal connections with broader social patterns found in data.

This study highlighted the opportunities in an arts-based approach for allowing students to make inferences that give data personal and social meaning. It also emphasized the need to ensure that students are grounding their interpretations in evidence. Findings will inform future research and design on arts-based data literacy and art at the middle school level.

References

D'Ignazio, C., & Klein, L. F. (2020). Data feminism. MIT Press.

Franklin, C., Bargagliotti, A., Case, C., Kader, G., Scheaffer, R., & Spangler, D. (2015). The Statistical Education of Teachers. Washington, DC: American Statistical Association. Retrieved from http://www.amstat.org/education/SET/SET.pdf

Hall, P. A. (2008). Critical Visualization. In, *Design and the Elastic Mind*. Museum of Modern Art, New York.

Hug B. & McNeill K. L. (2008). Use of first-hand and second-hand data in science: Does data type influence classroom conversations? *International Journal of Science Education, 30*(13), 1725-1751, DOI: 10.1080/09500690701506945

Kahn, J. (2020). Learning at the intersection of self and society: The family geobiography as a context for data science education. *Journal of the Learning Sciences, 29*(1), 57-80.

Lupi, G., & Posavec, S. (2016). *Dear Data*. Chronicle Books.

Makar, K., & Rubin, A. (2018). Learning about statistical inference. In *International Handbook of Research in Statistics Education* (pp. 261-294). Springer, Cham.

Pew Research Center. (2015). Teens, Social Media & Technology Survey. [data file and code book]. Retrieved from https://www.pewresearch.org/internet/2015/04/09/teens-social-media-technology-2015/

Saldaña, J. (2015). *The Coding Manual for Qualitative Researchers* (3rd edition). Sage Publications Ltd.

Soep, E. (2005). Critique: Where art meets assessment. *Phi Delta Kappan, 87*(1), 38-63.

Stornaiuolo, A. (2020). Authoring data stories in a media makerspace: Adolescents developing critical data literacies. *Journal of the Learning Sciences*, *29*(1), 81-103.

Turkle, S., & Papert, S. (1990). Epistemological Pluralism: Styles and Voices within the Computer Culture. *Signs: Journal of Women in Culture and Society*, *16*(1), 128–57.

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Reasoning about Equations with Tape Diagrams: Insights from Math Teachers and College Students

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Abstract: Research has shown that tape diagrams are beneficial for algebra learning. However, it is unclear whether certain visual features of tape diagrams have implications for learning. We investigated, with undergraduate students and math teachers, whether tape diagrams with different visual features (color, presence of outer lines, and position of the constant) differentially support reasoning about equations and whether people have preferences for certain visual features. Variations in visual features did not affect students' or teachers' reasoning accuracy; but each group displayed systematic preferences for most visual features considered. Future research should examine the effects of these visual features on performance while solving equations.

Introduction

Diagrams are a valuable tool for helping students understand mathematical concepts and procedures (e.g., Chu et al., 2017; Murata, 2008). Diagrams are thought to support students in solving problems, understanding structural relationships, and building conceptual understanding (e.g., Larkin & Simon, 1987). As such, curricular standards, such as the Common Core State Standards for Mathematics (CCSSM, 2010), designate diagrams as important learning tools. The CCSSM specifically recommend a type of diagram called tape diagrams (henceforth TDs). In TDs, quantities are depicted in horizontal bars, similar to strips of tape.

One domain in which TDs may be especially useful is algebra. Algebra presents challenges to many students, in part due to an overemphasis in algebra instruction on procedural skills, rather than conceptual understanding (Richland et al., 2012). Past work has suggested that TDs may support students in generating and solving algebraic equations (Booth & Koedinger, 2012) and in transitioning from informal to formal strategies (Nagashima, Bartel et al., 2020). TDs thus appear to hold promise for supporting algebraic thinking.

A close inspection of the literature on TDs indicates that visual features of TDs vary substantially across studies, raising the questions of whether particular visual features influence performance, and whether teachers or learners have preferences for specific visual features. Both questions are important when designing instructional materials, because small variations in design features can lead to large variations in learning (e.g., Barbieri et al., 2019).

One relevant study sought to analyze the affordances of TDs for student learning using a qualitative, teacher-centered approach termed Pedagogical Affordance Analysis (PAA) (Nagashima, Yang, et al., 2020). This study identified an optimal design for TDs based on substantial input from teachers. In a later classroom experiment, such TDs enhanced students' conceptual knowledge when used in early algebra learning activities (Nagashima, Bartel, et al., 2020). However, it remains unknown whether specific visual features have differential effects on student performance, or whether students' preferences align with the preferences of teachers. Understanding students' and teachers' preferences may inform researchers and practitioners who design instructional materials. Further, it is possible that a misalignment between the preferences of students and teachers could lead to misconceptions or student disengagement.

In the present investigation, we address three corresponding research questions: (1) What visual features of TDs help undergraduate students and math teachers accurately symbolize equations? (2) What visual features of TDs do students and math teachers prefer? (3) Do students and math teachers believe that TDs are useful, and do these judgments relate to their performance when working with TDs?

Method

Participants

We collected data with two samples of participants: undergraduate students ($N = 50$) and math teachers in the US ($N = 163$). Undergraduates were recruited through an introductory psychology participant pool at a Midwestern university; teachers were recruited via postings on social media. Per self-report, the student sample was 56% female and 36% male; 8% declined to report gender. The student sample was 78% White and 20% Asian; 2% declined to report race or ethnicity. Students had varying levels of math knowledge, with 18% of students having never taken Calculus, 68% of students having taken one or two semesters of Calculus, and 10% having taken beyond two semesters of Calculus; 2% declined to report. The teacher sample was 49% female and 49% male; 2% declined to report gender. The teacher sample was 50% White, 15% Hispanic/Latinx, 14% Black/African American, 8% Asian, 5% Native American, 2% Native Hawaiian/Pacific Islander, and 4% multiple races/ethnicities; 2% declined to report race or ethnicity. On average, teachers had 9.4 years of experience (*SD* = 7.1). 121 (74%) of the teachers reported having seen TDs in the past, and 113 (69%) reported using diagrams similar to TDs in their teaching. Of the teachers, 48% taught grades 1-5, 31% taught grades 6-8, 11% taught grades 9-12, and 8% taught multiple grades, with 2% teaching other grades or declining to report.

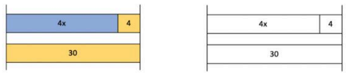
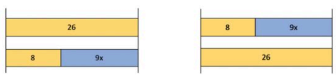
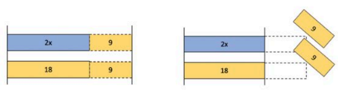
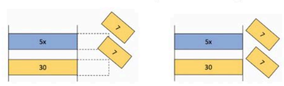
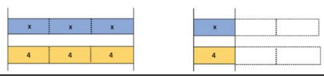
Design and procedure

Each participant completed an online survey via a web-based platform. In the survey, participants were presented with three tasks: Symbolization, Preference Ratings, and Ratings of Perceived Usefulness.

Symbolization Task: Participants were presented with TDs and were asked to generate corresponding equations. For example, participants might be presented with the TD in the first row of Table 1 and be asked to generate the corresponding equation (the correct answer is 4x + 4 = 30). The diagrams varied in visual features, including whether or not they used color, whether they included vertical lines, and whether the constant was on the top or bottom tape. Responses were coded as correct or incorrect. Undergraduates were asked to symbolize six one-operation and six two-operation equations; teachers were asked to symbolize four equations of each type.

Preference Ratings: Participants were then shown 12 pairs of TDs that varied by one feature and were asked to choose which TD best represented the equation (see Table 1). Following this task, participants responded to a set of general questions regarding their preferences (e.g., "What features did you like/dislike about the tape diagrams you just saw?"). Responses were coded for the specific visual features and for whether they noted *aesthetic* or *conceptual* reasons for liking or disliking a feature (see Table 2).

Table 1: Variations in visual features of diagrams.

Equation	Feature	Examples
4x + 4 = 30	Color	
8 + 9x = 26	Constant Location	
4x + 6 = 50	Line	
2x + 9 – 9 = 27 - 9	Dynamic: Subtraction	
5x + 7 – 7 = 37 -7	Phantom Dashed: Subtraction	
3x = 12	Full Dashed vs. Phantom Dashed: Division	

Ratings of Perceived Usefulness: Participants responded to questions about the perceived usefulness of TDs on a five-point Likert scale (Strongly Disagree to Strongly Agree) (e.g., "Tape diagrams helped me represent the equations"). They also responded to three questions regarding whether they thought younger students would find TDs helpful or not helpful (e.g., "Tape diagrams would help younger students represent equations").

Results

We first analyzed whether specific visual features influenced participants' abilities to generate equations to correspond with TDs. Success on the one-operator items was at ceiling, so we focus here on the two-operator items. Based on previous research (Nagashima, Yang et al., 2020), we selected the "baseline" TD as including color, including outer lines, and having the constant on the bottom. We then compared each of the variants to this baseline. Thus, the TDs were categorized into four groups: baseline, baseline without color, baseline without outer lines, and baseline with the constant in the top tape.

Undergraduates performed similarly at symbolizing all four types of TDs ($M = .69$, $SD = .06$), $F(3, 196) = .54$, $p = .65$. Likewise, teachers also performed similarly at symbolizing all four types of TDs, ($M = .44$, $SD = .04$), $F(3, 486) = .83$, $p = .47$. Thus, variations in visual features did not affect symbolization accuracy.

We next analyzed whether participants preferred specific visual features. We evaluated the same features used in the symbolization task, as well as additional features that represented intermediate steps in equation solving (Table 1). Descriptively, both students and teachers had general, group-level preferences for four of the six features: use of color, having the constant in the bottom tape, using full dashed lines to represent division, and using phantom dashed lines to represent the removal of break-away pieces (Figure 1). The only feature for which there was no clear preference in either group was representing subtraction with dynamic break-away pieces vs. a static representation.

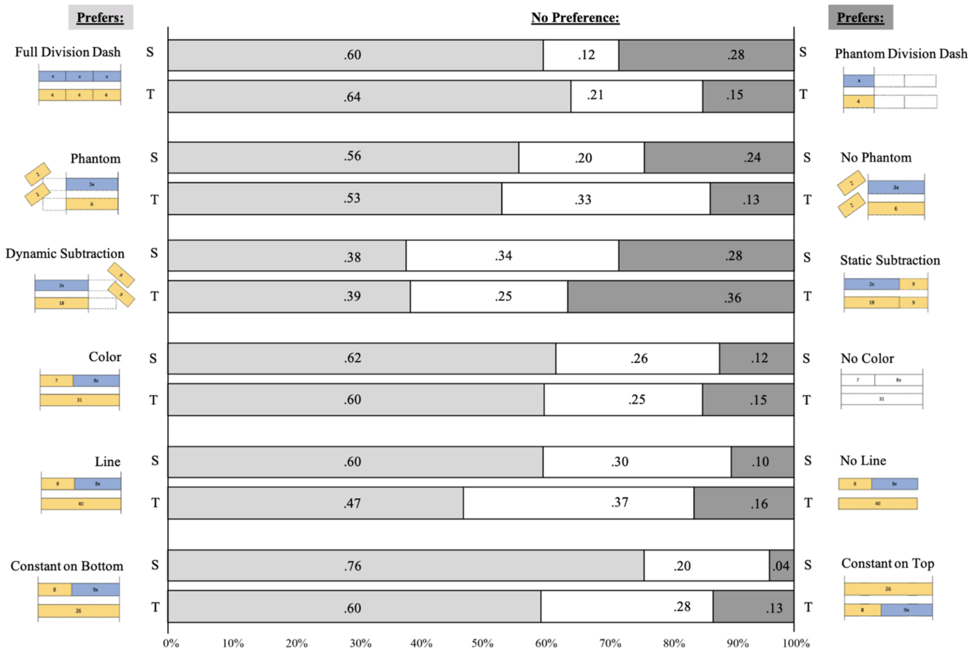


Figure 1. Preferences for TD visual features as a function of specific features and whether the participant was a student or teacher. "No preference" ratings indicate participants who were inconsistent in their ratings (e.g., stating that they preferred color on the first trial and no color on the second trial).

Table 2 presents data on participants' responses to the open-ended questions (e.g., "What features did you like about the tape diagrams you just saw? Be as specific as possible"). Descriptively, across groups, the majority of responses focused on either color/no color or line/no line. Students tended to provide aesthetic reasons for their preferences, while teachers tended to provide conceptual reasons. Teachers mentioned the representation of intermediate steps (e.g., dynamic subtraction) more frequently than students.

Table 2: Number of students (S) and teachers (T) who provided aesthetic and conceptual reasons for their preferences for specific types of TDs.

	Aesthetic			Conceptual		
	Like	Dislike	Example	Like	Dislike	Example
Color v. No Color	S: 20 T: 5	S: 6 T: 7	"I liked the different colors used…"	S: 8 T: 17	S: N/A T: 11	"I liked the colors to distinguish constants from expressions with *x*"
Line v. No Line	S: 8 T: 1	S: N/A T: 1	"I like the bars on the ends"	S: 4 T: 12	S: 1 T: 1	"I also liked the vertical lines to show clearly that the two values were equal"

Finally, we asked whether participants viewed TDs as useful for supporting equation solving. For each sample, we regressed the percent of equations that participants accurately symbolized on their self-reported usefulness of TDs score. For both samples, the more useful participants perceived the TDs to be, the higher their accuracy at symbolizing (students: $F(1,48) = 6.03$, $p = .017$, $R2 = .11$; teachers: $F(1,161) = 87.17$, $p < .001$, $R2 = 35$). Undergraduates rated TDs as more useful for younger students than for themselves, $t(49) = 4.42$, $p < .001$, whereas teachers rated TDs as equally useful for younger students and themselves , $t(163) = .24$, $p = .81$.

General discussion

Both students and teachers preferred TDs that used color, represented the constant in the bottom tape, used full dashed lines to represent division, and used phantom dashed lines to represent removing break-away pieces in subtraction. A smaller majority preferred outer lines. Participants based these preferences on aesthetic and conceptual grounds, with teachers' preferences being primarily conceptually based. Variations in visual features did not affect undergraduates' or teachers' success at generating equations to correspond to the TDs.

For teachers who wish to use TDs in instruction, this information about preferred features may be useful. Building on their pedagogical content knowledge, teachers may integrate the preferred TDs in lessons, for example, to illustrate solution procedures or to support self-explanation activities. Using TDs with preferred visual features may promote students' enjoyment of and engagement with the material.

In both samples, success at symbolizing TDs was associated with the perceived usefulness of the diagrams. Some participants may have understood the conventions upon which TDs are based better than others, and this third variable may have given rise to the observed association. Participants who viewed TDs as useful also tended to judge that they would be useful for younger learners. Future studies should investigate younger students' preferences for visual features and should examine whether visual features differentially support learning and symbolization in younger students.

In sum, this study revealed systematic preferences for visual features of tape diagrams in both teachers and undergraduates. These preferences can inform the design of curricular materials that involve such diagrams.

References

Barbieri, C. A., Miller-Cotto, D., & Booth, J. L. (2019). Lessening the load of misconceptions: Design-based principles for algebra learning. *Journal of the Learning Sciences*, *28*(3), 381-417.

Booth, J. L., & Koedinger, K. R. (2012). Are diagrams always helpful tools? Developmental and individual differences in the effect of presentation format on student problem solving. *British Journal of Educational Psychology, 82*(3), 492-511.

Chu, J., Rittle-Johnson, B., & Fyfe, E. R. (2017). Diagrams benefit symbolic problem-solving. *British Journal of Educational Psychology, 87*(2), 273-287.

Common Core State Standards Initiative. (2010). Common core state standards for mathematics. http://www.corestandards. org/assets/CCSSI_Math% 20Standards.pdf.

Larkin, J. H., & Simon, H. A. (1987). Why a diagram is (sometimes) worth ten thousand words. *Cognitive Science, 11*(1), 65-100.

Murata, A. (2008). Mathematics teaching and learning as a mediating process: The case of tape diagrams. *Mathematical Thinking and Learning, 10*(4), 374-406.

Nagashima, T., Bartel, A. N., Silla, E. M., Vest, N. A, Alibali, M. W., & Aleven, V. A. (2020). Enhancing conceptual knowledge in early algebra through scaffolded diagrammatic self-explanation. In M. Gresalfi & I. S. Horn (Eds.), *Proceedings of International Conference of the Learning Sciences* (pp. 35-43). Nashville, TN: International Society of the Learning Sciences.

Nagashima, T., Yang, K., Bartel, A.N., Silla, E. M., Vest, N., Alibali, M.W., & Aleven, V. (2020). Pedagogical Affordance Analysis: Leveraging teachers' pedagogical knowledge for eliciting pedagogical affordances and constraints of instructional tools. In M. Gresalfi & I. S. Horn (Eds.), *Proceedings of International Conference of the Learning Sciences* (pp. 1561-1564). Nashville, TN: International Society of the Learning Sciences.

Richland, L. E., Stigler, J. W., & Holyoak, K. J. (2012).Teaching the conceptual structure of mathematics. *Educational Psychologist, 47*(3), 189–203.

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Student Epistemic Agency and Coherence-seeking through Laboratory Experiments

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Abstract Overly simplistic school science laboratories constrain student agency. We share and discuss a case from 9th grade science classroom in which students all conducted highly varied independent investigations that were each highly coherent and scientifically well-motivated. We discuss the conditions that led to their experiments in terms of instability and uncertainty. Our findings suggest that it may be beneficial to support and recognize multiple forms of uncertainty simultaneously to encourage multiple forms of investigation to respond to those uncertainties. Finally, an "instability" caused by having *multiple* candidate models or explanations in play may be more generative than uncertainties based on gaps in knowledge.

Introduction

Recent efforts in K-12 science education have focused on the design of coherent curricular "storylines" (Sikorski & Hammer, 2017). Rather than "pre-meditated coherence" as a property of the curriculum, Sikorski and Hammer (2017) suggest that coherence should be seen as an emergent result of students' coherence-seeking. For this to be fruitful, students must be positioned with the epistemic agency to seek coherence for themselves— yet this still is rare within school science activities (Greeno, 2006; Miller, Manz, Russ, Stroupe & Berland, 2018). As a field, we are beginning to recognize that students must be positioned with epistemic agency throughout the full cycle of scientific inquiry—deciding on phenomena of importance, approaches to studying it, what forms of data are useful to collect, how to represent and analyze that data, and in argumentation from evidence.

However, when it comes to laboratory work in school science curricula, students are rarely positioned with epistemic agency. Epistemic agency involves students being "positioned with, perceiving, and acting on, opportunities to shape the knowledge building work in their classroom community" (Miller, Manz, Russ, Stroupe & Berland, 2017). In particular, experimental design, research questions, and methods of collecting and analyzing data are often strongly prescribed (Greeno, 2006; Hardy, Dixon & Hsi, 2020). Supporting student agency in inquiry requires educators to move beyond "cookbook" scientific investigations, to investigations that are motivated by student questions and ideas, and designed, carried out and iterated on by students. Doing "real science"— with the full complexity, uncertainty and messiness that it entails— is often in tension with narrow conceptual learning goals (Hardy, Dixon & Hsi, 2020). Moreover, school laboratory investigations rarely allow for or resemble the various forms of "coherence-seeking" found in professional scientific practice (Chinn & Malhoutra, 2002). Frequently, students all do the same experiment in parallel, or work to investigate the same underlying "driving question." Commonly, as part of teaching a "control of variables strategy," students may be asked to identify a parameter to vary regardless of whether "fair testing" or controlled experiments are actually motivated or appropriate.

Productive uncertainty

Building uncertainties into epistemic work may be a fruitful way to support both student epistemic agency and authentic scientific activity (Manz, 2018). Contending with uncertainty is an important component of science learning (Metz, 2004). Uncertainty has primarily been discussed as a sort of cognitive or metacognitive state of not knowing, for example in qualifying claims in the context of argumentation (Metz, 2004). In other views, uncertainty characterizes a state of ongoing activity that is recognized, maintained, or resolved by participants by re-organizing social or conceptual resources for that activity (Kirch, 2010). Uncertainty can thus play an important role in science learning by opening space for students to exercise agency. Uncertainties can be strategically designed into classroom activity such that students have opportunities to negotiate the forms of data to collect, how to represent data or phenomena, and what counts as evidence (Metz, 2004; Lehrer, 2009; Manz, 2015). Manz (2018) argues that this *productive uncertainty* should be evidenced by a variability, rather than convergence, of student ideas and questions and approaches. However, traditional laboratory investigations in science classrooms rarely promote a productive uncertainty, with the aims and results of these experiments often known in advance, and with a straightforward conceptual interpretation arrived at similarly by all students. The field needs a better understanding of how disciplinary uncertainties and ambiguities can be designed into students' laboratory work in ways that support student agency and deepened engagement in practice.

Instabilities in science practice

The view of *uncertainty* as a state of ongoing activity resonates with descriptions of science practice as an iterative, goal-directed "mangling" (Pickering, 2010) of conceptual, material and social resources. In Pickering's view, the material world resists the scientists' efforts to know and control; the scientist exercises agency in determining the future course of the activity by shifting goals, revising conceptual understandings, or modifying instruments and material practices. Over time, knowledge is established through processes of *stabilization* of these various elements of scientific activity. In authentic scientific investigations, there are many possible pathways forward; moments of 'material resistance' (Pickering, 2010) are characterized by uncertainty not only in how to interpret data but how to proceed in inquiry. Thus moments of material resistance are periods of *instability* in scientific activity, in which scientists exercise conceptual agency (Pickering, 2010). We conceptualize students' epistemic agency as an extension of Pickering's notion, to include the ways that students reorganize activity to align with their own interests, objectives, or desired learning trajectories. This includes shifting or forming new goals, or re-organizing conceptual (e.g., re-thinking, re-explaining, revising models) or social resources (e.g., taking on a new role, positioning someone else in a new role, drawing on available expertise in new ways). Our hypothesis is that uncertainty, as a form of instability in scientific activity, can provide opportunities for students to exercise conceptual agency, and align their empirical investigations with their own areas of interest or goals.

Research context and data collection

Our data come from a research project to design sensor-based labs that support computational thinking through data acquisition and control. Our designed activities were used in three 9th grade Integrated Science classes at a large urban public charter school in Northern California, taught by Mr. B. Over two weeks, students were introduced to the sensors and software, and conducted two investigations related to photosynthesis and cellular respiration. In the first investigation, students observed changes to carbon dioxide levels in container of spinach leaves when it was placed either in the dark or in the light. After a discussion of the results of that investigation, the students then conducted follow-up experiments of their own design. We observed all class sessions, video-recorded selected groups of fully consented students, collected written student work, and conducted follow-up interviews with 18 student participants about their experiences and their final investigations. One aim of our analysis, at this stage, was to better understand opportunities for student epistemic agency within the curriculum, and in particular how material resistances, or surprising "pushback" from the material world, may provide opportunities for student agency.

Case report: Student responses to instability and uncertainty due to an anomalous dataset

Part 1: Instability and uncertainty

After the initial introduction to the sensors and software, students were tasked with collecting data about the relationship between light intensity and CO2 levels in closed containers of spinach leaves. The teacher showed the students a demonstration setup that consisted of a plastic container, sealed with plastic wrap and placed inside a cardboard box that both held the lamp above the spinach leaves, and blocked out stray light. Over two class periods, each small group built a similar setup, and collected CO2 data under two conditions: with the spinach leaves under a bright lamp, or in the dark. With the light off, cellular respiration in the leaves will increase the CO2 levels in the container. When the light is turned on, the leaves then photosynthesize, and the carbon dioxide levels drop.

In each period, after groups had collected their data, Mr. B facilitated a discussion of the results. He began by establishing a class consensus about what trends they had seen in their data (carbon dioxide levels rising in the dark, and dropping in the light). Students readily offered the explanation that the levels dropped in the light condition due to photosynthesis. However, as we expected, they were surprised and perplexed by the rise in CO2 levels in the dark. Mr. B elicited the students' ideas about why they might rise in the dark. In each class section, some students attributed the rise to a reversal of the photosynthetic process of taking in CO2, and others to the idea that spinach was dying, and/or decomposing, when the light wasn't on to sustain the plant's health. In each class, Mr. B noted the surprising results, and their collective uncertainty about the explanation.

However, in Mr. B's Period 2 classroom, this discussion proceeded differently. Fernando's group had contributed a dataset that was very different than the others. Instead of constructing the cardboard box to hold the lamp vertically, they placed their lamp on the table nearby the container of spinach, such that when the light was on it was effectively at a much lower intensity. As a result, instead of the carbon dioxide levels going up in the dark and down in the light, Fernando's went up in the dark, and up (just more slowly) in the light. When he showed his data to Mr. B, Fernando initially thought he would have to re-start a botched experiment. However, Mr. B recognized the value of this anomalous dataset and brought it to the other students' attention.

In the next session, the class discussed their experimental results. Akeem suggested that the rise in CO2 was due to the plants decomposing when in the dark. Raeleen expressed skepticism about this explanation. Alejandra brought up Fernando's data, which showed the leaves releasing CO2 even when the light was on. This suggested to the class that rising CO2 levels may not be due to decomposition of the leaves. Fernando then took up the position within the discussion that plants are *always* releasing carbon dioxide, but photosynthesis may happen in parallel, just more or less slowly. Akeem wondered aloud how this would happen— whether the plants are doing something like breathing in and out. As in his other two class sections, Mr. B left the discussion in a state of uncertainty, and directed the students to design and carry out follow-up investigations.

Part 2: Student follow-up investigations

In Mr. B's two other sections, students chose many different variables to investigate: the intensity of the lamp, the color of the light, the type of plant, whether spinach leaves were kept in a sealed or open container, the age of the spinach leaves, or even to use leaves before and after being cut from a whole plant. Of these experiments, only this last one was conceptually motivated by their previous experimental results or the discussion of them. This group hypothesized that the rise in CO2 would no longer happen if they could keep the leaves from dying, by leaving them attached to the plant. In contrast, the students in Period 2 who had discussed Fernando's data each took on a variety of projects directly motivated by the previous experimental results and discussion. Below we briefly describe each group's follow-up experiment.

Fernando: Seeking additional data

Fernando requested an oxygen sensor to add his experiment. Oxygen sensors were not already available in the hardware kits, so we brought him a prototype. He wanted to re-do his first experiments, while additionally monitoring the oxygen levels as the carbon dioxide levels changed to see how they could be related.

Alejandra and Linda: Investigating an alternative hypothesis

Alejandra and Linda did not agree that Fernando's dataset was different because his light was effectively dimmer. Instead, they thought that his lamp did not heat the spinach as much as other students', and that the release of carbon dioxide could depend on temperature. They used their project as an opportunity to investigate this alternative hypothesis, through a unique experimental design to create extreme temperature conditions. They heated spinach in a water bath, and froze spinach in a freezer.

Akeem and Maala: Model development

Akeem initially thought that the plants were decomposing at night and releasing CO2, though this was challenged by Fernando's data, which showed carbon dioxide being released even in the light. Akeem was curious how the plants could both take in and release CO2, and thought that the plants might be doing something like breathing. He then reasoned that changing the amount of CO2 in the container might affect how quickly or slowly the plants breathe in or out CO2. Akeem and his partner Maala followed up by investigating the effect of starting CO2 levels on the plants' absorption or release of CO2, breathing into the containers to create the different starting concentrations.

Raeleen: Realizing implications

As Fernando's data showed that CO2 levels could either go up or down depending on light intensity, Raeleen recognized that this implied that they could find a balance point at which they remained steady. Her project became to create "flat data" by incrementally adjusting the light intensity. Her group added sheets of wax paper in between their lamp and spinach leaves to gradually dim the light.

Discussion

Each of the groups in Period 2 pursued investigations that were coherently linked to and motivated by Fernando's dataset and their own thinking about its explanation or implications. This contrasts with Mr. B's other two periods, in which students primarily conducted investigations that did not substantially build on the previous results or discussion. In Periods 1 and 3, there *was* a recognized gap in knowledge— no one was quite certain how to explain the rise in CO2 levels. This illustrates that simply *not knowing*— or, recognizing gaps in knowledge (here, their ability to explain the rise in CO2 levels)— is an insufficient condition for maintaining and motivating coherent inquiry "storylines." In particular, prescribing "fair testing" experiments, despite the apparent choices and design decisions involved, may fail to position students with epistemic agency by severing (potentially) continuous epistemic threads.

In contrast, in Period 2 there were many acknowledged sources of uncertainty, beyond the lack of explanation for the rise of CO2 levels: uncertainty about particular claims (whether the plants were indeed dying at night), mechanisms (whether plants do something like breathing), evidence (what did Fernando's data really mean?) as well as implications of their results (could the data ever be flat?). Further, the instability inherent in having *multiple* candidate models or explanations in play may have been more generative than uncertainty based in gaps in knowledge. This broader set of recognized uncertainties allowed for a variety of student independent projects to all remain conceptually tied to the classroom inquiry. Thus, we see uncertainties as opportunities for students to exercise epistemic agency, and to contribute uniquely to the scientific activity.

We agree with Sikorski and Hammer (2017) that coherence is an emergent property of student sense-making. To fully support student epistemic agency, even in laboratory investigations, we will need to allow for more variation in student empirical work. Our findings suggest that it may be beneficial to support and recognize multiple forms of uncertainty simultaneously, and to encourage multiple forms of investigation to respond to those uncertainties. Further, we will need to design ways to make students' varied individual contributions to epistemic work explicit— to ultimately weave together students' continuous epistemic threads, at the classroom level, into a collective tapestry.

Conclusions

To design for student epistemic agency in laboratory work we must consider and support forms of investigation beyond students all replicating the same experiment, or each investigating the effect of single variables. Instead, we can allow students to respond to various forms of uncertainties or instabilities with more varied forms and goals of empirical work (e.g. seeking additional evidence, investigating an alternative hypothesis, investigating a particular model, or realizing implications). This will involve creating and recognizing multiple forms of uncertainty and instabilities, and positioning students as capable of managing or responding to them.

References

Chinn, C. A., & Malhotra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. Science Education, 86(2), 175-218.

Greeno, J. G. (2006). Authoritative, Accountable Positioning and Connected, General Knowing: Progressive Themes in Understanding Transfer. Journal of the Learning Sciences, 15(4), 537–547.

Hardy, L., Dixon, C., & Hsi, S. (2020). From data collectors to data producers: Shifting students' relationship to data. Journal of the Learning Sciences, 29(1), 104-126.

Kirch, S. A. (2010). Identifying and resolving uncertainty as a mediated action in science: A comparative analysis of the cultural tools used by scientists and elementary science students at work. Science Education, 94(2), 308–335.

xManz, E. (2018). Designing for and analyzing productive uncertainty in science investigations. In Kay, J. and Luckin, R. (Eds.) Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS) 2018, (Volume 1, pp. 288-295). London, UK: International Society of the Learning Sciences.

Metz, K. E. (2004). Children's Understanding of Scientific Inquiry : Their Conceptualization of Uncertainty in Investigations of Their Own Design Children's Understanding of Scientific Inquiry : Their Conceptualization of Uncertainty in Investigations of Their Own Design. Cognition, 0008(February 2015), 37–41.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. Journal of Research in Science Teaching, 55(7), 1053–1075. https://doi.org/10.1002/tea.21459

Pickering, A. (2010). The mangle of practice: Time, agency, and science. University of Chicago

Sikorski, T. R., & Hammer, D. (2017). Looking for coherence in science curriculum. Science Education, 101(6), 929-943.

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(Re)presenting Nature: Sixth Graders' Place-based Field Trip Experience through Restorying

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Abstract: Western science privileges particular ways of knowing nature and ignores nature as a cultural construct, which results in normative ways to describe the human-nature relationship in learning. Our work as a team of Indigenous and non-Indigenous K-12 educators, learning designers, and university researchers seek to join existing efforts to create transformative science learning. We explore how we can use place-based learning to engage learners with diverse ways of knowing and being, particularly through transcending typical Western ideas of a separated human and nature relationship. In this short paper, we focus on how Naomi, a sixth-grade student, represented her class field trip experience and negotiated the human-nature relationship through restorying. Naomi's restorying demonstrates the main characteristics of socioscientific perspective taking across different layers of her story. Further research is needed to understand how restorying impacts learners' value orientations and supports socioscientific perspective taking.

Context

The rapid development of science and technology privileges science and its related disciplines in learning, which leads to the normative practices that value science over other disciplines and ways of knowing. Researchers have described the process as the scientific gaze, with which people tend to judge non-science with modern scientific standards (Mcneil, 2005). Although science is often seen as acultural, it is shaped by particular cultural, historical, and political beliefs and values and, thus, is one way of reality-making (Hu, 2019).

The dominance of Western science has resulted in the settled expectations in education. Harris (1995) used settled expectations to describe racial hierarchies that attach a set of assumptions, privileges, and benefits to being white. From this perspective, culture and nature are positioned in opposition, with culture being defined by whiteness (and more human) and nature being defined as property (and less than human) (Bang et al., 2012). The distinction between "fully" or "not fully human" explains the gradation of human beings (Smith, 1999), which demonstrates a particular human and nature relationship shaped by settled expectations. Bang et al. (2012) further argues that settled expectations, in schooling, leads to entrenched and hidden boundaries that "tend to control the borders of acceptable meanings and meaning-making practices" (p.303). In fact, Western education is often criticized for anthropocentric characteristics (Lindgren & Öhman, 2019), which represents a separation of humans from nature. The separated and anthropocentric understanding of the human and nature relationship is, however, one perspective of knowing, which often marginalizes other ways of knowing.

In response to these issues, we join scholars (e.g., Bang & Marin, 2015) who are pushing educational researchers to seek understanding "of divergences, convergences, and productive generativity between Western science and Indigenous ways of knowing to create transformative science learning" (p.530). In this paper, we explore how place-based pedagogy can engage learners with diverse ways of knowing and being in ways that transcend typical Western ideas of a separate human and nature relationship. Specifically, we investigate how sixth graders engage with human and nature relationships through a five-day field trip experience. Our study is centered on the following research question: *how do learners negotiate the human-nature relationship in their re-storying of a place-based field experience?* Our findings indicate that restorying of field trip experiences can prompt socioscientific perspective taking (Kahn & Zeidler, 2019). We discuss implications for schooling and future research.

Related literature

Restorying place

Knapp (2005) describes place-based learning as an "instructional approach designed to help students learn about the immediate surroundings by capitalizing on their lived experiences" (p. 278). Prior studies have found that place-based learning does not necessarily benefit learners by engaging them with diverse ways of knowing and being. For example, Friedel (2011) discussed that *Western-orientated* place-based learning could pose challenges and often causes harm to learners with Indigenous backgrounds. Thus, how humans relate to place is culturally varied, and the historical and persistent colonization and settling of the land has resulted in deep trauma for many minoritized communities. Kimmerer argues "our relationship with the land cannot heal until we hear its stories," which is a process she calls "re-story-ation" (Kimmerer, 2013, p.9). This process of "re-story-ation" demands a re-understanding and re-engagement with place from varying perspectives.

While re-story-ation manifests in many forms, in this paper, we connect it to the idea of restorying as a literary practice. Restorying is a learner's rewriting or retelling of "a personal, domain relevant story based on the application of concepts, principles, strategies and techniques covered during a unit or course of instruction" (Slabon, 2009, p.2). Therefore, learners can construct knowledge by reframing and making meaning of their previous experiences through narratives (Foote, 2015). As a pedagogical approach, restorying serves as an important means to engage learners with conceptual application, critical thinking, and ill-structured problem-solving skills (Slabon et al., 2014). In this paper, we seek to capture learners' lived experiences from their written restorying of their field trip experience.

Nature as cultural

Our work is rooted in the belief that nature is cultural; it is socially constructed and has cultural variations (e.g. Medin & Bang, 2014). Scholars have unpacked the cultural perspectives of nature through human and nature relationships. Gallagher (2001) argues that how people relate to nature is one of the key values that vary culturally. In the Value Orientation Model, he identifies three types of human-nature relationships: humans are subordinate to nature, humans are in harmony with nature, and humans are dominant over nature (Gallagher, 2001). The three different human-nature relationships are also associated with the psychological distance between human and nature. The psychological distance between humans and nature is one recognized aspect of cultural differences (Medin & Bang, 2014). Medin and Bang (2014) captured the differences into three categories. Specifically, "nature as the foreground" depicts human activities such as forest walks and berry picking and "nature as a background" depicts human activities such as playing sports. Other human activities that physically change nature can be seen as "intermediate," such as mowing the lawn. Furthermore, Medin and Bang (2014) found that both children and adults from urban and rural Native American communities are more likely to participate in practices with nature as the foreground. These models serve as practical tools for us to understand the relationships between human and nature that are represented in learners' experiences.

Methods

Context

The work presented in this paper is part of a larger, ongoing design-based implementation research (Fishman et al., 2013) project to understand how to design culturally centered sixth grade curriculum (Litts, Tehee, Jenkins & Baggaley, 2020; Litts, Tehee, Jenkins, Baggaley, et al., 2020). As a team of Indigenous and non-Indigenous K-12 educators, learning designers, and university researchers, we focus in this paper on how students restory their field trip experience. The research takes place at Edith Bowen Laboratory School (EBLS), a K-6 elementary public charter and Title I-Targeted Assistance school located in the Mountain West. We invited all 55 sixth graders across two classrooms in one school year, and 39 sixth graders fully consented. Participants were 11-12 years old at the time of data collection. The student demographics of the school are 86% White, 5% Multiracial, 6% Hispanic, 1% Black or African American, 2% Asian, 1% American Indian or Alaska Native, and 0% Native Hawaiian or Other Pacific Islander.

EBLS has a place-based learning emphasis and provides unique field experiences to students throughout their schooling. In this paper, we focus on a five-day field trip with three days and two nights river rafting on the San Juan river, a natural border with the Navajo Nation. During the trip, teachers designed structured engagements with nature and culture for students. For example, prior to visiting ancient ruins in the area, which are sacred lands to local tribes, Jen (Author 7), the Math and Science teacher, shared a short story written by a former student, who self-identifies with one of the local tribes, to highlight the significance of the ruins and promote respect of place (Litts, Tehee, Jenkins & Baggaley, 2020). Throughout the trip, Stu (Author 6), the English Language Arts and Social Studies teacher, employed the hero's journey narrative structure to frame the field trip experience. The hero's journey is a recurring template of many stories, myths, folktales, and legends that tells the story of a main character facing a significant life problem and setting off for an adventure to resolve it (Campbell, 1993). Upon returning from the trip, the students were tasked with restorying their experience through writing their own version of a hero's journey.

Data collection and analysis

As part of the broader project, we collected a range of data such as recordings of meetings, fieldnotes, and documentation of student work, as well as students' interviews and surveys conducted at three different time points throughout the school year. In this particular study, we focus on students' short story writings that they wrote based on their experiences during the trip. Even though the prompt for the story emphasized actual experiences, students could include fictional elements in their stories. To capture how students represented the relationship between humans and nature in their restorying, we constructed each story as a case and compared the specific ways in which students represented nature across cases (Stake, 1995). We triangulated themes with fieldnotes, teachers' perspectives, and students' interviews. In this paper, we present one case to illustrate how learners' negotiation of human and nature relationships in the restorying demonstrates perspective taking.

Findings

As a part of their collective experience, the sixth graders engaged with nature in multiple ways during the river trip. Naomi (pseudonym), an 11-year-old girl who identifies as white, was particularly drawn to the red rocks, which are unique compared to where she lives in the northern part of the state. She explained, "it was like, there was a lot of like rock there, like, pretty like rock…" (Naomi, Post Interview, 10/08/2019). Rock, in fact, is a significant feature of the natural landscape in the field trip area. This feature became the centerpiece of Naomi's hero's journey story, "The Rock". In this story, she introduces two main characters, which was a unique literary move compared to her counterparts: a talking rock named Ned and a 12-year-old boy named Aaron are the two main characters. Ned, the rock, lost his family in a flood and was eventually picked up by Aaron, the human, who was jogging by the river. Naomi writes,

> "The boy stared at the rock in confusion. Ned decided to start talking. This was his big moment. He had always wanted to talk to a human! The rock said, "I am Ned." The boy was startled! The rock said again, "I am Ned." The boy said, "I am Aaron." Without saying a word, he [Aaron] ran to the raft with Ned in his hand...Once they got to the mellow water Ned learned how to jump! He was jumping and bouncing around the raft having fun! Then Ned noticed Aaron's brand new phone on the ground! Ned couldn't stop bouncing and shattered his phone! He [Aaron] got so mad at Ned! Aaron [t]hrew Ned out of the boat! (Naomi, Short Story, "The Rock").

Naomi then follows Ned's perspective, "once [Ned] landed on the sand, Ned had to find his way to the end of the river. Now, Ned had to face his greatest fear, THE DARK! The first night he chose to keep walking 10 hours later, he faced his greatest fear." (Naomi, Short Story, "The Rock"). The next day, Aaron was preparing to leave the river, yet he felt remorse for what he had done to Ned. Naomi continues, "He turned around and saw Ned talking with his family!" The rock and the boy apologized to each other and Ned requested of Aaron, "throw me and my family up into the stars. If you do, we will turn into constellations. Then we can see the river forever!" (Naomi, Short Story, "The Rock").

Naomi's story shows two perspectives of one incident. It consists of two intertwined hero's journey stories: (1) For Ned, he goes through the separation from his family, fears and difficulties, and reunion with his family; (2) For Aaron, he changes from being angry that his phone was broken to feeling regretful about what he did to Ned and apologizes to Ned. The hero's journey is usually about the change of a single protagonist (Campbell, 1993), yet in this story, Naomi intertwines two perspectives to create a larger narrative. Even more than that, Naomi situates this all in a moral context with Aaron's struggle and empathy after expressing anger at Ned. The resolution of the story comes when Aaron moved beyond his own world to seek new understanding from Ned's perspective, and they reached harmony together as human and nature. Interestingly, this narrative arc demonstrates socioscientific perspective taking (Kahn & Zeidler, 2019), which is defined by three characteristics: "(1) engagement with others and their circumstances, (2) etic/emic shift, and (3) moral context" (p. 623). Naomi engages all three in her restorying of the field trip experiences.

Implications and future directions

One key insight demonstrated through this case that resonated across cases is that the sixth graders represented the relationships between human and nature through socioscientific perspective taking (Kahn & Zeidler, 2019). Naomi's restorying includes several layers of perspective taking that resulted in harmony between the rock and the human, which is a potential marker of Naomi's value orientation (Gallagher, 2001). Our data and analysis do not clearly indicate whether restorying is a *real* or *imagined* expression of students' value orientation toward nature or if restorying leads to a shift in value orientation, so further research is needed to understand the role of restorying in students' value orientations. We also note a need to further explore how we can support socioscientific perspective taking through restorying place-based experiences.

References

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*(4), 530-544.

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*(5-6), 302-318.

Campbell, J. (1993). *The hero with a thousand faces* (3rd ed.). Novato, CA: New World Library.

Fishman, B., Penuel, W. R., Allen, A., Cheng, B. H., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *National Society for the Study of Education Yearbook*, *112*(2), 136-156.

Foote, L. S. (2015). Re-storying life as a means of critical reflection: the power of narrative learning. *Christian higher education*, *14*(3), 116-126.

Friedel, T. L. (2011). Looking for learning in all the wrong places: Urban Native youths' cultured response to Western-oriented place-based learning. *International Journal of Qualitative Studies in Education*, *24*(5), 531-546.

Gallagher, T. (2001). The value orientations method: A tool to help understand cultural differences. *Journal of Extension*, *39*(6), 165-177. Retrieved from https://www.joe.org/joe/2001december/tt1.php

Harris, C. I. (1995). Whiteness as property. In K. Crenshaw, N. Gotanda, G. Peller, & K. Thomas (Eds.), *Critical Race Theory* (pp.276-291). New York: New Press.

Hu, S. (2019). Boundary-crossing species: Making the realities of the caterpillar fungus. *Science as Culture, 28*(4), 470-491.

Kahn, S., & Zeidler, D. L. (2019). A conceptual analysis of perspective taking in support of socioscientific reasoning. *Science & Education*, *28*(6), 605-638.

Kimmerer, R. W. (2013). *Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants*. Milkweed Editions.

Knapp, C. E. (2005). The "I–thou" relationship, place-based education, and Aldo Leopold. *Journal of experiential education*, *27*(3), 277-285.

Lindgren, N., & Öhman, J. (2019). A posthuman approach to human-animal relationships: Advocating critical pluralism. *Environmental Education Research*, *25*(8), 1200-1215.

Litts, B.K., Tehee, M., Jenkins, J., & Baggaley, S., (2020). Developing Sixth Graders' Cultural Competence Across the Curriculum: A Collaborative Redesign Process. In M. Gresalfi, M. & I. S. Horn (Eds.). *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences* (ICLS) 2020, Volume 3, Nashville, TN: International Society of the Learning Sciences, pp.1625-1628.

Litts, B. K., Tehee, M., Jenkins, J., Baggaley, S., Isaacs, D., Hamilton, M. M., & Yan, L. (2020). Culturally disruptive research: a critical (re) engagement with research processes and teaching practices. *Information and Learning Sciences, 121*(9/10), 769-784.

McNeil, M. (2005) Introduction: postcolonial technoscience, *Science as Culture*, 14, 105–112.

Medin, D. L., & Bang, M. (2014). The cultural side of science communication. *Proceedings of the National Academy of Sciences*, *111*(Supplement 4), 13621-13626.

Slabon, W. A. (2009). Learning by restorying: A naturalistic case study of an instructional strategy in a master's level conflict management course. (Doctoral dissertation). Retrieved from ProQuest Dissertations and Theses. (UMI 3399238).

Slabon, W. A., Richards, R. L., & Dennen, V. P. (2014). Learning by restorying. *Instructional Science*, *42*(4), 505-521.

Smith, L.T. (1999). *Decolonizing methodologies: Research and indigenous peoples*. New York: St. Martin's Press.

Stake, R. E. (1995). *The art of case study research*. Thousand Oaks, CA: SAGE Publications.

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Connecting with Computer Science: Two Case Studies of Restorying CS Identity with Electronic Textile Quilts

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Abstract: Recent studies for developing CS identities promote interrogating dominant narratives about CS while learning computing in order to better understand how minoritized youth negotiate who they are and who they want to be in relation to computing and technology. In this study, we propose "restorying" as an approach to engage minoritized youth in examining dominant CS narratives while designing interactive, electronic textile quilt patches. Through analyzing interviews and participant artifacts, we present two case studies highlighting youth's reimagining of dominant narratives of CS as "boring" and for "only white men" as well as their future connections to computing. We discuss how engaging minoritized youth in restorying who they are becoming in relation to CS might help researchers and educators better understand ways to design learning environments that support their computing identity work.

Introduction

While major efforts are underway to bring computing into K-12 education, most have focused on examining how *all* students learn computational thinking concepts and practices. However, we cannot ignore how Black, Latinx, and Indigenous youth have been systematically denied access to quality computing learning opportunities (Margolis, Estrella, Goode, Holme, & Nao, 2008). Disciplinary learning is embedded with political and ethical values that promote particular ways of being that can support or limit minoritized youth's disciplinary learning and identities (Vakil, 2020), especially during an age when youth are asking critical questions about the roles computing and technology play in their lives and who they want to become. If we are to expand youth's connections to computing, we need to design learning environments that support the computing identity work of youth whose disciplinary learning experiences have been marginalized (e.g., raced, gendered, and classed) based on the dominant cultural values of that discipline (Bell, Van Horne, & Cheng, 2017). While CS identity has been a research focus since early computing education, it mainly focused on describing racial or gender demographics of research participants; what is less understood is how youth's multiple social identities shape learning processes and trajectories of future engagement with computing—both theoretically and empirically.

Recent studies have taken more action-oriented approaches towards developing positive identities in computing education. One approach uses STEM contexts to leverage minoritized youth's political and cultural identities by promoting critical reflection of equity in order to develop their critical computational literacies beyond technical skills (e.g., Lee & Soep, 2016). Another approach towards developing Black girls' interest and identification with STEM and computing involved researchers and youth co-designing counternarratives about girls in a parallel program who differ from dominant computing stereotypes as girls from different racial/ethnic backgrounds with diverse interests and computing experiences (Pinkard, Erete, Martin, & McKinney de Royston, 2017). However, youth provided feedback on narratives originally created by the researchers rather than constructing their *own* original narratives based on their own computing experiences.

We propose restorying as a novel effort for integrating computing identity work with the learning of computational concepts and practices through youth's creation of counternarratives about CS. An analytical concept prominent in literacy research, restorying is defined as individuals "[narrating] the word and the world, analyzing their lived experiences and then synthesizing and recontextualizing a multiplicity of stories in order to form new narratives" (Thomas & Stornaiuolo, 2017, p. 318). In addition to challenging the reproduction of dominant CS narratives, restorying also provides youth the space to *imagine alternate ways of being, thinking, and doing in computing* as they reimagine new connections to the discipline reflective of their multiple social identities and lived experiences. Here we want to examine how restorying as a learning practice can offer minoritized youth the opportunity to interrogate dominant CS narratives while learning computing so we can better understand how they negotiate who they are becoming in relation to computing and technology.

In this paper we present cases of Matthew and Layla, participants in a workshop we developed for a racially diverse STEM program at a local science museum, who designed interactive, electronic textile (hereafter, e-textiles) quilt patches that restoried dominant CS narratives. Through combining crafting, circuitry, and coding, e-textiles creators connect sewable Arduino-based microcontrollers with conductive thread to actuators (e.g., LEDs and sensors) to make interactive craft projects (Buechley, Eisenberg, Catchen, & Crockett, 2008), and broaden and deepen participation in computing. Building on frameworks of identity as narrative through the stories we tell about ourselves, others, and our experiences (e.g., Sfard & Prusak, 2005), minoritized youth in this study combined e-textiles with the historical practice of quilting to develop counternarratives about who participates in computing. To this end, we ask: What is revealed about computing identity work when high-school-aged youth design interactive, e-textile quilt patches that restory dominant narratives about CS?

Methods

Employing a social design experiment approach (Gutiérrez & Jurow, 2016), we facilitated a workshop during Spring/Summer 2020 for 19 participants (16 consented) from a racially diverse program at a local science museum serving high-school-aged youth who are passionate about STEM. Demographically, participants in the program consisted of 9 boys and 10 girls, and the racial/ethnic breakdown of youth includes the following: Black or African American (8 youth), Asian (5 youth), White or Caucasian (2 youth), Hispanic or Latinx (2 youth), and Other (2 youth) (anonymous demographic data was collected from the program manager and reflects descriptions used by the program).

The first part (4 hours) of the workshop was initially facilitated at the museum, but due to the COVID-19 pandemic, the remainder (30 hours) was facilitated virtually. Workshop activities included youth designing various artifacts representing their personal relationship with CS and computing, as well as class-wide discussions about the dominant (and concealed) narratives about CS and computing technology (including its history and representation), the history of quilting as a tool used by minoritized groups to resist dominant narratives, and the appropriation of computing technology to resist systemic oppression.

Data collected and analyzed included participants artifacts (e.g., photos and videos of youths' quilts in interaction, reflection worksheets, and design journals), researcher memos, and post-interviews of participants. We have begun initial rounds of comparative, inductive analysis of interview and worksheet data in order to develop a codebook and framework for understanding what restorying while designing e-textiles quilt patches reveals about CS identity work. Having so far analyzed data from three youth, we present case studies of Matthew and Layla, whose quilt patches clearly restoried dominant CS narratives surrounding identity.

Findings

Engaging in the practice of restorying through designing e-textiles quilt patches served as an ideational resource for Matthew and Layla to (1) use computing to develop counternarratives about who can participate in computing (see also Figure 1), and (2) reimagine future possibilities for participating in computing.

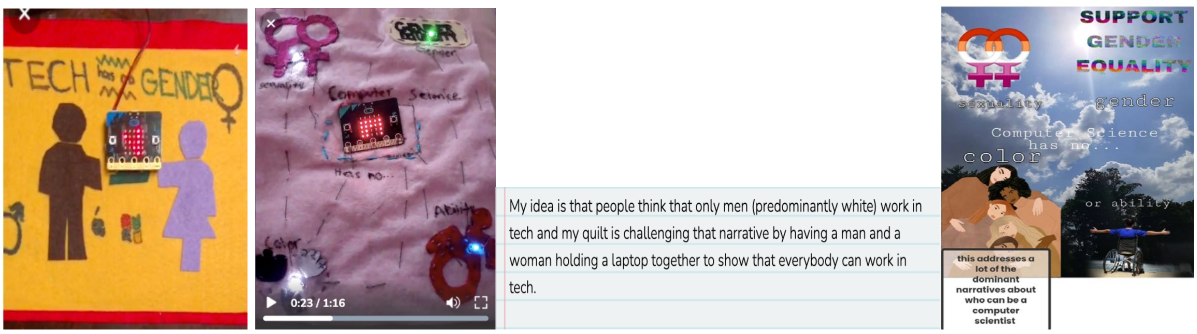

Figure 1. Screenshot of Matthew and Layla's quilt patches and reflections on the patches' themes.

Finding 1: Reimagining dominant narrative of CS as only for nerdy, white men

Restorying afforded Matthew and Layla the opportunity to both discover and reimagine dominant narratives surrounding who participates in CS. When reflecting on the kinds of people normally thought to be computer scientists, both participants identified nerdy, white men, which reflects the dominant group whose values, norms, and practices have been historically privileged within computing education (Rodriguez & Lehman, 2018). "I'm going to be honest, every time I pictured a computer scientist, I pictured some white man with glasses," Matthew admitted in his post-interview, "but now, I didn't even realize I was doing it. I didn't realize how much of a dominant narrative that was." Layla echoes this sentiment by acknowledging that no one really thinks about dominant narratives. Furthermore, they identified how CS as a discipline normalizes this dominant narrative, whether through dominant representation of white men throughout history (Matthew) or people being excluded based on their “sexuality, gender, color, and ability” (Layla). Matthew and Layla were able to tackle these dominant narratives by not only challenging how “they only show the men” as people working in tech (Matthew) but by also learning that “if I can [restory] in [CS], I can do it out in the world, I can do it at school, I can do it with friends. And I can be like, ‘This is my story, and I don't have to be excluded (Layla).” By being exposed to counternarratives that challenge the dominant white maleness of CS [e.g., through learning the stories of (mostly white) women’s role throughout the history of CS], restorying served as an ideational resource for Matthew and Layla to imagine new ways of being in CS.

It is interesting to note that while the dominant narrative Matthew critiques used an intersectional lens in addressing race and gender specifically, his quilt patch only restoried based on gender. This might reflect a limitation in the diversity of examples of female programmers we showed during the workshop, highlighting a need in future workshops to explicitly address multiple levels and intersections of oppression (across gender *and* race *and* class, etc.) throughout CS and provide counternarratives reflecting those intersections. Through restorying dominant narratives about who belongs in CS in their interactive quilt patch designs, both Matthew and Layla reimagined CS as a field more inclusive towards people, despite their race, gender, ability, and sexual orientation.

Finding 2: Reimagining present and future connections to CS

Despite having different prior interests in learning CS, the workshop provided both Matthew and Layla the opportunity to reimagine dominant narratives surrounding what CS is and the types of activities involved. At the start of the workshop, Matthew had no interest in learning CS due to assuming that CS learning environments consisted of “very boring” lectures and activities like “figuring out how to get past a firewall or something.” Further, when asked what type of student would enroll in an imaginary new CS class offered at his school, he pictured students interested in learning more about computers or pursuing a career in CS. Conversely, even though Layla was interested in learning programming prior to the workshop, like Matthew she said she would also not enroll in an imaginary new CS class offered at her school (due to being more interested in coding). She also noted that other students might fear enrolling in the class due to “the genius narrative.” These statements further reflect perceptions regarding the types of youth interested in learning CS, particularly the perception that CS courses would be attractive to students interested in more complex or *professional* authentic computing experiences (NASEM, 2021). However, after participating in the workshop, both participants expressed interest in participating in future CS workshops (if time permits) and shared that their feelings changed to seeing CS as a more artistic, intricate (Matthew), and accessible (Layla) field.

That being said, when asked whether or not they identified as computer scientists, both participants expressed identifying as computer scientists, but within limits. More specifically, Matthew identified himself as a “semi-computer scientist” but “on the artsy side, not the boring side.” Layla, on the other hand, recognized herself as computer scientist because she learned CS but on a smaller level at home where she could share what she learned with others. Restorying dominant CS narratives while designing e-textiles quilt patches also provided participants the opportunity to reimagine their future engagement with computing. Not only did Layla find the concept of interactive quilts innovative and interesting but she also appreciated learning how to program the Micro:bit, which she felt was the first step in programming a lot of other things. Furthermore, Matthew expressed that learning how to sew circuits and code his Micro:bit “enhanced [his] artist side more, by adding another style of art” (despite not seeing connections between quilting and computing in his post-interview).

Given that e-textiles prioritizes aesthetics, it provided multiple entry points for Matthew and Layla to engage in computing, whether it was Matthew’s prior sewing experience or Layla’s prior coding interest and knowledge of quilts. However, both participants noted how the CS they were doing in the workshop did not involve “going out in the world and doing these things (Layla)” or “it's not gonna be in the news or anything (Matthew).” Although exposure to materials like fabric, sensors and microcontrollers expanded their perceptions of what CS is, there still seems to be this separation between CS as a *professional* discipline that’s out in the world and the more *personal* side of CS that integrates personally relevant activities, like crafting (NASEM, 2021).

Discussion

By changing restorying from an analytical to a pedagogical framework, we provide a new approach for engaging Black, Latinx, and Indigenous youth—groups historically excluded in CS education—in discovering and challenging dominant narratives about CS while also developing their computing learning and identities. However, before bringing these activities to youth, we as researchers and educators first need to reflect on the extent to which we may be perpetuating dominant CS narratives in our own epistemologies and pedagogies. For example, by not distinguishing between “CS, the broad discipline focused on programming, computing theory, and data structures" and "computing, the designing computational devices" in our workshop, we see how Matthew and Layla associated CS learning with pursuing a career in CS, working in technology, or engaging in CS activities out in the world. Consequently, we see parameters placed on their identification as computer scientists based on their perceptions of CS done in the world (e.g., at technology companies), despite engaging in a practice of restorying the dominant ways of being, thinking, and doing in CS during the workshop. This highlights an opportunity for us as researchers to also engage in restorying by interrogating our desire for youth (particularly minoritized youth) to identify *with* the discipline as opposed to identifying as an individual leveraging computing to make transformative change [e.g., technosocial agents (Ashcraft, Eger, & Scott, 2017)]. Finally, in reflecting on the use of quilt patches in K-12 CS education, we understand that building on the history of quilts and fabric arts as media for self-expression and resistance presents a unique learning opportunity for e-textiles research. Currently, the e-textiles unit developed for the *Exploring Computer Science* curriculum includes a classroom-wide mural project where pairs of students created portions that each incorporate two switches to computationally create four lighting patterns (for more details, see Kafai & Fields, 2018). Normally themes for these murals focus on school or popular culture references; however, by leveraging the collective storytelling roots and aesthetic elements of quilting, we see potential for e-textiles quilts to serve as collaborative artifacts that reflect the CS learning experiences of youth from groups who have been historically excluded from CS. As we conceptualize what equity and inclusion means for computing education, our study hopes to expand minoritized youth's computing practices to involve critical interrogation of the discipline as well as speculative practice to reimagine computing as a tool for social transformation.

References

Ashcraft, C., Eger, E., & Scott, K. (2017). Becoming Technosocial Change Agents: Intersectionality and Culturally Responsive Pedagogies as Vital Resources for Increasing Girls' Participation in Computing. A*nthropology and Education Quarterly, 48*(3), 233-251.

Bell, P., Van Horne, K. & Cheng, B. (2017). Special issue: Designing learning environments for equitable disciplinary identification. *Journal of the Learning Sciences, 26*(3), 367-375.

Buechley, L., Eisenberg, M., Catchen, J., and Crockett, A. (2008, April). The LilyPad Arduino: Using computational textiles to investigate engagement, aesthetics, and diversity in computer science education. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 423-432). Florence, Italy: CHI.

Gutiérrez, K. D. & Jurow, S. A. (2016). Social Design Experiments: Toward Equity by Design. *Journal of the Learning Sciences, 25*(4), 565-598.

Kafai, Y., & Fields, D. (2018). Some reflections on designing constructionist activities for classrooms. Proceedings from Constructionism 2018. Vilnius, Lithuania.

Lee, C. H., & Soep, E. (2016). None But Ourselves Can Free Our Minds: Critical Computational Literacy as a Pedagogy of Resistance. *Equity & Excellence in Education, 49*(4), 480-492.

Margolis, J, Estrella, R., Goode, J., Holme, J. J., & Nao, K (2008). *Stuck in the Shallow End: Education, Race and Computing.* Cambridge. MIT Press.

National Academies of Sciences, Engineering, and Medicine (2021). Cultivating Interest and Competencies in Computing: Authentic Experiences and DesignFactors. Washington, DC: The National Academies Press. https://doi.org/10.17226/25912.

Pinkard, N., Erete, S., Martin, C., & McKinney de Royston, M. (in press). Digital youth divas: Exploring narrative-driven curriculum to trigger middle school girls' interest in computational activities. *Journal of the Learning Sciences, 26*(3), 477-516.

Sfard, A., & Prusak, A. (2005). Telling identities: In search of an analytic tool for investigating learning as a culturally shaped activity. *Educational Researcher, 34*(4), 14-22.

Thomas, E. E., & Stornaiuolo, A. (2016). Restorying the self: Bending toward textual justice. *Harvard Educational Review, 86*(3), 313-338.

Vakil, S. (2020). "I've Always Been Scared That Someday I'm Going to Sell Out": Exploring the relationship between Political Identity and Learning in Computer Science Education. *Cognition and Instruction, 38*(2), 87-115.

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Computational Art Ecologies

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Abstract: We argue for a broader approach to understanding computational thinking that decentralizes CT from the definitions in CS and STEM and works toward authentic definitions in other fields. We contribute to this scholarship by exploring the intersection of computational thinking and art. While there have been myriad successes in creative computing initiatives in education, there has been little research to characterize the authentic computational practices in art fields. We propose a new theoretical frame, *computational art ecologies*–based on Dewey's theory of art as experience–which can be used to capture and visualize an artist's relationship to computation and art. We introduce two cases of computational artists within this theoretical frame and highlight the differences in their relationships to these fields of practice.

Introduction

Within K-12 education, initiatives to teach computational thinking have largely been aligned with computer science (CS), and more recently science and mathematics (Grover & Pea, 2013). While important for providing exposure to authentic skills and practices, the alignment with CS and STEM constrains the epistemologies and perspectives that learners can bring to their explorations in computing (Kafai, Proctor, Lui, 2019; Harell, 2013). We argue for a broader approach to understanding computational thinking that decentralizes CT from the definitions in CS and STEM and works toward authentic definitions in other fields. We seek to contribute to this scholarship by exploring the intersection of computational thinking and art. In this paper, we propose a new theoretical frame, *computational art ecologies*–based on Dewey's theory of art as experience–which can be used to capture and visualize an artist's relationship to computation and art. We introduce two cases of computational artists within this theoretical frame and highlight the differences in their relationships to these fields of practice.

Creative computing and computational art

Scholars in computational fields have a rich history of designing educational programming that leverages creative and artistic practices. Youth-friendly programming languages often focus on digital media creation (Resnick et al., 2009). Similarly, studies of youth designing and developing their own games have showed gains in a wealth of creative and artistic practices, literacy, and critical thinking practices (Peppler, 2010). Constructionist scholars have advocated for interdisciplinary computational learning environments, shown to be successful in engaging children in deep thinking while sparking new creative epistemologies (Eisenberg, 2003; Sendova, 2001). To support learners in gaining the authentic computational practices seen in art, like those constructing situated definitions of CT in other fields (Weintrop et al., 2016), additional work needs to be done in capturing the computational practices and perspectives that appear when engaging in artistic practice.

We turn to literature on visual art to better understand authentic computational practice. One of the characteristic perceptions of twentieth-century art is its persistent tendency to question the tradition of painting as the privileged medium of representation (Rush, 2005). As art is a highly expressive and reflective practice, advances in technologies are often mirrored in artistic ventures. Artists who practice with computation or technology will explore and often subvert both the critical and technological potentials of new media (Rush, 2005). Computational methods add new elements to the artist and user experience, including potential for interaction with the viewer, additional sensory features, and expanded temporality (Wands, 2006).

There is has been little research on the role and use of computation in the art process. Early research in this vein highlights the integration of technology in the lives of artists but focuses more on the day-to-day impact rather than on how it changes art expression (Beardon et al., 1997). In this work, we extend the scholarship within CT education and art to explore the intersection of the two fields. Like those who extended CT definitions into STEM fields, we argue for the need for observation and study of experts to construct definitions of computation in art that are reflective of authentic practices and perspectives within the field (Wilensky, Brady, Horn, 2014; Weintrop et al., 2016). We interview artists who self-identified themselves as using technology or computation in their practice to begin to capture the computational perspectives and practices that are valued within the art field.

Methodology

Theoretical lens: Computational art ecologies

We extend Dewey's theories of art as experience and art ecologies to conceptualize how artists experience computation in their art practice (1934). Dewey attempts to shift the perception of art away from focus on a product. Instead, he argues that art is a process that is reflective of social and cultural experience. We leverage Dewey's theory to construct a simpler model of an ecology that can holistically capture the unique agents, institutions, and factors relevant to each singular artist, as not all are participating in the same type of art world. As such, we propose the use of *computational art ecologies* to capture the factors that impact an artist during the creation of a piece of computational artwork (see Figure 1). In this model, nodes reflect the artist, the audience, computing and art fields, and the artwork. These are situated in a broader sociocultural and historical context that impacts both the artist and the audience. The connections can be weighted to reflect stronger influences between nodes, while the nodes themselves can be added or removed to reflect unique ecologies for a given artist.

Participants, data, and analysis

Artists were recruited through cold contact to participate in an interview on their use of computational tools and practices in their artwork. A total of 9 artists were interviewed by the first author (6F, 3M). For this paper, we identified two artists, both female, who leverage different mediums and computational approaches to present cases of art ecologies. These were selected based on post-interview memos to capture contrasting cases. Janell Baxter waived anonymity. Alex is a pseudonym. Interviews were sixty to ninety minutes in length and asked into the artist's experience with and perception of art and computing. Interviews were coded with thematic codes derived from the *computational art ecology* model. We coded interview episodes for the artist's *relationship with computing*, *relationship with art*, *relationship with audience*, and the *intersection between art and computing*, reflecting the connections between key nodes in the model (see Figure 1). In each coded episode, emergent themes were qualitatively described and then synthesized across these sections.

Results

In the following two cases, we summarize two artists' experiences with and perceptions of computation in their personal art practice. Finally, we compare the ecology for each artist to suggest ways in which these two cases differ in meaningful engagement with computation.

Janell: Case of self-reflection

Janell Baxter is faculty at Columbia College in Chicago and Associate Chair of the Interactive Arts and Media Department (IAM). She describes herself as "exploring the synergies between programming, design, and art" in her bio. Janell has focused much of her artistic practice on the creation of generative art bots. She programs these artificially intelligent bots to generate their own artwork after interpreting libraries' visual or textual artifacts. She has created over 13 versions of these bots since her first show in the late 90's.

Surveying Janell's computational art ecology

Relationship with art. Janell expressed an early interest in art that continued throughout her undergraduate studies, where she obtained a Bachelor of Fine Arts in Studio Art. She went into art "to express [herself] and to communicate…it was a sort of therapeutic way of working through issues with artwork." The time she spent in her studio arts program shaped her approach for thinking about programming and computation, namely in directing focus on "concepts" rather than technique. For Janell, her art practice appears to be personally reflective and expressive, helping her to make sense of both internal and external factors that emotionally impact her.

Relationship with computing. Janell expressed a rich relationship with computing that started when she was a young girl. She opened by telling a story of attending an early punch card computing course with her mother, described with religious language, that sparked her curiosity and awe around the "mystery" of computation. After finishing her undergraduate, she went to graduate school at the University of Chicago for computer science, where she studied CS in a program with a rigorous mathematics focus. She reflected on the difficulty she had in connecting with the framing of the program, mentioning the focus was on goals traditionally associated with computer science (e.g. efficiency, algorithms) and that the "human" perspective was missing in the education. For her, the practices and skills learned were vital, but she needed to spend a lot of time independently to contextualize these practices in her own ethical and moral perspective of society. This self-reflection carries into her art practice.

Intersection of art and computation. Janell's conception of art and computation are strongly tied, with her focus on the practice of creation and programming as the output. She began her bot series after an invitation to an art show on the theme of the 'goddess.' As she explained, "in trying to figure out how to addresses idea of goddess, I sort of became like a God in that form. And I made something that would then make something and that's how I could connect to it." In this show, she displayed her code in a book on a pedestal, almost like a holy book. Throughout her practice, she has maintained the perspective that her code is the art. Others have critiqued or expressed confusion about her work, saying, '"Oh, well the code is just a tool, or the computer is just a tool." Or, you know, "this part of your medium, like the code is your medium."' She reflected on this, saying, "And I was thinking well, but no, the code is the thing that I'm really interested in."

Relationship with the audience. Janell's practice is heavily self-motivated. Her purpose for creating artwork translates into her relationship with the audience, in that she creates these bots for herself with no desires or attempts to sell them. The shows she has participated in have largely been to reach professional goals. The artwork itself, the code, has always been prominently shown and the artwork of the bots, the generated art, put on display so the audience could connect with something. She likens her practice to Buddhist monks creating sand mandalas: "You see those people who make those very intricate, amazing sand designs, and then they sweep it away…like let's write the code and run the code and then it's done kind of a thing. And it can kind of go away because it just bringing it into existence in me thinking about that."

Alex: Case of critiquing technology

Alex is an artist using video, sculpture, and performance to explore questions around technology, identity, and labor. Alex is formerly from the tech industry and currently a master's student in fine arts. Alex's art focuses on a critique of technology, primarily around the social and cultural biases throughout the tech industry. Her work leverages myriad tools and mediums to critique these constructs. For example, in one series, Alex whether technology could take on identity. She created sculptures that were each a functioning battery made with copper and zinc electrodes, blood, and simple electronic components.

Surveying Alex's computational art ecology

Relationship with art. Alex spent most of her childhood engaging in artistic practices like drawing and painting. Professionally, she did not consider art until after her undergraduate program and experience in the tech industry. She attended a hybrid school focusing on the intersection of code, design, hardware, and theory. Despite attending with the goal of gaining more programming and computation skills, she began to realize her identity as an artist. She describes her motivation throughout her art as "critiquing the tech industry".

Relationship with computing. Alex's interest in computation started when she was in undergrad, focusing on the ways new technologies could be leveraged for social mobilization and other political practices. After graduating, she moved into the technology sector but quickly became "disillusioned…with how these technologies are being created." She spent several years teaching herself programming before attending an interdisciplinary school for art and computation. Alex's critique of the tech industry uses computational traditional materials and mediums to draw out the biases and inequalities within the field. She mentions that she "[uses] technology as intended, [with the] critique coming from the way it is used, opposed to using it itself."

Intersection of art and computation. Despite engaging deeply in conversations of technology and participating professionally in computing fields, Alex sees herself as an outsider in computational art. In her perception of the field, there are some artists using cutting edge or immersive technologies and others who engage in building or subverting tools, and she sees herself as external to both camps. She views technology as another tool that she can leverage when it best fits the purpose and critique of a given project. Ultimately, she remains conflicted on her use of computation, stating: "If you told me you're never allowed to use technology again in your art, I would be like, okay, I can figure that out. I guess that's a little sad, but it's okay."

Relationship with the audience. Alex's goal is to start a discussion or conversation about technology rather than focusing on the technology itself. As such, she spends considerable time reflecting on how technology will interact with and impact her audience to engage in the underlying message most deeply. Beyond the audience of laypeople, she struggles with situating herself in computing and art fields, reflecting people in the tech industry or tech artists are not very impressed with her artwork since "it is not very complicated or flashy or interesting."

Computational art ecologies

Both Janell's and Alex's work with computational art focuses on themes of humanity within computation. Within their critical reflection of how computation impacts social and cultural contexts, we see differing practices and goals emerge while creating artwork. Two key differences are the centrality of computational practices in the creation of artwork and the intended relationship with the audience. Based on their coded interviews, we identified unique art ecology models for each artist to visualize these differences (see Figure 1).

Janell uses art as a process for self-reflection and expression, so we strengthen the arrow connecting her to her art node. Her engagement in technology appears to support her understanding and exploration of theories and assumptions about social and cultural contexts. We make a one-directional arrow towards the computing node and add an arrow leading from computing into the broader sociocultural, historical context. Her experiences with art and computing are closely tied, and she sees the code or the bots as the true artwork. As such, these nodes are clustered. Finally, Janell's audience interacts primarily with art her bots create, and Janell explicitly denied her ownership of this generated art. We add a node for the bots' artwork and a dashed line to denote the diminished importance of audience interaction for Janell.

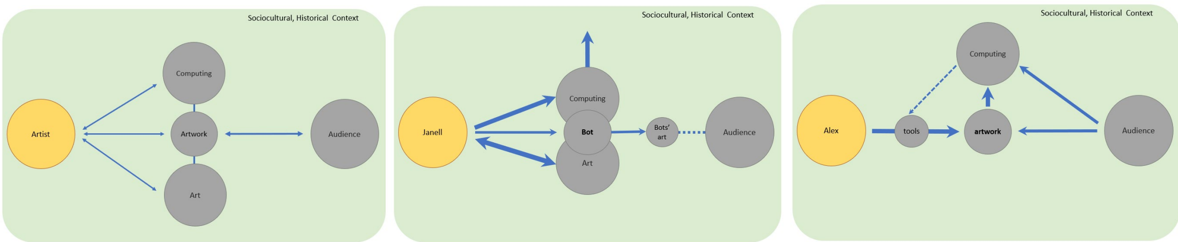

Figure 1. On left, a model of a computational art ecology. In middle, the art ecology for Janell. On right, the art ecology for Alex.

Alex uses her art to openly critique computational fields. She places focus on the artwork and leverages a variety of tools, both traditional and computational, to accomplish her goals. As such, there is a one-directional weighted arrow between her and her artwork node. We add a node for tools, reflecting the importance of this selection in her art process. A one-directional arrow leads from her artwork to the computing node, and a dashed arrow leads from computing to tools, to highlight the occasional use of computational tools. Lastly, Alex seeks to spark discussion and reflection of technological practices within her audience; arrows connecting the audience node to the artwork and computing nodes can be seen.

Discussion and Conclusion

Through analysis of two cases, we identified unique *computational art ecologies* that capture differing relationships with computation and art. Computational art ecologies are flexible models that can be easily manipulated through the addition or subtraction of arrows or nodes to reflect the unique experiences of a given artist. We found that the application of these models to Janell and Alex highlighted differences in their engagement with computation in their artwork. Between the two artists presented here, we already see gaps to explore for CT education. Future work will apply this methodology to all artists within the larger sample and generate thematic patterns across these relationships. This may be useful in characterizing emergent "types" of computational artists. We believe these models of art ecologies can support a richer conceptualization of computational thinking in art that can then be translated to education as authentic practices, especially as we work to characterize and build out a landscape of computational practices, perspectives, and goals unique to this space.

References

Beardon, C., Gollifer, S., Rose, C., & Worden, S. (1997). Computer use by artists and designers: some perspectives on two design traditions. Computers and Design in Context, The MIT Press.

Dewey, J. (1934). Art as experience. *New York: Minton, Balch, and Company*.

Eisenberg, M. (2003). Mindstuff: Educational technology beyond the computer. *Convergence*, *9*(2), 29-53

Grover, S., & Pea, R. (2013). Computational thinking in K–12: A review of the state of the field. Educational Researcher, 42(1), 38-43.

Harrell, D. F. (2013). *Phantasmal media: An approach to imagination, computation, and expression*. MIT Press.

Kafai, Y., Proctor, C., & Lui, D. (2019, July). From theory bias to theory dialogue: Embracing cognitive, situated, and critical framings of computational thinking in k-12 cs education. In *Proceedings of the 2019 ACM Conference on International Computing Education Research* (pp. 101-109).

Peppler, K. (2010). Media arts: Arts education for a digital age. *Teachers College Record*, *112*(8), 2118-2153.

Rush, M. (2005). *New media in art*. London: Thames & Hudson.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. Journal of Science Education and Technology, 25(1), 127-147.

Sendova, E. (2001). *Modelling creative processes in abstract art and music*. na.

Wands, B. (2007). *Art of the digital age*. Thames & Hudson.

Language, Modeling and Power: A Methodology for Analyzing Discourse in Interaction

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Abstract: We present a new methodology for demonstrating the connection between reasoning in interaction and larger sociopolitical discourses. We demonstrate this methodology in the context of modeling activities with preservice teachers. First, we explain critical discourse analysis, a methodology which illuminates how talk or text in social events is related to larger social practices or structures. Second, we describe how using critical discourse analysis with interaction data allows researchers to understand how language choices reflect larger discourses that circulate society. Finally, we demonstrate this methodology on a transcript of preservice elementary teachers reasoning about residential segregation using agent-based models.

Introduction

Models and modeling are a cornerstone of scientific practice (Giere, 2004; Lesh, Doerr, Carmona, & Hjalmarson, 2003). Scholarship in the learning sciences have studied modeling in a variety of ways influenced by cognitive perspectives on learning (Knoespel, 1999). Furthermore, a number of pedagogical tools have been developed to support teaching and learning with models. One such technology we explore in our own work has been the use of NetLogo models for developing preservice teachers' understandings of complex phenomena (Wilensky, 1999). However, the learning sciences are expanding. Now more than ever, our community is finding new ways to address political aspects of learning to compliment the cognitive, social, and cultural perspectives already well developed (Esmonde & Booker, 2016; The Politics of Learning Writing Collective, 2017). Our aim in this paper is to offer a new methodology for analyzing how sociopolitical discourses mediate reasoning and learning in the context of modeling. Specifically, we hope to add critical discourse analysis (CDA) as a tool for the learning sciences. In this paper we summarize CDA and select some techniques for applying it to interactional data. We close by demonstrating this analysis with an example from video data of preservice elementary teachers using agent-based models to learn about residential segregation.

Critical discourse analysis for the learning sciences

Discourse analysis techniques are widely used in the learning sciences, especially in interactional studies of learning (Greeno, 2006). CDA is one such technique, based on systemic functional linguistics (Halliday, 1978) which aims to understand how talk in interaction or written texts are shaped by sociopolitical discourses which circulate society (Fairclough, 2003; van Leeuwen, 1993). Fairclough defines sociopolitical discourses as relatively stable ways of representing the social world with language. For example, van Leeuwen examines how pro-nationalism discourses influence language choices in news articles about immigration (1996).

CDA scholars have developed a wide range of sophisticated techniques, adapted to different disciplines (communication and media studies, political science, etc.), which demonstrate the connection between talk and discourses. In this article we focus on one technique: the representation of social actors through talk. Social actors are any participant from the real world which are referenced in talk and capable of carrying out actions. They are typically indexed with nouns or pronouns. Social actors can be individual people, collections of people, institutions, or even ideas/objects. We can identify discourses by determining patterns in how people include and relate social actors as they speak. We find this aspect useful to analyze learning with models for two reasons. First, modeling is inherently a process of selecting, amplifying, and reducing aspects of the real world. For example, NetLogo models represent actors from the real world as agents or "turtles". Therefore, patterns in what is selected, amplified, and reduced are likely to be mediated by discourses, especially for models which relate to social phenomenon. Second, when learners modify models, we can observe changes to how they represent social actors and use these changes to understand how sociopolitical discourses relate to their reasoning about complex phenomenon. In the next section, we discuss in detail our method for applying CDA to interactional data.

Using critical discourse analysis with interactional data

To understand how political discourses influence reasoning we must closely examine talk in interaction (Greeno, 2006). First, we describe how to create transcripts which highlight the representation of social actors whether they are spoken about, gestured to, or referenced in artifacts. Then, we discuss two analytical aspects that can illuminate how social actors are represented and which political discourses shape these representations.

Generating transcripts of interaction data for CDA

Critical discourse analysis has typically been used to analyze text produced written *about* social events. For example, many CDA scholars examine news media articles. These forms of data are ripe for CDA because analysts can focus solely on information included (or excluded) by the author. Similar to texts, when people talk, they also represent the social world. Distinct from texts, talk in interaction is multi-modal, and includes actions of the individual, interactions with other individuals, and interactions with the environment. Therefore, the representation of social actors cannot be analyzed by only paying attention the words spoken. Instead, analysts must pay attention to the talk and gesture of the individuals, interactions between the individuals, and references to aspects of the environment. To capture the representation of social actors distributed across these areas, we create transcripts which vertically organize chronological interaction, and horizontally organize categorical information (Figure 1). This transcript method allows researchers to identify social actors whether they are referenced in talk, gestured to, or present in the environment.

Time	Participant [direction]	Talk	Video Still	Environment Still
Hr. Min. Sec.	Name of participant [who utterance was directed at]	Transcribed text Short Pause (..) Long Pause (...) ((gestures)) [reference to environment] *Notes from transcriber*	[still selected from video record, typically demonstrates a gesture or reference to proximal environment]	[photograph of important references from proximal environment]

Figure 1. Sections of the transcript for deploying representational analysis

Analyzing social actors for inclusion and activation

Once transcripts have been generated, we then identify which social actors represented. To do this, we read the transcripts while watching video footage and pay attention to any nouns or pronouns which conduct actions or receive actions. By conducting or receiving actions, we are referring to the verbs used within sentences. Once a list of social actors has been determined, we bold these in the transcript to proceed with closer analysis.

While there are a number of ways to proceed with closer analysis, we draw on two concepts related to the representation of social actors: (a) *inclusion* or *exclusion* of social actors; and (b) *activation* or *passivation* of social actors. When individuals talk, they select certain social actors from the social world to discuss and (intentionally or accidentally) ignore others. CDA scholars refer to this process as the *inclusion or exclusion of social actors*. For instance, in the clause "protesters were arrested last week": protestors are the only social actor which are included. Those who arrest the protestors, in this example, are excluded. Related to inclusion, participants or social actors can either be *activated* or *passivated.* For example, protestors are passivated in the above example (they were arrested), and the excluded participant (police) are activated (as the individuals responsible for making arrests).

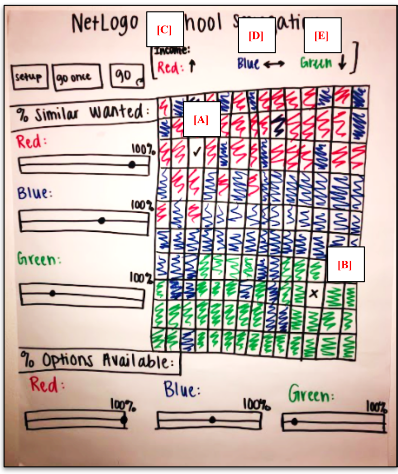
By examining patterns in inclusion/exclusion and activation/passivation of social actors, we can begin to see the way power is distributed with language as people reasoning through complex phenomenon with models. By making comparisons between different groups of people and how they include and activate social actors, we can witness how competing sociopolitical discourses relate to talk in interaction. In the next section, we demonstrate these techniques with interactional data, but save cross-group comparisons for future work.

Example: Preservice elementary teachers reasoning about segregation

Modeling as a practice involves reducing a complex phenomenon for the purpose of understanding and prediction (Lehrer & Schauble, 2000). Probing *how* the complex world is reduced then, provides insight into the way sociopolitical discourses mediate reasoning. The data we analyze here was selected from a 2-lesson modeling exercise with 16-preservice elementary teachers enrolled in a science methods course. Participants engaged in the modeling unit to use, evaluate, and modify a NetLogo model designed to simulate causes of residential segregation (Wilensky, 1997). We selected residential segregation because it is a complex phenomenon which clearly intersects with issues of power. Below we discuss the transcription and analysis of interactional data.

Generating the transcript identifying the social actors

The 2-lesson series was video recorded with a resulting 6-hours of video tapes to be reviewed. We also collected participants' final modification to the NetLogo model (in the form of a drawn schematic on a sheet of poster paper). CDA is too time intensive and complex for such a large corpus of data. Therefore, we decide to focus analysis on the last activity where participants presented their final modification of the NetLogo segregation model to the class. We chose this portion of the lesson series to analyze because participants will necessarily discuss and relate social actors in ways that will illuminate specific sociopolitical discourses. Below we include a photograph of the participants' modified NetLogo model (Figure 2) and an excerpt of the transcript from their presentation. (Table 1). We exclude images of the students talking for privacy purposes.



Social Actors referenced from Model Diagram in Talk:

[A] Good School
- Represented as "✓"
- Located at top of model
- Have more available resources/school funding

[B] Bad School
- Represented as "x"
- Located at bottom of model
- Have less available resources/school funding

[C] High Income Homes
- Represented with red shading
- Have highest "% similar wanted"
- Have highest "options available"

[D] Medium Income Homes
- Represented with blue shading
- Have middle "% similar wanted"
- Have middle "options available"

[E] Low Income Homes
- Represented with green shading
- Have lowest "% similar wanted"
- Have lowest "options available"

Figure 2. A modified NetLogo segregation model presented by three participants. Notes provided on the right-hand side were added by the researchers.

Table 1: Excerpt of transcript for two students presenting their modified NetLogo model

01:12:26	Sage [to class]	Okay so in this NetLogo there is a ((gestures to the top of the model)) [A] considered a **good school** ((uses air quotes around good school)) and there ((gestures to bottom of the model)) [B] is a **bad school**.. Just based on available materials and I guess school funding. So then we made three **turtles** based on household income. The **red** ((gestures to top of model where phrase "red ^" is written)) [C] is high income. The **blue** ((gestures back and forth with hands)) is medium [D]. And **green** low income [E]. And also, we didn't leave any space because in a perfect world, **everyone** has a household.
01:13:03	Bree [to class]	Okay so we basically did like.. the percent similar wanted was ((gestures to three percent similar wanted sliders)) like pretty similar to our regular one. So like the **red people** ((gestures to the red percent similar bar)) wanted to stay mostly around red but allowed for some blue. The **blue** would stay mostly around blue but would prefer maybe more red. And then **green** is like wherever they can.

Analyzing social actors for inclusion and activation

First, we identify which social actors are included in the interactional sequence. To do this, we recursively view the video footage, read the transcript (looking for nouns or pronouns which conduct actions), and cross reference the transcript with the artifact (Figure 2). We de-emphasize personal pronouns (we, I, us, etc.) and instead focus on those related to the model. In this excerpt, we see five important social actors emerging: (1) good school, (2) bad school, (3) high-income homes, (4) middle-income homes, and (5) low-income homes. These social actors are represented in the modified model symbolically, gestured to as students talk, and are bolded in the transcript to make them more noticeable. To examine excluded social actors, we can either: (a) compare this model with the original NetLogo model which included two social actors (red-homes and green-homes), representative of two racial groups; or, (b) compare this model with other models created by different groups of students from the class. Despite engaging in a 2-lesson series about modeling the causes of residential racial segregation, this group of students exclude race from their final modified NetLogo model and instead include socioeconomic status and schools.

Following analysis of the inclusion and exclusion of social actors, we can investigate how these social actors are activated or passivated with relation to the verbs. The social actors "good school" and "bad school" are both hypothetical institutions gestured to and represented symbolically in the model. They are first activated with the verb "is" signifying that they simply exist in the modified model. Both the good school and the bad school are mentioned with the gestured air quotes, which may indicate the speaker is acknowledging some fallacy in the categorization of schools. However, Sage then activates both the good school and bad school with a relational verb phrase "just based on" and mentions two qualities that make the school "good" and "bad": available materials and school funding.

The second group of social actors represented in this model and transcript are individual households in the simulation. First, Sage mentions the social actor "turtle" (a NetLogo term referring to any agent used in the model) and activates this social actor with the relational verb "is based on household income." Therefore, we know that households will be separated broadly into income groups. She follows this statement by naming three sub-classes of household and activating each of them with relational verbs. She activates red turtles with "is high income" and blue turtles with "is medium" (income). For the green turtles, she does not use a verb, but the verb is implied from the sentences before it, and the green turtles are activated as "low income" households.
Bree then steps in to further explain how these three social actors can behave in the modified NetLogo model. Bree activates the high-income social actors with two behavioral verbal phrases: "wants to stay mostly around red" and "but allowed for some blue." Bree activates middle-income social actors with two behavioral verbal phrases: "would stay mostly around blue" and "would prefer maybe more red." Finally, Bree activates low-income households with the behavioral verbal phrase "is like wherever they can." While none of these actors are passivated, they are activated with different amounts of power because of the verbs that are used with them. First, high-income and middle-income social actors are represented as having preferences for where they would like to live; whereas, low-income social actors are represented as moving "wherever they can."

Discussion

Here, we analyzed a single group's representation of social actors using two CDA tools: inclusion and activation. Already, we can begin to see the contours of sociopolitical discourses that mediate how they understand segregation. For example, schools are either good or bad based on the amount of resources they have, and only high and middle-income households have preferences for who they live near. The power in this method is amplified when comparisons are made between spoken or written text during different events. For example, examining how other groups in the class model and discuss the same phenomenon, we can begin to notice similar or competing sociopolitical discourses which mediate students reasoning.

References

Esmonde, I., & Booker, A. N. (2016). *Power and Privilege in the Learning Sciences: Critical and Sociocultural Theories of Learning*. Taylor & Francis Group.

Fairclough, N. (2003). *Analysing Discourse: Textual Analysis for Social Research* (1st ed.). Routledge.

Giere, R. N. (2004). How models Are used to represent reality. *Philosophy of Science*, *71*(5), 742–752.

Greeno, J. G. (2006). Learning in Activity. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed.). Cambridge University Press.

Halliday, M. A. K. (1978). *Language as social semiotic: The social interpretation of language and meaning*. University Park Press.

Knoespel, K. J. (1999). Models and diagrams within the cognitive field. In L. Magnani, N. J. Nersessian, & P. Thagard (Eds.), *Model-Based Reasoning in Scientific Discovery* (pp. 59–73). Springer US.

Lehrer, R., & Schauble, L. (2000). Developing model-based reasoning in mathematics and science. *Journal of Applied Developmental Psychology*, *21*(1), 39–48.

Lesh, R., Doerr, H. M., Carmona, G., & Hjalmarson, M. (2003). Beyond Constructivism. *Mathematical Thinking and Learning*, *5*(2–3), 211–233.

The Politics of Learning Writing Collective. (2017). The Learning Sciences in a New Era of U.S. Nationalism. *Cognition and Instruction*, *35*(2), 91–102.

van Leeuwen, T. (1993). Genre and field in critical discourse analysis: A synopsis. *Discourse & Society*, *4*(2), 193–223.

van Leeuwen, T. (1996). The representation of social actors. In C. R. Caldas-Coulthard & M. Coulthard (Eds.), *Texts and practices readings in critical discourse analysis* (pp. 32–104). Routledge.

Wilensky, U. (1999). *NetLogo*. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Sustaining Community and Relationships with Black and Latina Girls in an Out-of-School STEAM Learning Program during a Global Crisis

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Abstract: Despite widespread and concerted efforts, women and people of color are still dramatically underrepresented in STEM fields. Research in this area suggests the oppressive cultures surrounding STEM are one reason for the disparities in STEM participation across social categories. Cultivating counterspaces in STEM for girls and Black and LatinX learners continues to be critical, especially in the current moment when the vast majority of learning activities have shifted online. In this study, we examine an out-of-school time STEAM learning program designed for Black and Latina middle school girls to better understand how community and relationships can persist as the learning landscape shifts from in-person to online due to a global pandemic. We argue that counterspaces are critical to understanding why supportive community is necessary for Black and Latina girls particularly.

Introduction

Despite widespread and concerted efforts, women and people of color are still dramatically underrepresented in science, technology, engineering, and mathematics (STEM) careers (Corbett & Hill, 2015). Overall, much of the research in this area suggests that differences in STEM participation across social categories are likely due to the nature of the cultures surrounding STEM (Ong, Smith, & Ko, 2017). Cultivating communities and cultures in STEM that value diverse voices and that are open to shift and change along with members' needs is critical (e.g., Margolis, et al., 2008). Even in the midst of a public health pandemic (i.e., COVID-19) that has shifted the global and educational landscape, it is still vital to engage in both community-building and creating inclusive counterspaces. As program designers of a STEAM program for girls, we, like many others, had to quickly shift our in-person efforts to build culture and community in STEM to the virtual space, requiring us to redesign our activities, social practices, and expectations for interaction. However, as the landscape of in-person and remote learning is still shifting, it is not yet known how these two spaces interact and how the changes impact community and cultures in STEM learning.

Thus, we explore the following research question: How can community and relationships for middle school girls in an out-of-school-time (OST) STEAM learning program persist during a sudden shift to online learning? In this study, we describe our efforts to continue Digital Youth Divas (DYD), an OST program that aims to engage middle school girls, especially those who identify as Black and Latina, in design-based STEAM and computing activities (Pinkard et al., 2017). Our findings have implications for educators, researchers, and program designers as they seek to understand the importance of community and relationship building and develop interventions or strategies to build community in both online and in-person learning programs.

Background and theory

Our work takes a sociocultural perspective of learning (e.g., Lave & Wenger, 1991), understanding that learning happens through participation in communities. We also view learning as taking place dynamically across contexts such as home, school, and community through interactions with peers and adults (Barron, 2006). Studying an OST STEAM program like DYD, we acknowledge the importance of and intentionally aim to engage two groups in girls' learning ecosystems: parents and mentors. Prior research suggests family involvement in OST settings benefits academic performance and program retention (Deschenes et al., 2010). Furthermore, parents' interests, knowledge, and values influence youth's computing and technology learning and expertise (Barron et al., 2009).

In oppressive STEM climates, girls' lack of sense of belonging and a shortage of mentoring appear to be instrumental in women's decisions to leave STEM (Fabert, et al., 2011), particularly those who face gendered racism (Thomas et al., 2018). Mentoring programs, especially those engaging near-peer mentors have helped students develop an interest in STEM, positive STEM identities, a sense of belonging in the community, and the will to persist in academic STEM journeys (Zaniewski & Reinholz, 2016). Further, same-gender peer mentoring increased mentees' confidence, motivation, sense of belonging, and retention (Dennehy & Dasgupta, 2017).

In addition to parent and mentor support, a crucial factor impacting Black and Latina girls' participation in STEM is the underlying culture of STEM itself. STEM cultures and communities are often built on practices typically associated with stereotypical white and hypermasculine ways of being (Simon, Wagner, & Killion, 2016). As such, learners who do not identify with these ways of being may feel that their full, authentic selves are unwelcome or must be changed in order to participate in STEM (Thomas et. al, 2018). Thus, it is necessary to create counterspaces, or safe spaces where Black and Latina learners can grow, learn, and be in community with others (Ong et al., 2017). These counterspaces can form in different ways and do work to alleviate negative impacts from oppressive structures and cultures created by negative stereotypes and deficit narratives (Ong et al., 2017). In the current study, we seek to create a counterspace by providing inclusive, welcoming spaces for Black and Latina girls and their families to engage in STEM learning.

Methods

Program description

DYD is a program created to engage Black and Latina middle school girls in design-based STEAM and computing projects that are introduced by narrative stories (Pinkard et al., 2017). Since its inception in 2013, DYD has had over 500 girls participate and trained over 40 high school, undergraduate, and graduate students to be near-peer mentors. Led by the near-peer mentors, each session involves hands-on learning experiences designed to make connections between STEM and girls' own interests, such as art, fashion, or music. To build community in and beyond the DYD, the girls' parents and caring adults participate in workshops and social events designed to support family engagement in STEAM called Caring Adult Network (CAN).

Participants

During the program year 2019-2020, a total of 47 girls between ages 10 and 12 in a midsized racially and socioeconomically diverse community joined in the 16-week program. Parents of the girls were racially diverse, where approximately 30% identified as African American, 26.42% Latino/a/x or Hispanic, 11.32% Caribbean Islander, 11.32% White (non-Hispanic), 9.43% Asian American, and 11.32% other (Biracial, Jewish, Asian Latino, Native American, American Indian, or Alaskan Native). Household incomes were also diverse, with 27.66% between \$20k -\$50k, 21.28% between \$60k - \$100k, 27.66% between \$100k - \$150k, and 19.15% making \$150k or more.

Data sources and analysis

We distributed a post-program survey among youth participants to understand their experience in and beyond DYD, asking questions such as *How much do you feel supported by your mentors?* Activities were facilitated through an online learning platform; through this, we were able to collect attendance and participation data even while engaging in remote learning. We also distributed a post-program survey among parents to collect feedback on their experience in DYD and CAN as well as the impact of COVID-19 on their families. We observed and recorded the final program showcase event with a focus on the experience and relationship between the mentors and the girls. In this paper, we present preliminary results that describe the ways families, mentors, and girls built counterspaces and a supportive community in-person and virtually.

Preliminary results

We provide preliminary results from this work by briefly describing changes we made to accommodate the shift to online programming, sharing the extensive impact of COVID-19 on the families, and sharing reflections on the program from parents and youth participants.

Programmatic shifts

When faced with a required lockdown due to the COVID-19 pandemic, we made use of the online video platform Zoom, in lieu of our in-person sessions, workshops, and events for both girls and parents and caring adults in CAN. The scheduling of DYD sessions remained on the same day and time to encourage girls to stay engaged and connected as the pandemic began. We used breakout rooms, online quiz and game websites, virtual whiteboards, and other online resources to create fun and interactive learning experiences during the Zoom sessions. We also invited girls to connect with their peers and program mentors via weekly social Zoom sessions to chat about their DYD projects and life in general. We scheduled two CAN events for parents during this time; one was an online chat to discuss supporting families, and the other was a final showcase. We also communicated with families more often, incorporating SMS and phone calls in addition to emails (Coleman et al., 2021).

Impact of the pandemic on families
Participation in DYD in the year 2019-2020 could not be fully understood without accounting for the impact the COVID-19 pandemic had on families. Parents and caring adults reported a significantly negative impact on their daily lives due to the COVID-19 pandemic, indicating that bandwidth was stretched incredibly thin for families during this time. In the post-survey, we asked parents, "What impact did the COVID-19 pandemic have on you and your family?" All respondents reported at least one negative impact of COVID-19. Of the 26 respondents, 18 reported difficulty transitioning to remote learning for DYD, 16 reported difficulty transitioning to remote learning for school or work, and 10 reported an immediate negative economic impact due to COVID-19. This clearly indicates that DYD families were deeply impacted by the pandemic and reminds educators and researchers the importance of moving forward with open understanding.

Responses to the program
The programmatic shifts, in addition to the larger pandemic context, impacted attendance for both DYD workshops and CAN events. The average attendance at youth sessions and CAN events did drop significantly after the shift to virtual programming. However, the impact of the programming and the quality of participation remained high. Evidence from the workshops, parent, and youth surveys indicates that DYD was overall an important part of the families' lives and continued to play a positive role in learning and socialization. For example, in an open-response question that asked parents to comment on the program and the impact of the pandemic, one parent responded, *"Thank you for doing the program, I would not be able on my own to expose my child to the STEM topics and activities in addition to the role models."* Another parent described that their child looked forward to every Zoom session, missed seeing her friends in person, and attended every event possible. This parent concluded, *"Doing the online meetings on Saturday brought a sense of normalcy to this chaotic situation."* Similarly, in the post-program youth survey, the majority of girls indicated that they felt like they belonged in the DYD community. Together, these responses suggest that DYD remained a safe space and a positive influence for the girls and families who were able to continue participating.

Importantly, the care and effort put forth by the mentors to create a safe and supportive space for the girls can be seen in the way they structured the final showcase event of the program year. Mentors made personalized videos for each of the girls who attended the final showcase, congratulating them on a year of growth and learning, and taking time to point out things they appreciated about each one. The mentors publicly shared personal sentiments such as *"I loved your positivity and your kindness."*; *"I really enjoyed how quick you were to adapt."*; and *"...I really liked your enthusiasm..."* These affirmations demonstrate that building community throughout DYD meant focusing on personal growth, social and emotional support, and individual connections. In the post-program survey, the girls generally indicated that they felt supported by their mentors. This demonstrates that even remotely, a community can be built and sustained for Black and Latina girls by focusing not only on STEAM learning but also on validating girls' emotions and experiences and explicitly praising their efforts and persistence.

Reflections and implications
Our study examined the implementation of DYD as learning activities shifted to virtual spaces due to COVID-19 and how culture and community could be built and sustained around STEM for Black and Latina girls in particular. While we cannot know the impact the pandemic had on program participation of other demographics as compared to our participants and their families without comparative study, we acknowledge that large-scale crises tend to make more visible existing structural inequities that impact Black and Brown communities (Sequist, 2020). While we needed to make decisions quickly about how to organize our program in response to the pandemic, we could not know all the ways the crisis would impact families' ability to participate. Even now, much is still unknown about the constraints and opportunities faced by our diverse population of families.

These initial findings provide lessons to build on as we continue establishing online community connections for 2020-2021. First, a supportive community must be willing to adapt and shift to members' needs, while also not placing blame or fault on families for situations beyond anyone's control. While at first glance the downward trend in attendance may seem disappointing, it serves as a reminder that families may have competing demands on time and energy, resource constraints, or other concerns that may impact their ability to prioritize OST STEM learning. Strategies such as more frequent contact with families through multiple communication modes should be designed to meet girls' and their families' needs and preferences. Next, much like the DYD mentors gave the girls words of praise and encouragement in the final showcase, a mentoring relationship that provides a STEM counterspace must highlight and celebrate the full, authentic selves of the learners and validate both their STEM interests and other aspects of their identities. Last, we acknowledge that community and counterspace building takes intentional work and time, and may be even more challenging online. Understanding what families have gone through during the pandemic helps us design a better experience for all families while remaining mindful of our program mission. Educators should adopt an ethic of care now and always and continue to commit to providing counterspaces for learners who are too often subjected to gendered racism in STEM and computing. Future work should also further examine the role of race, ethnicity, class, and other factors on families' abilities to thrive and learn during crises.

References

Coleman, M., Garcia, I., Hill, J., Ju, B., Lawler, B., Osorio, M., Thompson, N., Standberry-Wallace, M., Nacu, D., Erete, S., & Pinkard, N. (2021, March). Navigating a pandemic: Evaluating communication with parents in a STEM program for Black and Latina girls. In A. Decker (Chair), *Special interest group computer science education*. [Proceedings in press]. Online.

Pinkard, N., Erete, S., Martin, C. K., & McKinney de Royston, M. (2017). Digital youth divas: Exploring narrative-driven curriculum to spark middle school girls' interest in computational activities. *Journal of the Learning Sciences*, *26*(3), 477-516.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecologies perspective. *Human Development* 49:193–224.

Barron, B., Martin, C. K., Takeuchi, L., & Fithian, R. (2009). Parents as learning partners in the development of technological fluency. *International Journal of Learning and Media*, *1*(2), 55–77.

Corbett, C., & Hill, C. (2015). Solving the Equation: *The Variables for Women's Success in Engineering and Computing*. American Association of University Women. 1111 Sixteenth Street NW, Washington, DC 20036.

Dennehy, T. C., & Dasgupta, N. (2017). Female peer mentors early in college increase women's positive academic experiences and retention in engineering. *Proceedings of the National Academy of Sciences, 114*(23), 5964- 5969.

Deschenes, S. N., Arbreton, A., Little, P. L., Herrera, C., Grossman, J. B., & Weiss, H. B. (with Lee, D.). (2010). *Engaging older youth: Program and city-level strategies to support sustained participation in out-of-school time*. Cambridge, MA: Harvard Family Research Project.

Fabert, N., Cabay, M., Rivers, M., Smith, M. L., & Bernstein, B. L. (2011). Exaggerating the typical and stereotyping the differences: Isolation experienced by women in STEM doctoral programs. *Proceedings of the American Society for Engineering Education* (AC 2011-704).

Lave, J. W., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Margolis, J., Estrella, R., Goode, J., Holme, J. J., & Nao, K. (2008). *Stuck in the shallow end: Education, race, & computing*. MIT Press.

Ong, M., Smith, J. M., & Ko, L. T. (2017). Counterspaces for women of color in STEM higher education: Marginal and central spaces for persistence and success. *Journal of Research in Science Teaching, 55*(2), 206–245.

Sequist, T. D. (2020). The disproportionate impact of COVID-19 on communities of color. *NEJM Catalyst Innovations in Care Delivery*, *1*(4).

Simon, R. M., Wagner, A., & Killion, B. (2016). Gender and choosing a STEM major in college: Femininity, masculinity, chilly climate, and occupational values. *Journal of Research in Science Teaching, 54*(3), 299–323.

Thomas, J. O., Joseph, N., Williams, A., & Burge, J. (2018, February). Speaking truth to power: Exploring the intersectional experiences of Black women in computing. In *2018 Research on Equity and Sustained Participation in Engineering, Computing, and Technology* (RESPECT) (pp. 1-8). IEEE.

Zaniewski, A. M., & Reinholz, D. (2016). Increasing STEM success: A near-peer mentoring program in the physical sciences. *International Journal of STEM Education*, *3*(1).

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Caregivers' Role-taking during the Use of Discussion Prompts in At-Home Engineering Kits

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Abstract: This study presents a video-based case study of families who used discussion prompts in the at-home engineering kits. We examine different roles that caregivers took on during the implementation of the prompts to organize families' engineering learning activities. Narrative accounts and transcriptions were analyzed to investigate the different roles that caregivers took. Three roles emerged: caregivers as *monitor*; caregivers as *mentor*; caregivers as *partner*. We further coded families' talks to investigate how three different caregivers' roles influenced families' engineering practices and caregiver-child talk types. Preliminary findings illustrate how three caregivers' roles enabled and constrained different types of engineering practices and caregiver-child talk types. Findings contribute to future considerations in designing discussion prompts for at-home engineering kits.

In response to COVID-19 pandemic, caregivers' engagement in their children's learning is an emerging priority. We provided at-home engineering kits, which included open-ended engineering challenges and discussion prompts to facilitate families' engagement in engineering practices at home. While research has examined the role of prompts in informal learning settings (e.g., Zimmerman, McKinley, Kim, & Grills, 2019), most studies are from contexts where facilitator support is available; less is known about how prompts can support caregivers to guide children's' learning at home. In this paper, we examine different roles that caregivers took on during the implementation of the discussion prompts to organize families' engineering learning activities.

Theoretical framework

We focus on families' social interaction and conversations by building on work that applies sociocultural theories to family learning (Dierking & Falk, 1994). In families' shared activity, caregivers can take on roles to structure families' participation and support negotiation of meanings (Rogoff, 2003). Prior research suggests that caregivers take on roles such as teachers, collaborators, and learning brokers (Barron, Martin, Takeuchi, & Fithian, 2009). Our conjecture is that caregivers' roles influence the degree of structure and formalness when using the prompts in the at-home engineering kits, which can consequentially influence families' engineering practices. Our work explores how caregivers organize families' engineering learning activities—through the configurations of interactional roles—during the use of at-home engineering kits.

We adopted Engineering is Elementary (EiE) model (ask-imagine-plan-create-improve) to guide our understanding of families' engineering practices (Cunningham, 2009). For younger learners (K-5), the engineering practices of asking is related to understanding the problem scope; imagining and planning relate to the idea generation; creating is concerned with the application of scientific and engineering knowledge to address the design problems; and improving is making optimization on their design (National Research Council, 2012).

Methodology

Our study is a qualitative case study of families with children (6-12 years) who used the at-home engineering kits. The unit of analysis was family members' engagement while utilizing one kit. If one family split up into two groups and used two kits separately, we considered them as two cases. The research team worked with Boys and Girls Clubs and public libraries that had existing relationships with economically disadvantaged families to recruit study participants. Eight families represented European American, Asian, and African American backgrounds. Out of 16 families (27 children) that completed one to five kits and recorded their interaction (230 hours of data), we focused on eight family cases that completed the same kit. The kit included an instruction card and craft materials to construct a package for delivery, out of pasta, that can travel along a zipline to deliver a package to a friend 30 feet away. Four discussion prompts contained questions: 1) prompt 1: What is the function of each container? What kinds of shapes form a good container? What material will you use? Explain your choice of material; 2) prompt 2: Is your container sturdy enough? How do you know? How might the type of pasta make a difference? Is the size and depth of the container appropriate?; 3) Prompt 3: Why do you need a handle and a hook?; 4) prompt 4: Construct a zipline and test your design. Explain how you attached the zipline. Why is your design working or not working? How can you improve your design?

We conducted interaction analysis (Jordan & Henderson, 1995) in two phases. First, we created content logs to identify episodes where families utilized the prompts. When the families' video-records did not provide clear evidence of revoicing the prompts, we did not engage in further data analysis to prevent from making ungrounded assumptions. As such, two family cases were excluded. For each case, we created a narrative account with a summary of how many prompts were implemented and transcribed families' talk that resulted from the implementation of the prompts with screenshots and timestamps from the video-records to provide a "thick description." We further examined the narrative accounts by conducting a thematic analysis to explore the different roles that caregivers took during the implementation of the prompts. Three themes emerged: caregivers as *monitor*; caregivers as *mentor*; caregivers as *partner*. In the second phase, to investigate how three different caregivers' roles influenced families' engineering talks, we coded families' talks at the level of individual's utterances, defined as a turn of speech by a speaker, with atlas.ti. using the coding scheme by Cardella et al. (2013) with three elements: 1) engineering practices (problem scoping, planning, modeling, evaluation/testing), 2) caregiver-child talk types (asking, affirmation, disagreement, explanation), and 3) interest (excitement, frustration). The codes for the engineering practices aligned with the EiE practices. We refined the codebook until there was a consensus on the codes. Consequently, sub-codes were added (e.g., kit revoicing, asking questions to express uncertainty). Coding results were compared and contrasted within and across three different groups. We acknowledge that the study sample in each participant structure is not sufficient to provide generalizability.

Findings

The occurrences of talk demonstrated that families' conversations sparked by the discussion prompts were predominantly related to the engineering practices of planning, followed by equal occurrences of problem scoping and modeling and evaluation/testing (Figure 1). Explanation, asking questions, and providing affirmation/ encouragement were the most frequent talk types. When occurrences of talk were compared across three groups, caregivers as *monitor* utilized all four prompts and the other families used 1 to 3 prompts. The families' talk related to engineering practices and caregiver-child talk types had nuanced differences across three groups. Notably, families with caregivers as *monitor* engaged in more planning talk while families with caregivers as *partner* engaged in more problem scoping talk. Talks related to asking questions to express uncertainty or having conflicts were only evident in families with caregivers who took on the role of *monitor*.

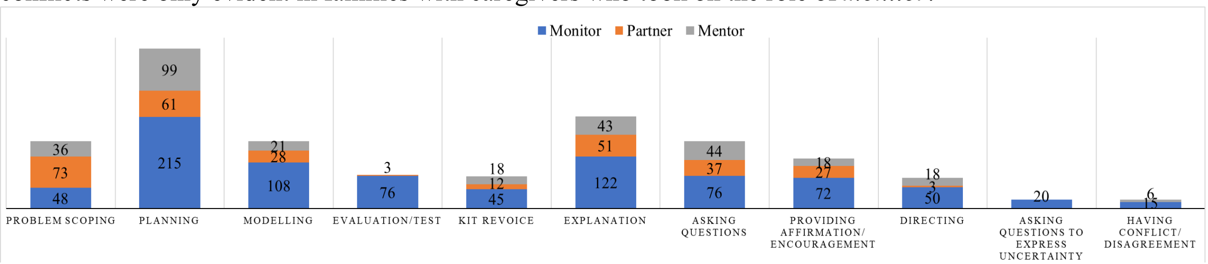

Figure 1. The graph represents occurrences of talk at the level of individual's utterances related to engineering practices and talk types in three groups (caregivers as monitor, caregivers as partner, caregivers as mentor).

Caregivers monitor the design process with faithful implementation of the prompts

Caregivers took on the role of *monitor* by faithfully revoicing all four prompts, which supported families' engagement in all four engineering practices. Edward and Roberto's families that had caregivers taking the role of *monitor* were the two cases that revoiced prompt 2 to test the sturdiness and the appropriate size of the containers. As such, these two families were able to also engage in engineering practice of evaluation and testing, which most families did not engage in (Figure 1). Families' engagement was characterized by product-driven approach—towards constructing a complete prototype that addresses the function—as highlighted in higher occurrences of planning and evaluation/testing talk.

Analysis of families' interaction showed that caregivers used the prompts to provide executive directions on what to do next or provide approval to the child's responses, as demonstrated in the excerpt from Edward's family below. Edward's family discussed what the function of the container would be after revoicing prompt 1. Initially, Edward suggested that the container be easy to use and deliver the package fast. The caregiver disagreed and emphasized to focus on keeping the package secure inside the container. Afterwards, the family did not engage in further discussion to reach a consensus on the function or discuss different ways to add safety features to the container. The episode starts as the caregiver observes Edward making the container.

01	Caregiver:	((shakes head)) You are gonna hurt it, you are gonna hurt it. No, mm-mm (negative)…
02	Edward:	((moments passed; the plastic figure is put inside the container))

03 Caregiver: Ok. I don't think it's the best way, but it's what you wanna do…I am thinking if I had to put you
04 in one of these and sent you across the way, would you want to be in here?
05 Edward: ((frowns)) No!
06 Caregiver: Think about it. Ok. We need to make something that's safer.

The caregiver expressed uncertainty and disapproval towards Edward's design approach (line 1). She expressed disagreement even after Edward successfully put the figure in the container (line 3) since the container did not look safe and secure (lines 4, 6) to address the function that she had emphasized previously. Findings showed that caregivers who took on the role of *monitor* faithfully implemented the prompts to monitor the design process, but also questioned the appropriateness of the child's approach and shifted their design trajectory towards implementing approaches that caregivers perceived as important.

Caregivers mentor to mitigate challenges through on-the-fly use of the prompts

An additional role that caregivers took on was that of *mentor*. In Sara and Eden's families, caregivers mentored their children by utilizing the prompts on-the-fly to mitigate challenges experienced by the children. Sara and Eden were part of the same family, but each worked with different caregivers. (Therefore, two separate video-records were created.) Sara, being the older sibling, independently worked on the engineering challenge without much challenges by using the instruction card. Eden, on the other hand, experienced difficulties understanding the engineering challenge and the constraints, although the caregiver had previously utilized the discussion prompt 1 to discuss them. After discussing prompt 1, the caregiver left to do chores. When the caregiver started observing Eden after she finished her work, Eden stated: "I have no idea what I am doing." The caregiver then helped Eden to construct the container. The episode starts after the caregiver reads the discussion prompt 4 to brainstorm ways to attach the container to the zipline.

01 Caregiver: How will we ((looks at the prompt)) attach this zipline? ((rephrases the same question again))
02 Eden: You just use another pipe cleaner ((attaches to the container)) but then it would…
03 Caregiver: What other materials do we have in here?
04 ((Eden mentions fishing line, scissors, paper clips, rubber bands.))
05 So, let's think about what might….let's… you wanna feel this ((passes the fishing line))?
06 Eden: ((feels the fishing line))
07 Caregiver: What might slide along there very easily?
08 Eden: ((takes paper clip))

The caregiver utilized the discussion prompt and asked questions to help Eden notice a material that might slide easily along the zipline (lines 1–2). As Eden was unable to notice the material property of the paper clip, the caregiver asked Eden to feel the fishing line (line 5) and find a material that might slide down the fishing line (line 7). As highlighted in the episode, the caregiver positioned herself as the mentor who would step in to mitigate challenges experienced by the child—by utilizing questioning to strategically guide the child find ways to address the engineering challenge. While the caregiver continued to encourage the child to brainstorm and design the prototype, it was often challenging for Eden to figure out ways to construct the container or address challenges on his own. As such, the caregiver had to step in to provide strategic questioning and explanations to co-construct the container and the zipline. Later, Eden and the caregiver successfully constructed a zipline that delivered a package by adopting a pulley system. However, Eden expressed a lack of ownership over the design as the caregiver initiated many ideas: "I think I am copying Sara (his sister)." Without opportunities for the child to make sense of and resolve his inquiry steps, as the caregiver stepped in to deliver suggestions, the feeling of accomplishment at the end of the engineering challenge was low for Eden.

Caregivers partner with the children through equal usage of the prompts

The last role that caregivers took was that of *partner*. In two family cases (Billy, Abby), caregivers and children worked as partners by posing questions and suggestions while equally utilizing the prompts. A notable difference in this group was high occurrences of problem scoping talk (Figure 1). Billy's family discussed how long 30 feet is; Abby's family discussed which toy to send to estimate the size of the container. We note that similar type of problem scoping was not evident in other cases. Another notable difference was the level of caregivers' participation. The caregivers engaged as partners alongside the children who also questioned, shared uncertainty, and proposed ideas throughout the engineering design process instead of only voicing opinions when challenges emerged as an outsider. We present an episode to illustrate how caregivers took on the role of *partner*. Prior to the episode, Billy read aloud prompt 1 and began to sketch out his plan for the container. The caregiver revisited the prompt and questioned how the container could travel back and forth to deliver a package.

01 Caregiver: In the olden days…you could pull the clothing line towards you and then it would go back out.
02 Billy: Yes, but that's…we can do that, Mom. ((notices)) There's fishing, fishing line!
03 Caregiver: Do we want to use gravity or do we want use more like pull?

04 Billy: Pull.
05 Caregiver: Because why?
06 Billy: Because gravity would be hard.
07 Caregiver: If it was gravity, it would only be able to go to, let's say to Lia's house. But we couldn't get it back…

The caregiver continued to inquire different possibilities for creating the delivery system by suggesting a pulley (lines 2) and gravity (line 3) to deliver the package. When Billy quickly dismissed the possibility of using gravity (line 10), the caregiver continued to question whether gravity would be an appropriate option given that creating a different height between departure and arrival points, thus using gravity, would only work in one direction (line 7). After this episode, Billy resisted to inquire about this topic further as he emphasized sketching out their plans first to complete the challenge. As illustrated in the episode, the caregivers who took on the role of *partner* engaged in the engineering activity with genuine interest to construct a working solution by posing questions and suggestions. However, in two family cases, an opportunity for further inquiry was often constrained by the child's intellectual values on the completion of tasks.

Discussion and conclusion

Our preliminary findings from six family cases illustrate forms of guided participation (Rogoff, 2003) that caregivers took on to organize families' engineering learning activities at home. Barron et al. (2009) have shown that caregivers support children's technology engagement by taking different roles as their learning partners. Our case study findings demonstrate that caregivers took on roles as *monitor, mentor, and partner* which both enabled and constrained different types of engineering practices and caregiver-child talk types. While faithful implementation of the prompts by caregivers who took on the role of *monitor* was supportive towards engagement in engineering practices, the asymmetric relationship in which the caregiver was positioned as the knowledge validator seemed to echo the rhetoric of hierarchy. Caregivers who took on the role of *mentor*, as highlighted in Eden's case, demonstrated that moments of learning opportunities that emerge from the child's inquiries may not be taken up *just-in-time*. The on-the-fly support from the caregiver in Eden's case enabled the family to co-construct a working prototype; however, questions remain as to whether the caregiver's support also enabled Eden to take ownership of their prototype. Caregivers that took on the roles of *partner* demonstrated that caregivers' active participation to learn and motivation to guide their children in inquiry process can be hindered when children's motivation and goals are not aligned with that of the caregivers. One possible solution that can be embedded in the discussion prompts is to communicate the importance of taking up one another's ideas, questions, warrants—however small they may be. It may be necessary to first support family members to understand that the informal engineering learning activity as an opportunity to construct and evaluate knowledge rather than simply completing the challenge. In future, we hope to investigate further how different design elements in the at-home engineering kits, including the prompts, can provide learners to embody engineering ways of thinking without the presence of a facilitator, while considering the role of family members.

References

Barron, B., Martin, C. K., Takeuchi, L., & Fithian, R. (2009). Parents as Learning Partners in the Development of Technological Fluency. *International Journal of Learning and Media*, *1*(2), 55–77.

Cardella, M. E., Svarovsky, G. N., Dorie, B. L., Tranby, Z., & Van Cleave, S. (2013). Gender research on adult-child discussions within informal engineering environments (GRADIENT): Early findings. *ASEE Annual Conference and Exposition*. American Society for Engineering Education.

Cunningham, C. M. (2009). Engineering is elementary (EIE). *The Bridge*, *30*(3), 11–17.

Dierking, L. D., & Falk, J. H. (1994). Family behavior and learning in informal science settings: A review of the research. *Science Education*, *78*(1), 57–72. https://doi.org/10.1002/sce.3730780104

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences*, *4*(1), 39–103.

National Research Council. (2012). *A Framework for K-12 Science Education*. https://doi.org/10.17226/13165

Rogoff, B. (2003). The cultural nature of human development. In *The cultural nature of human development*. New York: Oxford University Press.

Zimmerman, H. T., McKinley, Z. A., Kim, S. H., & Grills, K. E. (2019). Discussion prompts to support family engagement in science: Talking about Astroengineering in library-based making programs. *Proceedings of the 18th ACM International Conference on Interaction Design and Children, IDC 2019*.

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Embodied Design versus Dynamic Visualization: Benefits for a Far Transfer Problem Solving in Trigonometry

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Abstract: The development of digital technologies enables visualizations of many scientific relations. In this paper, we question the efficiency of the visualizing tools from a theoretical perspective that combines cultural-historical and radical embodied approaches. Dynamic visualizations expose the target relations in a ready-made form, while embodied action-based design provides students with an opportunity to re-invent the target relations through active sensory-motor coordinations. In a multiple-case study, we compare these design genres for learning trigonometric relations. While dynamic visualizations were more efficient in simple tasks, embodied action-based design enhanced students' reasoning in a far transfer task.

Introduction

New technological tools provide unique opportunities for visualizing scientific relations, such as relativity theory principles in virtual reality or trigonometry relations in dynamic geometrical environments (e.g., DeJarnette, 2018). Putting the development of digital technologies in the broader context of technology evolution in society, researchers from cultural-historical tradition stress that technologies appear as a reification of cultural practices (Pea & Cole, 2019; Wenger, 1998). The most stable aspects of practice become fixated in a form of visual inscriptions and other artifacts. When providing students with a visualization of some mathematical or scientific relation, educators present a former scientific practice of establishing the target relation in a ready-made form. For example, a sine function was constituted in the history of mathematics as a practice of relating an arc on a circle to a chord (Toomer, 1974); a sine graph appeared later as depicting this relation (presumably by Albert Dürer). In many textbooks a sine graph is drawn as already connected with a unit circle. In this case, students come to learn about this relation in a ready-made form.

However, some approaches postpone involving ready-made scientific artifacts into teaching practice (e.g., Gravemeijer, 1999). The students are invited to re-invent the target mathematical or scientific relations—such as a relation between an arc and *y*-coordinate on a unit circle to *x*- and *y*-coordinates of a sign graph—in their own practice before embedding them into artifacts and technologies. These approaches are particularly meaningful from a radical embodied perspective that considers cognitive functions to be complex dynamic systems of perception-action loops (Abrahamson & Sánchez-García, 2016; Chemero, 2009). As students learn to use cultural artifacts, they incorporate artifacts into their extended cognitive functions by including them into perception-action loops. We suggest referring to this process as a genesis of *body-artifacts functional systems* (Shvarts, Alberto, Bakker, Doorman, & Drijvers, under review). In this study, we investigate if educational technology that invites students to re-invent a sine graph is beneficial for furthering students' reasoning compared to the technology that automatically generates a sine graph without students' active participation. We expect that the students who re-invent artifacts that reified mathematical practices—such as a sine graph—acquire perception-action loops for building these artifacts. Later, they might use the understanding of artifacts' constitution in reasoning. Contrary, students who encounter an artifact as automatically generated, might lack understanding of how it was built, similar to using a smartphone without knowing how it works.

Action-based embodied design versus dynamic visualizations

Various dynamic visualizations have been designed to show the students the relations between a point on the unit circle and a correspondent point on a sine graph (e.g., DeJarnette, 2018). In these technological solutions, educators invite students to *observe* mathematical relations, which are already embedded into technology. However, the demonstration of the relations does not automatically lead to their understanding by the students (Yerushalmy, 1991), questioning these designs' efficiency. As we combine a cultural-historical approach that states that perception develops (Radford, 2010; Vygotsky, 1997) and a radical embodied approach that claims perception serves action (Abrahamson & Sánchez-García, 2016; Maturana & Varela, 1987), we might wonder if the students are able to *notice the target relations* that designers are trying to show them.

Action-based embodied design (Abrahamson & Sánchez-García, 2016) provides a principal alternative to visualizing technologies. Mathematical relations are not explicitly exposed to the student, but delivered as a motor problem (Bernstein, 1967). Embodied interactive activities provide continuous feedback to students' hand-movements. Aiming to receive positive feedback, students maintain target distances on a visual display in a target mathematical relation. Thus students reinvent mathematical relations and artifacts in their sensory-motor practices. Instead of relying on students' existing perception abilities, an action-based embodied design fosters the development of new forms of perception by establishing sensory-motor coordinations.

The essence of the difference between dynamic visualizations and action-based embodied designs lies in the different answers to the question, "Who gets to constrain the student's interaction with the virtual objects: the software or the student?" (Abrahamson & Abdu, 2020, Context section). The embodied action-based design's research program assumes that emergent task constraints in interaction with a student might be beneficial for targeted conceptual learning. In this study, we collect empirical evidence to corroborate or reject this theoretical expectation. Thus we question: *What are the differences in reasoning about a novel trigonometry problem in learning with action-based embodied design and learning with interactive dynamic visualization?*

Methodology

We report the results of a contrasting multiple-case study (Miles & Huberman, 1994) that compares two design genres: embodied action-based design and interactive dynamic visualization.

Learning materials

Both types of interactive designs were programmed in the Numworx digital environment within broader design research on the embodied approach to trigonometry learning (see Alberto, Bakker, Walker-van Aalst, Boon, & Drijvers, 2019). There were four parts in the learning materials dedicated to (1) sine value in a unit circle; (2) relation between an arc of a unit circle and x-coordinate of a sine graph; (3) relation between a sine value in a unit circle and y-coordinate on a sine graph; (4) constructing a sine graph by relating an arc and a sine value on the unit circle to x- and y-coordinates of the sine graph (see Figure 1). Each part consisted of three sequential types of tasks: interactive sensory-motor task, reflection task, and mathematical task. In sensory-motor tasks, the students studied the relations between a point on a unit circle and a point on a sine graph. Then the students reflected on these relations in written form and through multiple-choice task. Finally, they solved mathematical tasks based on the studied relations.

Contrasting conditions

In the action-based embodied design condition (ED), the students studied the target relations in the form of a motor problem as they manipulated two points: a point on the unit circle and a point on the Cartesian coordinates. Continuous feedback from the system informed them when the points were in the corresponding positions by changing the color from red to green (see Figure 1). As students continuously maintained green feedback, they developed new coordinations, thus incorporated the target mathematical relations in their bodily functional system of perception-action loops. In the dynamic visualization condition (DV), the students moved only one point on the unit circle, while the point on the Cartesian coordinates was automatically moved in correspondence with the first point. So the experimental factor determined whether the students were maintaining the target relation in sensory-motor enactment based on the feedback or whether the target relation was maintained by the software and exposed to the students in a ready-made form. Figure 1 shows tasks from two conditions in Part 4. The reflection and mathematical tasks were the same in both conditions.

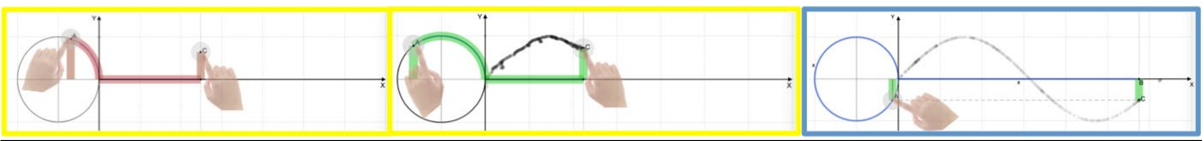


Figure 1. Embodied design (in a yellow frame, red and green feedback, ED): a sine graph emerged from active coordination of two hands. Dynamic visualization (in a blue frame, DV): a sine graph was automatically generated when moving one hand around the unit circle.

Research protocol and participants

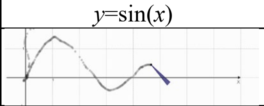
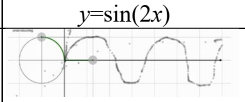
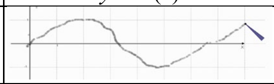
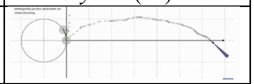
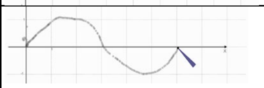
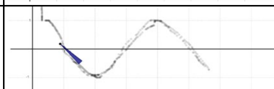
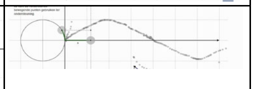
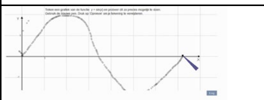
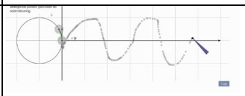
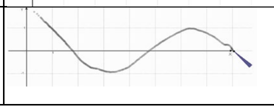
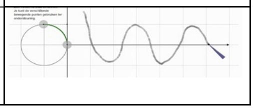
The procedure consisted of a pre-test, learning stage, a post-test, and an interview. The post-test included near transfer tasks similar to the tasks from the learning materials, such as estimating $\sin(\frac{7}{12}\pi)$ and drawing a graph y=sin(x), and far transfer tasks such as estimating sin(12) and drawing a graph of y=sin(2x). In the interview, we asked the students to explain how they solved the post-test tasks and scaffolded them towards accomplishing these tasks in a case of mistake, thus investigating their reasoning. All data collection was run online. The students (14-15 years old) had no pre-knowledge in trigonometry beyond trigonometric relations in a right triangle. Three students learned with embodied design and four students learned with dynamic visualizations.

Results

In solving the algebraic near transfer tasks in the post-test, the students from the DV condition performed better than the students from the ED condition: four DV students answered 100%, 57%, 50%, and 29% of the tasks, while there ED students answered 50%, 29%, and 14% of the tasks. In two cases, the ED students were still unsure how to quantify the sine value on a unit circle. However, as soon as the researcher in the interview would ask the students to recall their embodied experience, they could easily correct their mistakes. The disadvantage of ED might be explained by the need to communicate with a real tutor for a successful transition of embodied experiences into mathematical discourse when learning with embodied designs (e.g., Flood, 2018). This communication was provided only in the interviews, after the post-test.

For the drawing tasks, students from ED condition clearly benefited over students from VD condition. The vivid differences were observed in the far transfer task of drawing the graph y=sin(2x). The most challenging part of this task lies in the idea that the graph's period is two times smaller when x is multiplied by two. As Table 1 illustrates, all three students from the ED condition expressed this change in the period in their drawings. They could explain their drawings referring to the point moving around the unit circle two times quicker for the formula y= sin(2x), and, consequently, the waves of the graph appearing more frequently. Only one out of four students from the DV condition came up with this change in the graph; two students drew the graph extending in the horizontal direction, and one did not come up with any drawing (not shown in Table 1).

Table 1: Students' drawing of in the post test: initial sine graph and sin(2x) in the far transfer task.

Embodied action-based condition (ED)			Dynamic visualization condition (DV)		
	y=sin(x)	y=sin(2x)		y=sin(x)	y=sin(2x)
Ellie			Mark		
Janice			Bella		
Emma			Yana		

Emma, a student from the ED condition, explained: "*I assume that with 2x that [point] on the circle will travel twice the distance, instead of [the same distance as] on the x-axis.*" While explaining, she doubled two distances in her gesturing around the unit circle: she stopped at the distance π/6 and then at the distance π/3, she then stopped at the distance π/2 and then at the distance π. Further, Emma moved synchronously two fingers in the air, one going around the circle and another going on the x-axis, thus repeating the enactment from the embodied learning. However, in this gesture, she moved the finger around the unit circle faster, in correspondence with the new formula. Emma dived into the process of constructing the sine graph from a unit circle as she gestured out the coordination of the distance along the unit circle and the distance on the graph bodily adjusting this sensory-motor coordination to the new situation. The other ED students gave similar explanations, referring to their experiences of coordinating a point on the Cartesian plane with the unit circle.

The students from the DV condition also recognized the unit circle as being useful for building a sine graph. However, they could not adjust the construction process to the new situation. Instead, they were trying out any option of enlarging or diminishing the sine graph two times in a vertical or horizontal direction. Mark referred to the unit circle explaining how the initial sine graph was built, but then concluded with enlarging the graph along the x-axis doubling the distance due to the multiplication: "*Now it says 2x so I think that now the arc of the graph that is above the x-axis is twice as long. Because the distance that is covered on the circle is twice covered in the graph.*" Ada had drawn nothing, and when asked in the interview she supposed the graph should be two times longer. Later she changed her mind and suggested that graph "*Will become double as high.*" Yana had a correct idea of diminishing the graph's period: "*I thought I am just going through that circle twice. […] That I was just going to draw it [a wave] twice.*" However, she was uncertain and changed her mind: She gestured along y-axis and said that she should adjust the graph along y-axis as sine is y-value.

The students from the DV condition reasoned about the sine graph as an outcome of the construction procedure (which was done by the machine during their learning). They tried out any possible transformation that would match a change from x to 2x and did not consider if these suggested transformations harm the relations between a sine graph and a unit circle. On the contrary, ED students had embodied experience of actively re-inventing a sine graph based on a unit circle. This experience helped maintain the entire operation of graph building coherent and implement the formula's changes into this operation.

Conclusions

The embodied experience of actively coordinating distances on a unit circle and Cartesian plane helped the students from the embodied design condition (ED) realize how the sine graph was constructed. The students could apply this understanding in further reasoning about a composite function graph without being ever taught this new material. Thus, an embodied design might facilitate creative problem-solving in far-transfer tasks. Remarkably, students' reasoning involved adapting the sensory-motor coordinations, thus it run at the embodied level. For the students from the dynamic visualizations condition (DV), a sine graph was not constrained by their own enactment but by the software (Abrahamson & Abdu, 2020). The students could not flexibly adjust the procedure of sine graph construction to the new situation. Instead, they tried to adjust an outcome of constructing procedure—the sine graph per se. Without caring about relations between a unit circle and a sine graph, the students tried to enlarge y=sin(x) graph in *some* direction, matching the multiplication in the formula.

Ready-made mathematical relations—exposed in dynamic visualization of a sine graph—presented mathematical practice in a reified form (Wenger, 1998), thus an artifact—a sine graph—extended bodily functional system (Shvarts et al., under review) in a rigid way and fostered unwarranted manipulations. The embodied action-based design provided an opportunity to actively constrain the target relations. The students appropriated trigonometric relations into perception-action loops of their flexible body-artifacts functional systems. Once the mathematical relations were included in the systems of perception-action loops, the students could adjust them to a novel situation in further reasoning. While this small-scale study results are well explained from the chosen theoretical perspective, further scaling up is needed to corroborate the conclusion of the embodied design effectiveness over dynamic visualizations in far-transfer tasks.

References

Abrahamson, D., & Abdu, R. (2020). Towards an ecological-dynamics design framework for embodied-interaction conceptual learning: The case of dynamic mathematics environments. *Educational Technology Research and Development*, 1–35.

Abrahamson, D., & Sánchez-García, R. (2016). Learning is moving in new ways: the ecological dynamics of mathematics education. *The Journal of the Learning Sciences*, (25), 203–239.

Alberto, R., Bakker, A., Walker-van Aalst, O., Boon, P., & Drijvers, P. (2019). Networking theories in design research: An embodied instrumentation case study in trigonometry. In U. T. Jankvist, M. H. A. M. v. d. Heuvel-Panhuizen, & Veldhuis M. (Eds.), *Proc. of the 11th Congress of the European Society for Research in Mathematics Education* (pp. 3088–-3095). Utrecht, The Netherlands: Utrecht University.

Bernstein, A. N. (1967). *The co-ordination and regulation of movements*. Oxford etc: Pergamon press.

Chemero, A. (2009). *Radical embodied cognitive science*. MIT Press.

DeJarnette, A. F. (2018). Students' conceptions of sine and cosine functions when representing periodic motion in a visual programming environment. *Journ. for Research in Mathematics Education*, *49*(4), 390–423.

Flood, V. J. (2018). Multimodal revoicing as an interactional mechanism for connecting scientific and everyday concepts. *Human Development*, *61*(3), 145–173.

Gravemeijer, K. (1999). How emergent models may foster the constitution of formal mathematics. *Mathematical Thinking and Learning*, *1*(2), 155–177.

Maturana, H. R., & Varela, F. J. (1987). *The tree of knowledge: the biological roots of human understanding*. Shambhala.

Miles, M. B., & Huberman, A. M. (1994). *Qualitative Data Analysis: An expanded soursebook*. Thousand Oaks, CA: SAGE Publications.

Pea, R., & Cole, M. (2019). The living hand of the past: The role of technology in development. *Human Development*, *62*(1–2), 14–39.

Radford, L. (2010). The eye as a theoretician: seeing structures in generalizing activities. *For the Learning of Mathematics*, *30*(2), 2–7.

Shvarts, A., Alberto, R., Bakker, A., Doorman, M., & Drijvers, P. (under review). Embodied instrumentation in mathematics learning as the genesis of a body-artifact functional system. *Educ. Studies in Mathematics*.

Toomer, G. J. (1974). The chord table of Hipparchus and the early history of Greek trigonometry. *Centaurus*, *18*(1), 6–28.

Vygotsky, L. S. (1997). *The Collected Works of L. S. Vygotsky. The History of the Development of Higher Mental Functions.* (R. W. Reiber, Ed.), *The Collected Works of L. S. Vygotsky* (Vol. 4). Springer US.

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. New York, NY, US: Cambridge University Press.

Yerushalmy, M. (1991). Student perceptions of aspects of algebraic function using multiple representation software. *Journal of Computer Assisted Learning*, *7*(1), 42–57.

Mobile Augmented Reality in the Backyard: Families' Outdoor Spaces as Sites of Exploration about Pollinators

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Abstract: From the first iteration of a design-based research study with 16 families, we investigated at-home intergenerational exploration of pollinators and plants. The team developed a mobile augmented reality app focused on plant-pollinator interactions. We investigated how AR elements influence families' learning in their backyards. This analysis informs the design of mobile augmented reality apps that are site-independent for families' collaborative learning opportunities in outdoor, home-based settings.

Keywords: Informal learning, science learning, mobile technologies, augmented reality, family learning

Mobile augmented reality apps supporting learning at home

Sharples and Pea (2014) theorized a sociocultural view of mobile learning as "context-sensitive learning," where learning is embedded within interacting contexts of social, material, environmental, and individual resources. Mobile devices, with their range of affordances, enable designers to reimagine configurations for how and where learning takes place (e.g., Kawas, et al., 2019). Mobile augmented reality (MAR) expands opportunities for learning within real-world places through a virtual layering of digital material that can be viewed on devices in outdoor spaces (Ryokai & Agogino, 2013). MAR uses digital resources to reveal disciplinary meanings of a place that may not be visible to learners directly (Dunleavy & Dede, 2014). Our place-based MAR concept focuses on designing "micro sites" (Sharples & Pea, 2014) for families' science learning that draws upon both planned and emergent experiences within a setting to create out-of-school learning opportunities.

We conceptualize MAR as a cultural tool mediating science learning while people move through their community. MAR has been designed to augment science learning in the natural world in places such as parks, gardens, ponds, and woodland settings (e.g., Georgiou & Kyza, 2017). We add to the MAR designs the concept of learning-on-the-move, (Silvis et al., 2018; Taylor, 2017) where movement through familiar spaces supports people as they make sense of new information. Silvis et al. (2018) investigated families' technology practices within an ethnographic study and found that mobile computers and other technologies were integrated as learning tools in homes and communities. Similarly, Taylor (2017) used ethnographic methods to explore how youths came to understand their community as a designed, complex system.

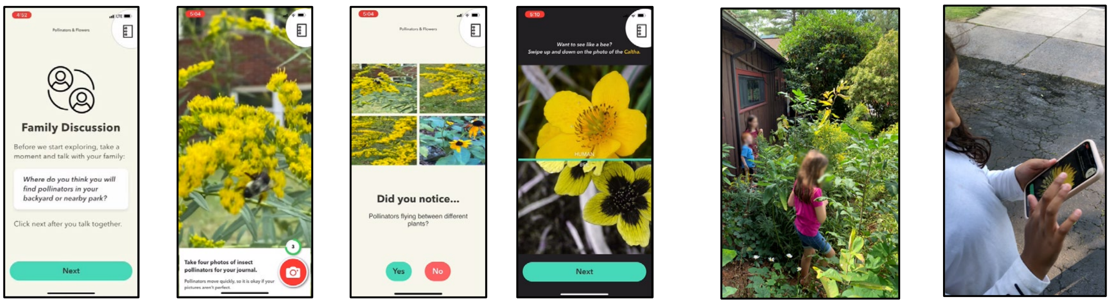
Learning scientists argue that to engage in scientific observations, people must be facilitated to notice scientifically through joint attention and guided participation (Eberbach & Crowley, 2017). Eberbach and Crowley found that parent-child conversation during their shared focus on insects and plants was an essential mechanism for understanding pollination. Using *wh-* questions is one of Eberbach and Crowley's elaborative conversational strategies to direct attention and elicit meaning-making conversations. Marin (2020) investigated observing-on-the-move in families with children as they walked together in forests; she explained how people's talk and movement across landforms work together to shape the families' field for observing and story-telling. We build from these findings to explore how MAR can engage and support families as they move and talk together to notice scientific phenomena in their backyards. As such, we ask the following research question: *How does a mobile augmented reality app support families to notice key features of pollinators and plants in their backyard?*

Methodology: Iteration one of a design-based research project

Using a sociocultural theoretical framework, we adopt cultural psychology-informed DBR (Bell, 2004), relying primarily on qualitative analyses of talk and action to understand how the MAR app could serve as a cultural tool. Our work here is the first iteration of an app on pollinator-plant interactions.

The *Backyard Explorers* MAR app features and technology

The *Backyard Explorers* experience was approximately 15-20 minutes. The app was divided into three sections: (a) Pollinators and flowers; (b) Seeing what we can't; and (c) Be a pollinator friend. Families were prompted to discuss where they think they will find pollinators in their yard (Figure 1a). Then, they were encouraged to locate flowers in their yard to observe pollinators. Families were offered a list of behaviors to attend to and were prompted to take four photos of pollinators (Figure 1b). Once complete, the photos are displayed on the screen as they answer five yes/no "Did you notice…" questions, which serve as a checklist (Figure 1c). This sequence of noticing key scientific features, photo-taking, and yes/no questions was repeated for flowers. After, the families were prompted to observe one pollinator closely and take a 10-second video. The next section of the app, *Seeing what we can't*, used AR to illustrate scientific phenomena that are difficult to see in one's backyard. One activity called 'See like a bee' illustrated through AR filters how some pollinators can see the colors from the light spectrum in ways that humans cannot (Figure 1d). The last section, *Be a pollinator friend*, prompted families to select from a list of activities they could engage in stewardship actions to promote pollinator wellbeing. All families completed the pollinator and flower activities; however, only five families completed the last activities.



(a) (b) (c) (d) (e) (f)

Figure 1: Images a) – d): our screenshots from the *Backyard Explorers* app: a) family discussion activity (left), b) photo-taking activity (middle left), c) one screenshot of the yes/no questions that make up the pollinator observation checklist (middle right), and d) the bee vision slider. Images e) and f) are families using the app.

Data collection and analysis

Data were collected via an online social distancing protocol due to the COVID-19 pandemic. Sixteen families living in rural counties completed the MAR app experience (18 adults, 28 youths). Participants reported themselves mostly as White (White: 85%, Hispanic or Latinx: 6.5%, No answer: 8.7%, Other: 2.2%). Children (female: 46%, male 54%, non-binary: 0%) were primarily between the ages of 5-12 (89%). Seven guardians were educators (39%) (e.g., teachers, professors); four were homemakers (22%); and other occupations were farmer, camp director, and self-employed. Six families (37.5%) homeschooled their children. Due to COVID-19, all families had to have internet access and an iPad or iPhone to participate (normally, families can borrow equipment). Lack of broadband access and high unemployment during COVID-19 stay-at-home orders limited our research; unfortunately, we only reached rural families with their own technological resources during this study period.

Primary data sources are *Backyard Explorers* screen recordings, which captured 15 families' voices, app interactions, and video from the AR browser of the families' yards. Five recordings were not fully captured. Additional data include (a) photographs and videos from four families, (b) online demographic surveys through Qualtrics, which included zip code, race/ethnicity, occupation, and age, and (c) pre- and post-experience interviews via the Zoom platform. In the post-interview, families were asked about their overall experience.

We conducted a qualitative analysis of the screen recordings via interaction analysis (IA) (Jordan & Henderson, 1995). The videos were professionally transcribed and confirmed for accuracy by two researchers. The authors held four co-viewing IA sessions to watch the 15 recordings. The team took notes on how the families: (a) talked about pollinator and plants, (b) used AR, photography, and checklist questions, and (c) made connections to their local community, home, and neighbors. Next, the IA notes were developed into codes to understand the families' experiences with our MAR app. Three authors coded the videos to compare and contrast the families' experiences, and then the code segments were placed in a shared spreadsheet. Based on the IA session notes and coding spreadsheet, themes were selected for this paper on how the MAR app worked as a cultural tool to support people to notice key scientific elements in their backyards. The first author selected two families' talk and actions to include in this analysis because these families clearly illustrated the phenomena of interest: noticing plants and pollinators in their backyard while engaging with the MAR elements of the app. Discussions were used to ensure confirming and disconfirming episodes were considered in the development of final analyses.

Findings

From the 15 families' screen recordings, we found that the pollinator MAR app supported talk that indicated they were noticing key concepts related to pollinators — including the presence of insects, insects on flowers, the color of flowers, and the types of plants in their yards. All families self-reported during the post-experience interview that the MAR app supported the way they saw pollinators and plants in their backyards.

Noticing key scientific phenomenon with the MAR app photo-taking and checklist

All families used the app and its checklist and prompts (in the form of yes/no questions) to notice scientific aspects of plants and pollinators. For example, a father and three children (Ava and Jillie, two 7-year-old girls, and Liam, a 3-year-old boy) used the app to observe pollinators on milkweeds, goldenrods, and daisies. The father used the app to ask questions to guide the children to notice aspects of the pollinator's behaviors:

Dad: So, what do you see? What are the bugs doing? Or what are the insects doing that we see?

Ava: They're landing on the flowers and then flying to other flowers. ***[noticing]***

Dad: Yeah, they really are. They're going from flower to flower. ***[noticing]***

Jillie: Oh daddy! I see a bee. ***[identification]***

Ava: A bumble bee. ***[identification]***

Dad: Yeah. I don't even know if that's a bumblebee. I think that might just be it. Oh, Oh, that big one. Oh yeah. That is a bumblebee. ***[identification]***

Liam: Where?

Dad: I think there's one on the, on this, on the golden rod over here. ***[identification]*** Liam, look straight ahead. ((crosstalk)) Yeah. It's just crawling all over the flower. ***[noticing]***

The excerpt shows the father started prompting the children to talk about the pollinator they saw, as suggested by the app. A conversation between Ava, Jillie, Liam and their father ensues where the family alternates between noticing key pollinator behaviors from the app and identifying plants and insects.

The family next walked to the plants alongside the wooden fences on the path in front of their house to find more pollinators such as bumblebees, honey bees, yellow jackets, and monarch caterpillars on plants. After taking photographs, the father read aloud the pollinators' observation checklist in the app (Figure 1c) to recall their children's observation about the pollinators and facilitate their ability to notice essential details.

Dad: Okay. Did you, have you seen pollinators sitting on one type of plant? ***[reads checklist]***

Ava & Jillie: //Yeah.

Dad: Yeah. Like that bumblebee. Just really did not want to leave. ***[recalls previous noticing]***

Jillie: It was just curling up ***[recalls the previous noticing]***

In this family case, similar to others in our dataset, the father used questions and content in the app, such as the checklist, to support the children's observation of pollinators. As the children observed the pollinators on the move in the garden, they attended to the physical environment and phenomena and engaged in the app's activities and content at the same time.

Using AR to connect backyard plants to the scientific phenomenon

In addition to using the app to support noticing insects and plants, five of the fifteen families used the MAR elements to make visible scientific phenomena in their backyards that they could not see without additional digital augments. An example of this comes from one family (Mother and Sofía, 7-year-old daughter) using the Bee Vision MAR (Figure 1d) to help further understand how bees could find the pollen and nectar in flowers.

Mom: Look. What do you see? Want to see like a bee? Swipe up and down from the photo. Okay, look, this is how a human sees it. And that's, that's how a human sees it and that's how a bee sees it.

Sofía: They see as black and brown? I mean, black and yellow?

Mom: Here, you can swipe it up and down to see. That's the human. And then, when you go up, that's how the bee sees it.

Sofía: Whoa... How, how does this help, how does this help them see the nectar.

Mom: Maybe they can like [inaudible] if they're more attracted to that color.

Sofía: Maybe they are.

Sofía engaged with the bee vision interface, swiping the AR representation back and forth (Figure 1f) while commenting on how people see the flowers versus how bees see them. Sofía said, referring to a flower in her backyard based on what she learned in the app about how insects see different aspects of light spectrum: "*This is a dry, dry land with just black and purple flowers. Mmm, that's pretty. That's the one we saw in the backyard. And there's a bunch of little ants in there.* [inaudible] *That's how they see it [the black and purple flowers]? That's terrible.*" Sofía did not appreciate how the flowers looked through the ultraviolet light simulated visualization (i.e., terrible). While she and her mother did not use scientific language like wavelength, they noted that insects could see flowers differently than humans and that helped pollinators found flowers. This case shows the utility of visualization of the bee vision to teach families about science in their backyard gardens.

Discussion

Our work informs the learning-on-the-move (LOM) theory by building on prior findings about LOM with technology (Silvis et al., 2018; Taylor, 2017) and without (Marin, 2020). Similar to Taylor's (2017) findings that mobile technologies can guide youth to create meaning in their own neighborhoods, our study shows promise for the potential of site-independent, mobile AR to support science learning in people's backyards. In regard to advancing the design of MAR technology for use in communities, our findings suggest that the *Backyard Explorers* app supported noticing, and the MAR features helped families to understand ideas that they could not easily see otherwise. To design such immersive experiences, researchers must consider the interactional, cultural context that people bring and create as they use mobile computers in situ (Georgiou & Kyza, 2017).

Regarding design implications from our findings, the summary of the fifteen screen recordings demonstrates that the yes/no checklists and discussion prompts supported families' observing-on-the-move in each of their different backyards. Ava, Jillie, Liam, and their father exemplified how these two elements were integrating into noticing, identification, and recall. From the five families that used all of the MAR elements, these were supportive of family talk around science that was not visible in the garden without enhanced visualization. The case of Sofía and her mother illustrates one example of how a family was able to look at the bee vision visualization and apply it to the flowers in their own garden. Future design and analyses will look more closely at how families use familiar referents, objects, and stories (Marin, 2020) to talk about pollinators' behaviors, plant diversity, and other flora and fauna in their backyard.

References

Bell, P. (2004). On the theoretical breadth of design-based research in education. *Educational psychologist*, *39*(4), 243-253.

Dunleavy, M., Dede, C., & Mitchell, R. (2009). Affordances and limitations of immersive participatory augmented reality simulations for teaching and learning. *Journal of Science Education and Technology, 18*(1), 7-22.

Eberbach, C., & Crowley, K. (2017). From seeing to observing: How parents and children learn to see science in a botanical garden. *Journal of the Learning Sciences, 26*(4), 608-642.

Georgiou, Y., & Kyza, E. A. (2017). A design-based approach to augmented reality location-based activities: Investigating immersion in relation to student learning. *ACM International Conference Proceeding*, Part F1314. https://doi.org/10.1145/3136907.3136926

Kawas, S., Chase, S. K., Yip, J., Lawler, J. J., & Davis, K. (2019). Sparking interest: A design framework for mobile technologies to promote children's interest in nature. *International Journal of Child-Computer Interaction*, *20*, 24-34

Marin, A. M. (2020). Ambulatory sequences: Ecologies of learning by attending and observing on the move. (Online in advance of print). *Cognition and Instruction*, 1-37.

Ryokai, K., & Agogino, A. (2013). Off the paved paths: Exploring nature with a mobile augmented reality learning tool. *International Journal of Mobile Human-Computer Interaction (IJMHCI)*, *5*(2), 21-49.

Sharples, N., & Pea, R. D. (2014). Mobile learning. In R. K. Sawyer (Ed.), Cambridge *Handbook of the Learning Sciences* (2nd ed., pp. 1513–1573). New York: Cambridge University Press.

Silvis, D., Taylor, K. H., & Stevens, R. (2018). Community technology mapping: Inscribing places when "everything is on the move". *International Journal of Computer-supported Collaborative Learning*, *13*(2), 137-166.

Taylor, K. H. (2017). Learning along lines: Locative literacies for reading and writing the city. *Journal of the Learning Sciences*, *26*(4), 533-574.

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Impact and Resilience: A Survey of Youth-serving Organizations During the Pandemic

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Abstract: The pandemic has shifted everyday realities of how we work and learn. Massive layoffs and shelter in place orders have led to unemployment and shuttering of local businesses across the country. There is widespread concern about youth and teen social and emotional health and loss of opportunities for meaningful engagement. While we know that youth-serving organizations are essential for youth learning and development, less is known about how those organizations are faring during this time. In this study, we present findings from a citywide survey of Chicago youth-serving organizations (N = 126) indicating that although there are challenges and needs resulting from the pandemic, there is also an important story of resilience and adaptation as the majority creatively shift their practices and engagement to the virtual space to continue to support youth and families in the communities they serve.

Keywords: COVID-19, out-of-school providers, equity, youth participation, resilience

Introduction

Concerns about academic achievement and social and emotional health for youth and teens are widespread. Researchers predict lower standardized test scores relative to a typical school year due to remote schooling (Kuhfield et al., 2020). Youth and teens are experiencing anxiety and fear, and the closing of locations where they spend time and connect with others means less structure and supports essential for mental well-being (World Health Organization, 2020; Darling-Hammond et al., 2020). These and other studies (e.g., Dorn et al., 2020) suggest that negative effects of the pandemic may be greatest for low income, Black, and Hispanic young people.

Youth-serving organizations and program providers (e.g., mentors, library and parks staff) support young people in learning and developmental outcomes including and beyond traditional school measures, such as creativity, confidence, and plans for the future (e.g., Montgomery, 2017; Sebring et al., 2013). While those people and services are essential for youth in this time of crisis, the pandemic has destabilized employment and services across the country. Recent analyses of US Bureau of Labor Statistics data reveal that low wage, part time, young, and minority workers are the most likely to hold jobs in danger of being cut or reduced (Dorn et al., 2020; Center on Budget and Policy Priorities, 2020). People who work with youth in out-of-school settings often fit such a profile and their lack of job security is documented in general (Baldridge, 2020) and during the current global health pandemic (Moore, 2020). Places where youth workers are employed are also impacted. A survey of nonprofits reported loss of revenue, reduction in services, and employment cuts (The Independent Sector, 2020). Despite this bleak picture, we also know that communities that have historically experienced some of the most social challenges also demonstrate immense resilience defined as "patterns of positive adaptation in the context of past or present adversity" (Riley, 2005).

Though it is apparent that structural challenges are even more visible during a pandemic, little is known about what youth-serving providers and organizations in particular are experiencing during this time and how they are adapting services. In this study, we present findings from a citywide survey of Chicago youth-serving organizations (N = 126) to explore the questions of: (1) How did organizations shifted their practices during the first wave of the pandemic (i.e., spring/summer 2020)? (2) What worked and what challenges do they face? and (3) What are their plans for the near-term future while the pandemic remains a reality?

Methods

A 22-question Qualtrics survey was designed to tap into four primary areas, including (1) information about the organization and who they serve, (2) strategies and capacity for communication with and opportunities for youth during the summer of 2020, (3) what worked and what they struggle with, and (4) needs of community and plans for the remainder of the calendar year. Questions included Likert-scale and multiple-choice responses as well as open-ended queries. Researchers are collaborators in *My CHI. My Future*, a Chicago Mayoral initiative conceptualized before the pandemic, focused on building a community of practice with citywide youth-serving organizations with the goal of equity in out-of-school time opportunities. An invitation and link to the survey was sent out in the initiative's weekly email. The survey was open from August 20 through September 25, 2020.

Participants

One hundred and forty-three individuals responded representing 126 unique Chicago youth-serving organizations, including city agencies (e.g., parks and libraries) and community-based organizations focusing on particular areas of learning and practice (e.g., technology, STEAM, arts, boxing) and youth services more generally (e.g., faith-based centers, Boys & Girls Clubs, BSA). Organizations served youth from preschool through 24 years old; most served multiple age groups and over three-quarters served middle (79%) and high school (84%) youth. They represented both smaller and larger organizational spaces (31% served 0-25 youth at one time in their physical space while 24% served over 100). Forty-one percent of organizations served youth across the city while the majority (59%) served one or more particular community areas closely (Chicago is broken into 77 geographically defined community areas). Sixty-seven communities were represented, with the highest representation of service in communities identified as most "socially vulnerable" (Center for Disease Control, 2020).

Findings

Organizational impact: "I don't know where to start; it feels like everything has been impacted"

Impact on organizations due to the pandemic was both positive and negative. At the time of the survey, 10% of organizations reported that they had lost their physical space, 3% were in danger of closing, and many described reduced funding streams in open-ended responses. Nevertheless, the story of impact is more complex than expected. Descriptions reveal details about the adaptive and creative processes organizations engaged in and most focus on short-term but positive predictions about the future, with one respondent saying, "We were at risk of closing but are finding our way forward day by day, [COVID] impacted the way we roll out programming."

Staff who kept their jobs gained knowledge and support. While a quarter of organizations (25%) reported that staff were furloughed or let go, respondents also reported personal and professional benefits for staff employed through the spring and summer. Over half reported staff developing new pedagogical knowledge about how to serve youth remotely (59%), and close to a third saw an increase in mental health/social emotional support for staff (30%) and internal staff bonding and organizational support (27%). Over half (59%) reported new or deeper collaborations with youth service providers and organizations outside of their own.

Despite reduction in programming, organizations continued to serve youth and families. Half of organizations offered fewer youth programs and limited hours of service during the summer (49%), but the vast majority (91%) did manage to continue providing programs, activities, and/or resources to youth and families and 64% did so regularly. Some were able to offer face-to-face opportunities (32%) but the majority adapted their usual approaches. Most moved online: 80% offered live programs virtually, 51% held Internet-based community events, and 50% offered asynchronous online activities for kids and teens to do on their own time.

Breadth of service was diminished but some saw increased depth and formed new relationships. While more than half of organizations (53%) reported serving fewer youth and families than usual, almost a third established new or deeper relations with youth and community they serve (29%) and broadened their reach to serve new youth (27%). Sometimes both happened simultaneously within the same organization. One respondent shared, "Though some of the youth and schools that we serve have not participated in our virtual programming, we have seen new students and new opportunities appear (in other words, we were able to serve fewer youth than normal AND we broadened our reach to serve new youth)."

Successful strategies: "Providing activities that opened [youth participants'] eyes to the world"

Organizations reflected on what worked during their quick pivot to remote learning and reflected on plans for continued services during the 2020-21 academic year, which Chicago Public Schools (CPS) began remotely. One provider advised, "Patience is key, and adjusting expectations for an online environment is a must."

Individual and synchronous methods of communication were preferred. Almost all organizations (96%) remained in touch with the youth and families during the summer of 2020. When asked which strategies were most effective for keeping in contact, almost three quarters (73%) identified video conference tools, half relied on mobile phones (52% through text messaging and 51% through direct calls), and some reported email (42% through listservs and 40% through individual correspondence). Most used multiple strategies, with one person saying, "Not all households are the same and youth may or may not feel comfortable with that and will not respond to any calls. We had to adjust in our approach and how we communicated with the youth in a safe and healthy way which for some were video calls, phone calls, and others it was text messaging." Many emphasized that personal approaches were essential, saying: "Individualized contact is very important. Reaching out and making sure that families know that we are here to support in whatever way we can has made a difference and allows families the opportunity to open and share their thoughts, concerns, and feelings during this challenging time."

A range of participation strategies were utilized, with a preference for authentic opportunities. Most organizations offered remote participation opportunities for youth (87%) in a broad range of content areas, with the highest frequency in categories of music and art (18%), helping your community (16%), and digital media (15%). Organizations that offered opportunities for youth participation were asked what approaches they used (from a list of 12 possibilities identified through author participation in virtual *My CHI. My Future.* conversations) and how successful they were (on a scale from 1-4, with 1 being *not at all successful* and 4 being *highly successful*). Organizations utilized multiple strategies (M = 3.9, SD = 2.8) with a range of success (Table 1).

Table 1: Remote implementation strategies used and their perceived success by practitioners who used them

	N	% that used strategy (N = 126)	% of users that found strategy highly successful
Synchronous activities			
Structured online workshops or classes	86	68.3%	36.1%
Opportunities for youth work / community service	49	38.9%	47.1%
Access to mentor-led activities via live stream (social media)	37	29.4%	25.7%
Access to peer-led activities via live stream (social media)	11	8.7%	36.4%
Asynchronous project-based work			
Physical activity kits for projects (to be picked up)	49	38.9%	44.9%
How-to videos for self-directed exploration	48	38.1%	11.4%
How-to guides (printed) for self-directed exploration	27	21.4%	18.5%
Spaces to share and observe			
Virtual connections to people/places (e.g., tours, speaker series)	47	37.3%	47.8%
Online youth showcases (e.g., performances, gallery space)	33	26.2%	48.5%
Online youth challenges (e.g., talent shows, art contest)	27	21.4%	48.1%
Synchronous discussions/conversation			
Access to adult mentors through online/phone office hours	47	37.3%	25.5%
Peer- and topic-based town hall meetings or group chat	29	23.0%	34.5%

Structured online workshops or classes were most common (68%), as organizations translated existing in-person programs to an online format using Zoom or other video conferencing tools. Also common were work and community service programs for youth, physical kits that youth could pick up and work through at home, and asynchronous videos for youth to work through projects. Close to 50% of organizations who used the common strategies of physical kits and work/community service opportunities identified them as particularly successful. Both approaches have a focus on equity (i.e., opportunities that do not require high speed internet and where youth are paid for their participation) and were highlighted in open-ended responses asking providers about best practices. One organization wrote that "providing garden kits that they could tend to at home was engaging for both the youth and their families" and another provided kits with a mask-making activity, saying, "youth [were] able to send us a photo of their completed project…[and] some youth create more masks for their family members and others." City funding to pay youth for participation in remote jobs and internships was identified as critical "for youth who desperately need pay and stipends."

Less frequently utilized but with higher reports of success were opportunities that allow youth to contribute, share, and observe, including connecting them to people and places such as virtual tours or expert speaker series, and opportunities for youth to create and showcase their own work and see that of others through contests and showcase opportunities. This aspect of youth voice and choice was emphasized in open-ended responses, "Allowing the youth to be part of the program planning, scheduling and designing process."

Remaining challenges and plans for the near-term future

Nearly all of the organizations (90%) planned to offer virtual opportunities during the school year and 40% were planning non-digital remote approaches, but even while organizations adapted offerings in creative ways, getting the word out was a struggle. For example, one person shared: "We did offer our live streaming event interviewing music industry executives [over the summer], but unfortunately, it didn't really reach youth." Almost a quarter of organizations (22%) did not have their own physical space and relied on locations in the community, most of which remained closed, to both offer and advertise their programs. The majority of organizations (80%) had existing relationships with Chicago Public School (CPS) and depended on these relationships to connect with youth and broaden their reach, but new mandates and requirements due to the pandemic made it such that most had lost this connection and there was confusion about new processes required for new partnerships. From a list of 18 organizational needs to support youth and families (including financial, personnel, and technology supports), clarity of information from CPS was the most frequently identified (61%), followed by technology equipment and hi-speed Internet for families (51%) and information regarding basic services (51%). Brokering information was a common theme in open-ended responses about community needs, “Wellness checks to the youth and families work very well. Families and youth shared what they were going through and were able to ask about the food pantry and other essential needs resources.” Also of interest was professional development in remote facilitation (48%) and equity and social justice (45%).

Discussion

In this paper, we share results from a survey of 126 youth-serving organizations in the City of Chicago as they reflected on the first wave of pandemic-disrupted service while preparing for the 2020-21 academic year. While these organizations represent a range of communities, organizational size, and ages served, a limitation of this study is that we only heard from organizations that have the capacity to complete a survey during this stressful time. Nevertheless, results offer a more complex picture of organizational resilience during the pandemic than might be suggested. Findings suggest several directions for design and research, as organizations continue to offer opportunities remotely and in preparation for future events. First, providers have a lot to share and are struggling to find the information they need. Opportunities for youth-serving organizations to exchange ideas about what they are learning has the potential to increase professional capacity, strengthen community networks, and crowd-source connections to up-to-date information and resources. Second, approaches to engaging young people that providers found to be more successful align with informal learning literature that emphasizes youth voice and brokering connections to meaningful opportunities (e.g., Ching et al., 2015; Montgomery, 2017). Examples of how providers are doing this remotely can inspire new technologies to better support organizations to engage in synchronous and asynchronous communication and experience design. Finally, youth-driven experiences were less frequently implemented but rated among the more successful strategies. Including young people in this research is an important next step to understanding conditions and strategies *they* find engaging and to invite them as co-designers of potential future experiences, including opportunities for youth to take the lead remotely.

References

Baldridge, B. J. (2020). The Youthwork Paradox: A Case for Studying the Complexity of Community-Based Youth Work in Education Research. *Educational Researcher*.

Center for Disease Control, Social Vulnerability Index [online database]. https://data.cdc.gov/Health-Statistics/CDC-Social-Vulnerability-Index-SVI-/u6k2-rtt3/data

Center on Budget and Policy Priorities (2020). Tracking the COVID-19 Recession’s Effects on Food, Housing, and Employment Hardships [online report]. https://www.cbpp.org/research/poverty-and-inequality/tracking-the-covid-19-recessions-effects-on-food-housing-and

Ching, D., Santo, R., Hoadley, C., & Peppler, K. (2015). On-ramps, lane changes, detours and destinations: building connected learning pathways in hive NYC through brokering future learning opportunities.

Darling-Hammond, L., Schachner, A., & Edgerton, A. K., et al. (2020). Restarting and reinventing school: Learning in the time of COVID and beyond. Palo Alto, CA: Learning Policy Institute.

Dorn, E., Hancock, B., Sarakatsannis, J., and Viruleg, E. (2020). COVID-19 and student learning in the United States: The hurt could last a lifetime. Report from the McKinsey Group.

Montgomery, D. (2017). The rise of creative youth development. *Arts Education Policy Review*, 118(1), 1-18.

Moore, T. (2020). What happened to YOUmedia? *Chicago Reader*, October 21, 2020.

Sebring, Brown, Julian, Ehrlich, Sporte, Bradley, and Meyer (2013). Teens, Digital Media, and the Chicago Public Library. Report sponsored by the Macarthur Foundation.

Riley, J.R., and Masten, A.S. (2005). Resilience in context. In *Resilience in Children, Families, and Communities*, pp. 13-25. New York: Springer.

The Independent Sector (2020). The Impact of COVID-19 on Large and Mid-Sized Nonprofits [online report]. https://independentsector.org/wp-content/uploads/2020/06/COVID19-survey-mid-size-nonprofits

World Health Organization (2020). Mental health and psychological resilience during the COVID-19 pandemic [online report]. https://www.euro.who.int/en/health-topics/health-emergencies/coronavirus-covid-19/news/news/2020/3/mental-health-and-psychological-resilience-during-the-covid-19-pandemic

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The Disciplinary Nature of Science Teachers' Talk in the Process of Formative Assessment Design

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Abstract: Formative assessment is an important instructional practice in K-12 science classrooms and yet continues to be challenging for teachers to enact. Designing science-specific formative assessments requires teachers to leverage their understanding of science ideas, their understandings of how student understanding of content develops over time, and their understandings of pedagogical strategies that draw out student thinking. In this study, we analyze teacher conversations during the process of formative assessment co-design during a two-year professional development. We found heterogeneity in teachers' contributions both within and across meetings as teachers engaged in co-design. We document how the structure of the professional development process surfaced varied contributions on the part of the teachers, which led to the collaborative design and revision of a formative assessment task.

Introduction

There exists near-consensus in the science education community that formative assessment, or the practice of listening and attending to student ideas during the course of instruction, are essential elements of effective and equitable science learning & teaching (National Academies of Science, Engineering & Medicine [NASEM], 2018). Facilitating formative assessment successfully can be challenging for science teachers to implement (Sezen-Barrie & Kelly, 2017). It relies on science teachers having a repertoire of classroom practices that center student ideas and experiences alongside the science students are learning. Researchers have emphasized links between teachers' formative assessment practices and knowledge of how student ideas develop in a domain, or pedagogical content knowledge, in addition to their content knowledge of a discipline and general pedagogical knowledge of teaching strategies (Magnusson et al., 1999). However, how these different facets of "professional competence" (Blömeke et al., 2015) are represented within a professional learning community remains unexplored. In this paper, we investigate the distributed expertise of science teachers' knowledge base for formative assessment through an analysis of their conversations during a professional development on formative assessment task co-design.

Theoretical and conceptual framing

Teachers bring a wealth of experiences and resources to their learning (Putnam & Borko, 2000). As teachers make sense of new teaching practices, they draw on personal, social, and material resources to interpret these new practices and make necessary shifts to their instruction (Spillane et al., 2002). In professional learning settings, teachers' varied experiences across science teaching and learning become resources for the co-design of new instructional tasks and provide opportunities for learning (Penuel et al., 2007). This paper considers the ways in which the distributed expertise (Hutchins, 1995) of teachers in a professional learning community supported teacher development of formative assessment tasks. The cognition of groups is constructed through interactions between internal structures of individuals within the group and the structures external to the group that mediate their work (Hutchins, 1995). In the next sections, we describe the external structure of the formative assessment design cycle, which guided our approach to professional development, and the important internal cognitive resources that teachers may draw on within this cycle to co-design formative assessment tasks.

Formative assessment co-design as a site for teacher learning

While formative assessment tasks are often designed away from the school site by curriculum developers and measurement specialists (Bennett, 2011), the very teachers that enact them can contribute to their design (Ainsworth & Viegut, 2006). We have used co-design as an approach to develop common formative assessment tasks with teachers (Furtak, 2012). These tasks are common in that all teachers enact the same task in their classrooms, but they also create a common frame of reference in which to interpret student thinking. This supports teachers to clarify their own understanding of the content, clarify the goals for student learning, and forge professional consensus around the quality of teaching and student work (Danielson, 2007).

Our project followed an iterative, five-step professional development cycle called the Formative Assessment Design Cycle [FADC]. The purpose of this cycle was to situate teachers' work in their own classrooms and to draw upon their knowledge and experiences to develop, enact, and revise a set of common formative assessments (Furtak, 2012). In this cycle, teachers *Explore* student thinking in a domain, *Design* instructional tasks for drawing out student thinking, *Practice* using those tasks, *Enact* the tasks and collect evidence of student learning in the form of student work and video, and then *Reflect* upon that process of enactment and make necessary revisions to the formative assessment task.

Science teachers' personal resources for formative assessment task co-design

Teachers enacting formative assessment need to complement their deep knowledge of formative assessment strategies and domain-specific content with understanding of how students learn in a given domain, the common everyday experiences they are likely to leverage as they learn, and strategies for supporting students as they advance in their understandings (Bennett, 2011). Research on science teachers' formative assessment practices highlight key personal resources that they may draw on as they as work to collaboratively develop science-specific formative assessment tasks. These resources include their understanding of the science content (Forbes et al., 2015) and their beliefs about how students learn in science (Box et al., 2015). We add teachers' domain-general practices, such as stop lighting, which are common school-based formative assessment practices.

In this paper we consider how science teachers, with heterogeneous experiences relative to different science ideas, science teaching, and pedagogy in general, contribute to the process of co-design of a formative assessment task during a two-year professional development program. Specifically, we ask (1.) What personal resources did teachers draw on during the process of formative assessment co-design? (2.) How did the heterogeneity of teachers' contributions relate to the co-design of a formative assessment task?

Method

We explore data gathered in a two-year study in which a department of high school biology teachers collaborated with university researchers to co-design, enact, and revise a set of common formative assessment tasks about natural selection. The study was conducted for two years on-site with a team of biology teachers at large suburban high school of a large city in the western US. Seven teachers participated in the professional development meetings across the two years of the study with a range of teaching experience (3-29 years) and varied expertise in science.

Content and curriculum

The content focus of the professional development was evolution by the process of natural selection. Natural selection provides rich opportunities for teachers to explore the myriad ideas students have about how populations of organisms and individuals change over time (Anderson et al., 2002). At the beginning of the study, teachers did not plan together, and there were few activities shared among teachers and no common assessments.

Sources of data

Sources of data include videotapes made during each of the on-site professional development meetings, each about 60-90 minutes long, supplemented by field notes and drafts of the formative assessments. We trace the co-design of one common formative assessment task. Although teachers and researchers developed several formative assessments during the study, we chose to focus on the trajectory of a single assessment task, *Natural Selection vs. Individual Change* for two reasons. First, teachers were central in problematizing and developing this formative assessment. Second, teachers used artifacts of practice, in the form of written drafts of the assessment and videotapes of enactment, to reflect upon and revise the assessments for use in their classrooms during the project. We reviewed content logs and identified all instances of discussion around the task and created detailed transcripts. Overall, we sampled 125 minutes of videotape across 5 professional development sessions. The transcripts corresponded with video excerpts varying in length from 13 minutes to 34 minutes, with a mean length of 25 minutes and median length of 24 minutes.

Data analysis

We segmented transcripts of the videotaped meetings into speaking turns and gave each segment a set of tags for length and speaker. We developed a coding system to categorize talk turns as having a focus on disciplinary ideas, discussions specific to the teaching of those ideas (science teaching), or more general teaching topics (general pedagogy). Three of the authors independently coded all transcripts (disciplinary ideas: agreement=89%, r= 0.58, K=0.53; science teaching: r=0.43, K=0.38; teaching: r=0.62, K=0.59; transitions: r-0.31, K=0.23). We then discussed and adjudicated all disagreements.

Results

Our coding of the discussions reveals heterogeneous contributions to the conversation about task design. Figure 1 illustrates how each of the teachers and the facilitator (Carrie) had similar contributions in terms of the talk within the meetings, although their contributions were often in different domains, illustrating both the heterogeneity of teachers' contributions and their own experiences in science and teaching. Furthermore, the emphasis on working out the details of the disciplinary ideas around natural selection was reflected in the contributions of each of these participants during the design phase, and then equally transitioned to discussions focused on science teaching during the reflect and revise phases of the study.

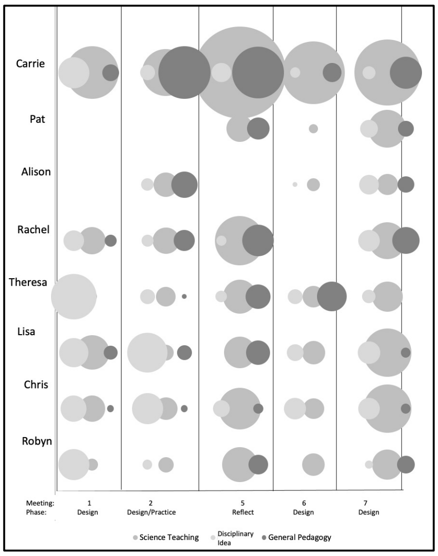

Figure 1. Bubble plot of relative proportion of teacher utterances.

Distribution of talk across the FADC

We next investigated the ways in which the types of talk and teacher contributions were distributed across co-design activities in different meetings. We mapped the distribution of the three types of talk segments across time for each of the meetings, which revealed differences in teacher talk between meetings focused on Design and Reflection (which includes revision of the task). When teachers talked about designing the task, they engaged in sustained conversations about disciplinary ideas, interspersed with conversations about science teaching, which involved turning those science examples into a formative assessment designed to get at student thinking about phenotypic variation and whether it was a result of natural selection or individual change. For example, in the following segment the teachers were working out an example for the task that asked students if rabbits' fur changing color in different seasons was an example of individual change or natural selection. Chris initiated a conversation about the science behind the example:

Chris:	Does anybody know about the rabbit, what if a rabbit had a baby in the winter?
Theresa:	But they are always born in the spring. [Laughter] Because they are hibernating in the winter.
Chris:	What if they had a baby in the spring and then you took the baby and put it in snow.
Alison:	In an environment, so you took it -
Chris:	Yeah, if you took out of the in the summer and stuck it in the freezer would it turn.
Rachel:	I believe you couldn't because there have been experiments you put ice packs on them.
Theresa:	Oh yeah, I've seen that.
Rachel:	It's an enzyme, it's a cold
Lisa:	That's one of the ones in the scientific method [referring to the textbook]
Chris:	I didn't know that.
Theresa:	Don't put the bunnies in the freezer [Laughter]

In conversations such as these, the teachers drew on each other's knowledge of the process of natural selection to better work out the mechanisms of change in the specific example of the arctic hare. While most of the talk in developing the assessment focused on disciplinary ideas during the reflection phase, teachers' conversations shifted to a focus on general pedagogical strategies and science teaching, with interspersed discussions on the science content as the assessment was revised. During meetings in these later phases of the design process, teachers watched a video of Theresa leading her class in a discussion around the examples and engaged in conversations about general pedagogy and science teaching early in the meeting, stimulated by the video, which then led into a sustained conversation later focused on a possible revision of the task. There are only a few talk turns dedicated to disciplinary ideas exclusively. Throughout these conversations, we observed teachers' different contributions to discussions as they raised questions about the nature of different aspects of natural selection, the ways it was represented in the task, and how they would lead the task with students.

Discussion

The analysis described in this paper provides evidence that the heterogeneity of the contributions by the group during the process of formative assessment task co-design provided opportunities for teacher learning about disciplinary ideas and practices, the students they teach, and pedagogy in general. Rather than looking at the knowledge within teachers' own minds, we explore how their contributions can productively contribute to the design of a task. In this way, we shift the focus from the knowledge teachers need to enact a task, to the ways in which their varied expertise in science and in schools contributes to formative assessment design. The majority of the changes to the formative assessment grew directly from teachers' conversations about science content, as well as student ideas and instructional approaches to teaching that content. Research models, such as research + practice partnerships (Coburn & Penuel, 2016) that include various stakeholders can further support these learning opportunities for teachers as they engage with various forms of expertise in the co-design process.

References

Ainsworth, L., & Viegut, D. (2006). *Common formative assessment: How to connect standards-based instruction and assessment*. Thousand Oaks, CA: Corwin Press.

Anderson, D. L., Fisher, K. M., & Norman, G. J. (2002). Development and Evaluation of the Conceptual Inventory of Natural Selection. *Journal of Research in Science Teaching*, *39*(10), 952–978.

Bennett, R. E. (2011). Formative assessment: a critical review. *Assessment in Education: Principles, Policy & Practice*, *18*(1), 5–25.

Blömeke, S., Gustafsson, J. E., & Shavelson, R. J. (2015). Beyond dichotomies. Zeitschrift für Psychologie.

Box, C., Skoog, G., & Dabbs, J. M. (2015). A Case Study of Teacher Personal Practice Assessment Theories and Complexities of Implementing Formative Assessment. *American Educational Research Journal*, *52*(5), 956–983.

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher*, *45*(1), 48-54.

Danielson, C. (2007). Assessment for Learning - For Teachers as Well as Students. In C. A. Dwyer (Ed.), *The Future of Assessment: Shaping Teaching and Learning* (pp. 191–214). New York: Lawrence Erlbaum Associates.

Forbes, C.T., Sabel, J.L & Biggers, M. (2015). Elementary teachers' use of formative assessment to support students' learning about interactions between the hydrosphere and geosphere. *Journal of Geoscience Education* 63 (3), 210-221

Furtak, E. M. (2012). Linking a learning progression for natural selection to teachers' enactment of formative assessment. *Journal of Research in Science Teaching*, *49*(9), 1181-1210.

Hutchins, H. (1995). *Cognition in the Wild*. A Bradford Book.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Washington, DC: National Academy Press.

National Academies of Science, Engineering and Medicine. (2018). *How People Learn II: Learners, Contexts, and Cultures.* Washington, DC: The National Academies Press.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and practice in technology enhanced learning*, *2*(01), 51-74.

Putnam, R. T., & Borko, H. (2000). What Do New Views of Knowledge and Thinking Have to Say About Research on Teacher Learning? *Educational Researcher*, *29*(1), 4–15.

Sezen-Barrie, A., & Kelly, G. J. (2017). From the teacher's eyes: facilitating teachers noticings on informal formative assessments (IFAs) and exploring the challenges to effective implementation. *International Journal of Science Education*, *39*(2), 181–212.

Spillane, J. P., Reiser, B. J., & Reimer, T. (2002). Policy implementation and cognition: Reframing and refocusing implementation research. *Review of Educational Research*, 72, 387-431

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“I Kept Going because We were Close”: Deepening Understandings of the Relational Work of RPPs

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Abstract: Research Practice Partnerships (RPPs) have emerged as a means of pursuing research that is of immediate consequence for K-12 U.S. education. While theorists have acknowledged the need to develop relationships between practitioners and researchers in RPP settings, questions remain about the ways that relational work can facilitate equity and support practitioner agency and engagement. In this paper, we look to feminist and sociocultural perspectives to examine two RPPs in the mountain west United States and the ways that practitioners and students expressed relational work as central to their engagement in the projects. We found that participants who engaged deeply over long periods of time with these RPPs felt mutual trust and personal connections with researchers, colleagues, and peers that led to their continued and deepened engagement.

Major issues

Over the past decades, research practice partnerships (RPPs) have emerged as a means of pursuing research that is of immediate consequence for K-12 U.S. education. Defined as “long-term collaborations between researchers and practitioners that leverage research to address persistent problems of practice” (Henrick et al., 2017), RPPs have extended design implementation research principles intended to include practitioners in the development of research questions and interventions. Because of their relative novelty and the extended timeframe that many RPPs require in order to successfully build equitable partnerships with practitioners, questions remain about how to effectively implement, assess, and sustain the success of these kinds of projects. A number of researchers have taken up these questions in order to develop parameters to assess and evaluate RPPs, while continuing to theorize about the parameters needed to define successful RPPs (e.g., Coburn, 2003; Henrick et al., 2017; Morrel et al., 2019; Penuel, 2019). In this paper, we focus on relationship building as a common feature across literature on successful RPPs and explore the ways that feminist perspectives on relationships can expand equity and extend the sustainability of these partnerships.

Theoretical approach

In this paper, we take up sociocultural, sociohistorical, and sociocritical perspectives on learning and human action that emphasize the social, cultural, historical, and political contexts of human activity . We understanding learning ontological, a process of development in relation to one’s self and others (Lee, 2017), and therefore centralize relational practices in our research. Additionally, we are concerned with the histories of the communities and participants with whom we collaborate and we take a critical stance toward the ways that historically marginalized communities have traditionally been positioned with deficits in educational spaces. Taking up an expansive understanding of learning means that we work to decenter whiteness, developing research-based solutions in educational settings that take into account the cultural funds of knowledge (Moll et al., 1992) of our participants. These approaches have direct implications for the ways that we build and work within research practice partnerships (RPPs) as well as beyond them.

Research practice partnerships

To conceptualize research practice partnerships (RPPs) in education, we rely on literature that describes the importance of interactions between researchers and practitioners as central to developing research that addresses the consequences of implementing educational policies and learning standards. For this analysis, we focus on RPPs grounded in design research and collaborative design of interventions by practitioners (teachers, administrators, and other district stakeholders) and researchers (Coburn et al., 2013). These authors described design research as a form of educational research that aims “to build and study solutions at the same time in real world contexts” (p. 8). In our work, we see solutions to longstanding issues in education as deeply intertwined with creating more equitable, representative, and just systems for all students. Because of these commitments, we study RPPs as a potential vehicle for articulating and addressing issues that have created opportunity gaps for historically marginalized students and students struggling with poverty (Carter & Welner, 2013). Coburn and co-authors (2013) wrote that RPPs that focus on design research tend to focus on long-term, place-based work so that designed interventions account for context. They emphasized that collaboration is a core tenet of these projects with practitioners' perspectives and expertise brought to bear on each stage of the process from defining the problem or challenge to assisting with adaptations and revisions.

Relationships as core design principle

Because RPPs are long-term partnerships, they often develop over a number of years and have proven difficult to assess (Coburn et al., 2003). However, researchers have begun to take steps to align the differences between RPPs by developing frameworks for assessing both their effectiveness (Henrick et al., 2017) and the ways their designed interventions and infrastructures can scale (Coburn, 2003; Penuel, 2019). Across each of these frameworks, relationships have been identified as a central practice to support both the initial development and continued adaptation of interventions within individual contexts. Additionally, a number of researchers have discussed the need to build and maintain relationships in design-based RPPs in order to identify the boundaries of collaborators roles and the ways that collaborators will participate in the design processes (e.g., Penuel et al., 2015). As Henrick et al. (2017) explained, effective partnerships are dependent upon "building trust and cultivating partnership relationships" (p. 5). While much of the research on RPPs appears to position relationships between practitioners and researchers as a means of addressing "the wide gap between the worlds of educational research and practice," (Penuel et al., 2015, p. 182), we question the ways that expansive feminist perspectives might expand and aid the development of relationships within these kinds of design environments.

Expanding approaches to relational work

Learning in relation to others is foundational to sociocultural theory. Similar to literature on RPPs, feminist theorists maintain that research cannot be successful without personal investment from both participant and researcher (Fonow & Cook, 1991). However, a feminist approach to also centers "friendship, intimacy, and trust" (Davids & Willemse, 2014, p. 1) and works to understand "the social through ourselves, [entering] a subjective, cultural space that is mediated *through* the researcher" (Olive, 2012, p. 75, citing Probyn, 1993). We take this perspective as an expanded view of relationships. While research often focuses on relationships as a means of developing successful RPPs (e.g., Henrick et al., 2017), we rely on critical feminist perspectives that support understandings of RPPs not just as long-term projects, but as long-term relational work extending beyond initial project goals. We see this perspective as essential in building RPPs that work toward equity and justice because we believe that self-reflection from researchers and practitioners is essential in understanding the ways that lasting problems of practice are tied to the social, historical, and cultural contexts in schools.

Methods

Participants and context

To examine the way that feminist approaches to relational work in RPPs support practitioner understandings of the RPPs in which they participate, we looked across two school-based design partnership projects in the Western region of the United States.

The Compose Our World (COW) project was a multi-year research practice partnership to collaboratively design and implement a year-long 9th grade English language arts (ELA) project-based learning (PBL) curriculum with nearly fifty practicing teachers and fifteen researchers. This paper focuses on relational work between researchers and three teachers who were part of the initial co-design team and continued to participate in research activities (i.e., participating in additional studies, supporting data collection, and publishing with researchers) even after the COW project had ended. The teachers, Elizabeth, Abby, and Evie, worked together as 9th grade ELA teachers at a rural high school and each described themselves as veteran teachers who had been in the classroom for at least ten years at the start of the study in 2015.

The Student Technology Action Research (STAR) was an RPP in collaboration with practitioners, students and other stakeholders at an urban university-affiliated high school. This project centered the ways that historically nondominant high school students were able to leverage community cultural wealth (Yosso, 2005) to participate in the participatory design (Bang & Vossoughi, 2016) of curriculum and practices intended to integrate meaningful technology practices into their school ecology. This paper focuses on relationships between one teacher partner, several students, and the researcher as they built relational practices that honored the diverse perspectives and cultural assets they brought to the design process.

Data collection and analysis

Each project took place over five years and used qualitative and ethnographic methods to collect observational fieldnotes, audio and video recordings, designed curricular materials, and student artifacts. Additionally, each researcher completed semi-structured interviews with participants to develop understandings about participants' interpretation of the relationships and relational practices that mediated the collaborative design process. Each project relied upon a design-based research model in which data collection and analysis was conducted while practitioners and students implemented designed materials (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003). We also conducted retrospective analysis, using qualitative methods (Miles, Huberman, & Saldana, 2014) to code data, identify themes about relational work, and conduct member checks to establish trustworthiness. Cross-project analysis was then done through dialogic spirals (Kinloch & San Pedro, 2014) to compare themes and identify representative examples and counterexamples.

Findings

Feelings of closeness trust aided collaboration

Across projects, we found that when practitioner and student collaborators were asked their investment in the research partnerships, they nearly always referenced feelings of closeness and mutual trust with regard to their co-designers. These feelings emerged in interviews, as participants voiced growing confidence and closeness within the design teams. In the twelve interviews (six from each project) analyzed for this paper, each participant repeatedly noted that they chose to continue collaborating because of the investment they felt had been made by researchers, not only in their classrooms, but also in their personal lives and development as teachers and learners. For example, Elizabeth, who felt she had been distant with colleagues because of her husband's medical needs, explained that becoming a co-designer gave her a way to build relationships with her colleagues while also working to improve her practice, rather than in time spent outside of her classroom.

> I just wanted [my colleagues] to recognize that there's a lot of things going on with me *and* I can connect. I can be vulnerable and I can show weakness and be self-critical, but that being smart is also part of my identity… I didn't consider myself a leader… until getting involved with COW because you all thought I had good things to say.

She went on to emphasize that her participation on the project offered her opportunities to see herself as a leader. When asked how she had decided to continue participating in the project for five years, particularly given her time constraints, Elizabeth replied, "For some reason I decided I was just going to trust you all. And the more I trusted you, the more I felt valued, like you also trusted me...I kept going because we were so close." For Elizabeth, the relationships fostered in the project were both personal and professional; ultimately the personal feelings of closeness were key to her continued investment in the RPP.

Honoring funds of knowledge led to deeper relationships

In her chapter introducing funds of knowledge, Gonzalez (2005) described the phenomena of *confianza* or mutual trust as key to developing social relationships that attended to the intersections of cultural knowledge (see also Velez-Ibanez & Greenberg, 1992). Across projects, participants from historically marginalized backgrounds expressed feeling deeper investment when they felt they were given opportunities to question dominant narratives in curricula and to bring their own knowledges to bear on the designs. This was especially true of the student co-designers in the STAR project, who were engaged in creating an e-portfolio system that would shift student evaluation away from the traditional models to those that better represented their linguistic, political, and aspirational assets. In collaborating to design the new system, students expressed feeling more autonomy and agency, and explained that their relationship with the researcher, who brokered (Ching, Santo, Hoadley & Peppler, 2016) access to broader academic and social domains related to their expressed interests and assets, played a critical role in their participation in co-design. Ultimately, students expressed that their participation as collaborators supported them in deepening their interest in school because they saw their ideas directly represented in the changes that took place in their learning environments.

Personal relationships as extensions of research

Both of the RPPs examined in this paper resulted in extended work beyond the initial RPP timeline. We each found that our relationships had led to an investment in research from teachers that led to new questions and new kinds of design partnerships, even after the larger RPP work had ended. Each of the three teachers who participated in COW went on to develop their own questions and partnered with small groups of researchers to explore these questions in their own classrooms. Similarly, researchers and teachers from STAR sought and won additional funding in order to continue co-designing school process and anti-racist practices with students and teachers. In each project, co-designers identified the personal relationships they had built with individual researchers as key to their continued engagement. Abby, from the COW project, explained, "I guess I just saw what we were doing as so meaningful…Why wouldn't I try and continue?" She went on to explain that her feelings were in large part due to the personal investment of researchers. "They've become more than colleagues, they're friends."

Discussion

Researchers have long acknowledged the complications of attending to power dynamics while working in collaboration with practitioners in RPPs. However, questions remain about how to attend to issues of equity and representation in these collaborations. Feminist perspectives on research—"emphasizing such issues as reflexivity, relations with 'subjects,' representation, and voice, particularly to concerns about power" (Monk et al., 2003)—call for attending to relationships as core to successful consideration of participant perspectives. In applying these feminist perspectives to our experiences in two long-term RPPs, we found that participants who continued to engage in long-term partnerships felt their own funds of knowledge and personal experiences were honored and valued both by researchers and by their colleagues and peers. When partners felt valued, they invested more in the projects, and as relationships grew, these partnerships extended beyond the boundaries that had initially defined our roles and goals as RPP collaborators (Penuel et al., 2015). Our research suggests that feminist notions of relational work has potential to expand understandings of how to support practitioners and students to engage in RPPs and the ways in which RPPs can act as vehicles for equity and educational change.

References

Bang, M., & Vossoughi, S. (2016). Participatory Design Research and Educational Justice: Studying Learning and Relations Within Social Change Making. *Cognition and Instruction*, *34*(3), 173–193.

Carter, P. L., & Welner, K. G. (2013). *Closing the Opportunity Gap: What America Must Do to Give Every Child an Even Chance*. Oxford University Press.

Ching, D., Santo, R., Hoadley, C., & Peppler, K. (2016). Not just a blip in someone's life: Integrating brokering practices into out-of-school programming. *On the Horizon*.

Coburn, C. E. (2003). Rethinking Scale: Moving Beyond Numbers to Deep and Lasting Change. *Educational Researcher*, *32*(6), 3–12. https://doi.org/10.3102/0013189X032006003

Coburn, C. E., Penuel, W. R., & Geil, K. E. (2013). Research-Practice Partnerships: A Strategy for Leveraging Research. *William T. Grant Foundation*. https://eric.ed.gov/?id=ED568396

Davids, T., & Willemse, K. (2014). Embodied engagements: Feminist ethnography at the crossing of knowledge production and representation — An introduction. *Women's Studies International Forum*, *43*, 1–4.

Fonow, M., & Cook, J. A. (Eds.). (1991). *Beyond Methodology: Feminist Scholarship as Lived Research*. Indiana University Press.

Gonzalez, N. E. (2005). Beyond culture: The Hybridity of funds of knowledge. In N. E. Gonzalez, L. C. Moll, & C. Amanti (Eds.), *Funds of Knowledge,* (pp. 29–46). Lawrence Eribaum.

Henrick, E. C., Cobb, P., Penuel, W. R., Jackson, K., & Clark, T. (2017). *Assessing Research-Practice Partnerships* (p. 31). William T. Grant Foundation. https://wtgrantfoundation.org

Lee, C. (2017). Foreword: Critical Learning Opportunities for the Learning Sciences. In I. Esmonde & A. Booker (Eds.), *Power and Privilege in the Learning Sciences.* Routledge.

Moll, L. C., Amanti, C., Neff, D., & Gonzalez, N. (1992). Funds of knowledge for teaching: Using a qualitative approach to connect homes and classrooms. *Theory Into Practice*, *31*(2), 132–141.

Monk, J., Manning, P., Denman, C. (2003). Working Together: Feminist Perspectives on Collaborative Research and Action. *ACME: An International e-journal for critical geographies, 2*(1), 91-106.

Olive, R. (2012). 'Making friends with the neighbours': Blogging as a research method. *International Journal of Cultural Studies*, *16*(1), 71–84. https://doi.org/10.1177/1367877912441438

Penuel, William R. (2019). Infrastructuring as a Practice of Design-Based Research for Supporting and Studying Equitable Implementation. *Journal of the Learning Sciences*, 1–19.

Penuel, W.R, Allen, A. R., Coburn, C. E., & Farrell, C. (2015). Conceptualizing Research-Practice Partnerships as Joint Work at Boundaries. *Journal of Education for Students Placed at Risk*, *20*, 182–197.

Velez-Ibanez, C. G., & Greenberg, J., B. (1992). Formation and transformation of funds of knowledge among US-Mexican households. *American Anthropological Association*, *23*(4), 313–335.

Vossoughi, S., & Gutiérrez, K. D. (2017). Critical Pedagogy and Sociocultural Theory. In *Power and Privilege in the Learning Sciences* (p. 23).

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International Society of the Learning Sciences

Seeing Learning Sciences Research as Modeling

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Abstract: Researchers in the Learning Sciences take two prevalent stances: research as building theories or as developing designs. The connection between theories and designs is most often filled in by methods, but an alternative stance is possible: research as improving models. The modeling stance seeks parsimonious, useful, illuminating descriptions of learning activity systems. Models can help us understand and express how variability (in all its forms) plays into, is enacted during, and results from designed learning activities. Building models often requires employing multiple theories, methods, and design elements; a modeling stance recognizes that our research often elaborates a multi-level systems view. An explicit modeling stance may lead to developing descriptions of complex systems, inviting multi-stakeholder teamwork to improve these systems, integrating advances in learning analytics and educational data mining, and adding to ability of learning sciences research to tackle challenges at scale.

Introduction: Beyond theory and design

What do learning scientists do? Often our self-descriptions begin with broad ambitions. The ISLS website announces that we are "dedicated to the interdisciplinary empirical investigation of learning as it exists in real-world settings and to how learning may be facilitated both with and without technology." Learning sciences has is an applied science or in the terms of Pasteur's Quadrant (Stokes, 2011), a pioneering science. As a pioneering science, we aspire to use-oriented, foundational, impactful research. And yet what we report may be constrained by what we can publish. The opening description of the aims of the Journal of the Learning Sciences states:

> JLS provides a multidisciplinary forum for research on education and learning that informs theories of how people learn and the design of learning environments. It publishes research that elucidates processes of learning, and the ways in which technologies, instructional practices, and learning environments can be designed to support learning in different contexts.

Note that the requested types of contribution have theories and designs as the two clear anchor points. In a recent handbook chapter, Kali & Hoadley (in press) provide a diagram (Figure 1) that locates Design-Based Research as an epistemic game that connects theory-oriented and design-oriented work. DBR has been subject to critique, e.g., for missing or idiosyncratic argument structures (Kelly, 2004). Some have also observed that design-based research does not adequately address challenges of scaling up, leading to self-critique within the field (e.g. Wise & Schwarz, 2017). This short paper suggests an alternative conception of our work: research as modeling. Modeling also occurs at a middle level between abstract and concrete and between simple and complex. Unlike design-based research, it places greater accountability on developing a logic model or theory of action that can account for variability throughout a learning activity system. This is common in much work that learning scientists do, but we underemphasize our craft of modeling in what we report in publications.

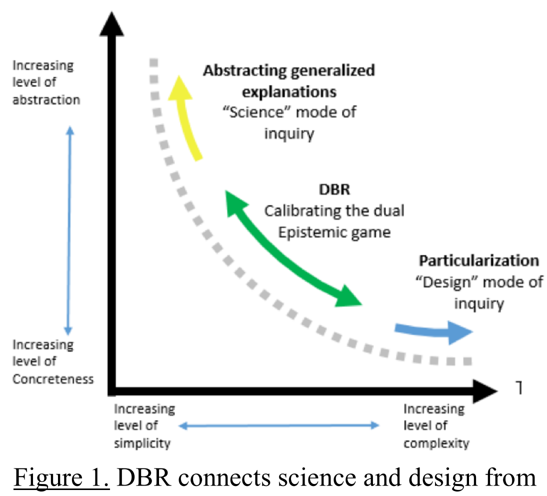

Figure 1. DBR connects science and design from Kali & Hoadley (in press), used with permissions

The aim of this paper is to foster discussion at our society's meeting about how to make the practice of *modeling* complex learning environments a priority pursuit for learning scientists. This could entail both a practice of doing modeling to improve theories and designs, but also a pursuit of models as a useful artifact in their own right. Models can help learning scientists to work with others in teams and that can enable scaling from smaller to larger data sets and from exploratory designs to designs ready for messy, real world contexts. This short paper will sketch what a modeling stance might look like in the learning sciences, discusses the potential significance of giving this stance more prominence, and draws out potential implications for individual learning scientists, for collaborations with other disciplines, and for the kinds of research reports our institutions solicit.

Sketching the Learning Sciences as modeling

The Oxford English Dictionary (2021) defines modeling as: "A simplified or idealized description or conception of a particular system, situation, or process, often in mathematical terms, that is put forward as a basis for theoretical or empirical understanding, or for calculations, predictions, etc.; a conceptual or mental representation of something." Models are useful to scientists because they enable gathering knowledge, forming concepts, clarifying theory, explaining and understanding phenomena, and evaluating truthfulness (Frigg et al, 2020) Modeling, thus, is the art of creating purposefully simple and useful approximations of reality. Credible models organize both knowledge and data to help us reason through a problem without becoming overwhelmed by every factor that could be relevant. Modeling is an iterative process. When we test an approach in expanding contexts, we see additional variation; we realize we need to address it and decide how best to capture and make sense of it. Modeling is purposeful or teleological; we build models to engineer improvement. Modeling is also often collaborative: a shared explanatory structure can make it easier for to integrate multiple perspectives.

What is a modeling stance?

In common with most work in the learning sciences, I suggest that the motivating or driving question for modeling work is to understand how a target population of students learns a complex or challenging subject matter. A tool like Activity Theory invites a modeling stance (see Figure 2, Bury, 2012). The interconnected relationships in the depicted triangles invite a team to look for and map the different interacting elements and processes that together form a learning activity system. In addition, in my experience as a reviewer of research proposals, many projects develop and refine a Theory of Action or a Logic Model, which is a spatial tool for organizing information about all the factors that have a plausible causal relationship to learning. A typical Theory of Action accounts for new inputs to a learning activity system, the training processes and other new resources that prepare teachers to enact it and the learning outcomes that are expected. Many logic models build on Cohen et al (2004). They express a contrast between the new and typical learning activity in terms of what changes among teachers, students and resources in a context. A conjecture map (Sandoval, 2014) can also serve as a logic model. Our field routinely uses models.

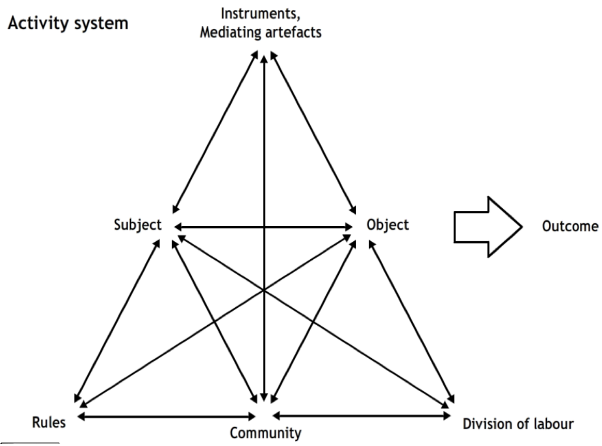

Figure 2. Activity Theory Diagram

The difference between a modeling stance and design-based research may the object of the activity (always in service of an outcome of better learning).

In **model-oriented research**, a more accurate model of how people learn is the *object* of the research; by having a better model, we can explain and predict all the factors that are important to determining the outcomes. A novel design is positioned as an *instrument or mediating artifact* that enables perturbing the business-as-usual model so we can better understand how learning might better take place

In **design-oriented research,** a novel learning design is the *object* of the research; the design is iteratively improved to incorporate what was learned about relevant factors in the learning process. A good model of these relevant factors is a *mediating artifact* that organizes information so that the design can be improved and/or tested with appropriate control of favors beyond the scope of the design.

To explore why this might make a difference, consider other elements of Figure 2. What happens when our community *rules* and *division of labor* are in service of publishing a design or theory? What happens when investigators (*subjects* in this use of Figure 2) are positioned as designers or theorists? My suggestion when the publishable object is only a theory or a design, much learning science competence is rendered invisible. If the publishable outcome could be a better model of learning in a context—a model that is simple enough to be widely re-usable and complex enough to account for the many factors that contribute to learning—I suggest we will make more visible our rules of good modeling building; we will invite a division of labor where different expertise can contribute to anticipating, explaining and predicting how learning may unfold; we may invite investigators who don't see themselves as theorists or designers, but have valuable contributions to make nonetheless.

An example may help:

Imagine that a newly available 5G sensor technology allows students in hybrid classrooms (some students are remote, some are together in a classroom) to more smoothly observe the presence of others and shift among different configurations of small groups.

With a theory stance, one researcher sees this as a system which could advance theories of embodied cognition, as the new sensors capture and represent gesture in new ways. With a design stance, another researcher sees opportunities to create new supports for classroom argumentation, based on allowing students to quickly change groups as they share ideas. With a modeling stance, a third researcher sees that in a data set emerging from early field studies, participation in the groups varies quite a bit – perhaps in ways that reflect who is remote and who is in the classroom -- and begins to wonder: in these patterns we see at scale, which kinds of variation should we focusing on? what different theoretical ideas might we need to explain all the variation we see? What kind of structured diagram would allow practitioners, developers and researchers to work together to make sense of what happens when classrooms use this technology? What structure provides the best tradeoff between simplicity and complexity and between particularity and generality? The stance may make an important difference, therefore, in how we frame our a project, what expertise we recruit, and what work gets done.

What are key objectives in modeling work?

As a discussion starter, I suggest some characteristics of model-oriented research below.

The system perspective is elaborated. Researchers taking a modeling stance elaborate a description of what makes up the relevant learning system. This involves *not* taking the designer's word for what the system is nor taking the learning environment for granted, but rather probing the other local resources, capacities, practices, agencies, and other forces that enter in to how the system is enacted and how it is adapted. Improvement Science, for instance, takes as a key practice "seeing the system" with useful but not too much detail (Carnegie, n.d.).

Multiple levels are considered. A modeling stance requires thinking about different levels of granularity and timescales. In one precedent, learning scientists talk about the meso-, midi- and micro-scales of learning activity. For example, Rogoff (2008) talks about cultural, social and personal "planes" of a learning activity. Learning scientists also think across different timescales, conceptualize interventions with different granularity, or developed nested systems of scripts to guide collaborative learning (references omitted to conserve space).

Multiple theoretical and design elements are integrated. In modeling complex learning environments, it is often the case that no one theory provides a comprehensive set of factors and relationships that is suitable for accounting how learning occurs or varies. Likewise, designs that scale incorporate multiple design factors (Roschelle et al, 2021). The modelling work brings heterogenous elements together in a comprehensive view, where theories are elaborated to fit the particulars of designs and implementations.

Logic models support fitting data. In modeling work, a theory of action is not just to organize the processes of evaluating a novel approach to learning, but also a guide to instrumenting all the relationship that need to be measured. As data comes in, we can see if expected relationships are present and strong, or whether the model needs to be modified to better predict and explain the phenomena. New theories or previously uninspected aspects of the design may need to be added to the model to better explain how learning unfolds. The process of fitting data is the key driver of model improvement.

Scaling research enables observing, making sense and adapting to variability. As others have pointed out (e.g. Coburn, , a large *n* is not necessarily the goal of scaling – for example, we should care about the depth of the innovation and shift of ownership (Coburn, 2003). Scale can also be an opportunity to understand and work with learner variability and variable implementations of teaching and learning processes. A modeling stance would collect data at scale not only to expand impact or improve the implementation, but also because we need to study learning at scale to get better at modeling. Gomez et al (in press) make the case, for example, that many issues of diversity, equity and inclusion really only emerge when a suitable scale of data is available.

Each version of the model serves as a parsimonious boundary object. Returning to the idea that the modeling stance involves multidisciplinary teams, success arises when a model is a useful common ground for conversations that bring together different roles and varied expertise. A good model gives each participant's perspective a place, but also enables a team to see the elephant and not just touch their own leg of the elephant.

Rigor is pragmatic and socially-constructed. Classically, rigor is in service of making a strong causal claim and eliminating threats to validity (e.g. in an RCT). Rigor in ethnographic or descriptive research can be about thoroughness and care in accountability to rich data – avoiding misrepresenting or overlooking phenomena. Although a modeling stance may incorporate aspects of rigor from these approaches, my sense is that the quality of modeling derives from contributions to a pragmatic goal of a community. As models are simplifications, methodological perfectionism nor empirically completeness are best criteria for rigor. A rigorous model should help a community pragmatically to organize its progression of inquiries to address a challenge.

Potential implications for the Learning Sciences

The learning sciences describes itself as publishing advances in theory and design. Yet, improving learner outcomes requires a middle ground between abstract and concreteness, as well as between generality and particularity. Design-based research is in the middle, but outputs a design. An alternative stance would produce models of complex learning phenomena. The field could consider how making modeling a priority at three levels:

- **Professional.** If our professional community were to better recognize individual contributions in making and using models, would that clarify what learning scientist do and open up additional career growth possibilities for early and mid-career scholars? Does this open opportunities for learning scientists who are not abstract theorists nor innovative designers, but are still exceptionally good at studying learning in all its glorious variability in complex contexts?
- **Scientific Community.** The International Alliance to Advance Learning in the Digital Era brings ISLS and learning analytic, educational data mining, learning at scale, and other scientific communities closer together. If learning scientists saw improved modeling as a core contribution (alongside advancing theories or designs), might that allow us to work with colleagues in other disciplines who build models? On a smaller scale, when multi-disciplinary teams form, would a focus on building shared models help the teams work better together?
- **Institutional.** Our journals and conferences more easily feature advances in theories, designs and specific research methods then they do contributions to our practices of modeling complex learning environments. We also often aspire to doing more in terms of diversity, equity and inclusion and we aspire to having impact at scale. Would considering modeling as an institutionally recognized form of scholarly contribution help us advance these aspirations?

References

Bury, M. (2012). Activity System Diagram. Retrieved from https://en.wikipedia.org/wiki/Activity_theory

Carnegie Foundation for the Advancement of Teaching. (n.d.). Using improvement science to accelerate learning and address problems of practice. http://www.carnegiefoundation.org/our-ideas/

Coburn, C.E.(2003). Rethinking Scale: Moving Beyond Numbers to Deep and Lasting Change. *Educational Researcher, 32(6),* 3-12. https://doi.org/10.3102/0013189X032006003

Cohen, D. K., Raudenbush, S. W., & Ball, D. L. (2003). Resources, instruction, and research. *Educational evaluation and policy analysis*, *25*(2), 119-142. https://doi.org/10.3102/01623737025002119

Frigg, R. & Hartman, S. (2020). Models in Science. In E.N. Zalta, *The Stanford Encyclopedia of Philosophy*, https://plato.stanford.edu/archives/spr2020/entries/models-science/

Gomez, K., Gomez, L. & Worsley, M. (in press). Interrogating the role of CSCL in diversity, equity, and inclusion. In Cress, U., Oshima, J., Rosé, C. & Wise, A. (Eds.) *International Handbook of Computer-Supported Collaborative Learning.* Springer. ISBN 978-3-030-65291-3

Kali, Y. & Hoadley, C. (in press). Design-based research methods in CSCL: Calibrating our epistemologies and ontologies. In Cress, U., Oshima, J., Rosé, C. & Wise, A. (Eds.) *International Handbook of Computer-Supported Collaborative Learning.* Springer. ISBN 978-3-030-65291-3

Kelly, A. E. (2004). Design research in education: Yes, but is it methodological? *Journal of the Learning Sciences, 13*(1), 115-128. https://doi.org/10.1207/s15327809jls1301_6

Oxford English Dictionary (2021). *Model.* https://www.oed.com/viewdictionaryentry/Entry/120577

Rogoff, B. (2008). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. Pedagogy and practice: Culture and identities, 58-74.

Roschelle, J., Means, B. & Mazziotti, C. (2021). Scaling Up Design of Inquiry Environments. In C. Chinn & R.G. Duncan et al (Eds.), *International Handbook on Learning and Inquiry.* Routledge. ISBN 9781138922600

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. Journal of the learning sciences, 23(1), 18-36.

Stokes, D. E. (2011). *Pasteur's quadrant: Basic science and technological innovation*. Brookings Institution Press. https://doi.org/10.1080/10508406.2013.778204

Wise, A. F., & Schwarz, B. B. (2017). Visions of CSCL: Eight provocations for the future of the field. *International Journal of Computer-Supported Collaborative Learning, 12(4),* 423-467.

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The Invisibility Issue: High School Students' Informal Conceptions of Everyday Physical Computing Systems

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Abstract: While making physical computational artifacts such as robots or electronic textiles is growing in popularity in CS education, little is known about student informal conceptions of these systems. To study this, we video-recorded think-aloud sessions (~10 minutes each) of 22 novice CS high school students explaining their understanding of everyday physical computing systems and qualitatively analyzed transcripts and student drawings for their structural, behavioral, and functional understanding of these systems. Most students identified the presence of programs in making these systems functional but struggled to account them structurally and behaviorally. A few students pointed out probable programming constructs in shaping underlying mechanisms, drawing from their prior programming experiences. To integrate these systems in computing education, we call for pedagogical designs to address the invisibility of computation—both of structural interconnections and of program execution.

Introduction

Physical computing systems (PCS) which involve microcontrollers, inputs, and actuators are used for designing art installations and robotic systems that can interact with the world (O'Sullivan & Igoe, 2004). As computing education grows in K-12 classrooms, these systems are being adopted across a variety of learning contexts. Novices' extensive user experience with everyday PCS may provide productive informal conceptions about these systems—what constitutes these systems and the mechanisms to realize observed outcomes. Indeed, one hope in using PCS in education is that in constructing these systems, learners will draw from their experiences as users, thereby transforming computing learning from being abstract to relevant and concrete (Przybylla & Romeike, 2014). However, relatively few studies have explored how novice learners interpret everyday PCS.

Physical computing systems traditionally consist of input (e.g., buttons and sensors) and output devices (e.g., actuators such as lights, speakers, motors) connected to a central processing unit. The processing unit receives input signals, performs required computation based on a program, and sends appropriate signals to the output devices (e.g., O'Sullivan & Igoe, 2004). PCS can be viewed as consisting of three key dimensions: structure, behavior, and function (SBF) (Bhatta & Goel, 1997). The physical parts of the system make the structural composition, while its overall purpose in terms of inputs and outputs covers the functional aspects; and, the underlying logic that brings together the different components in action accounts for the behavior (Bhatta & Goel, 1997). Extending this framework to understand PCS such as sensor-based stoplights and interactive toys: (1) the *structural* aspects include the different components such as sensors, lights, and the physical connections; (2) the *functional* aspects consist of the roles of each of these components and the overall goal; and (3) the *behavioral* aspects include the underlying logic causing the functionality.

Prior studies around novices' informal conceptions of PCS have touched upon certain aspects of SBF although they shed limited light on students' understanding of the role of computation. For instance, Cederqvist (2020) examined middle schoolers' conceptions of PCS such as car remote key to uncover their structural and functional understanding and found that most of their understanding pivoted around the visible components such as buttons and lights. Pancratz and Diethelm (2020) observed a range of ways in which middle and high school students understood the structural aspects of daily-use PCS such as robotic vacuum cleaners and video game consoles. But, this analysis—limited to uncovering students' structural understanding—revealed very little about how they understood the functional and behavioral aspects of the systems. With PCS making a foray into introductory computing programs, there is a need to examine students' informal conceptions of these everyday PCS, specifically their understanding of computation in shaping their function and behavior.

In this exploratory study, we conducted think-aloud interviews (Ericsson & Simon, 1998) with 22 high schoolers enrolled in an introductory computing class. We provided pictures of two common PCS, a sensor-based stoplight and an interactive plush toy, and invited students to explain SBF aspects of each. In this paper, we answer the following questions: (1) What aspects of computation did students attend to in their descriptions? And, (2) How did these descriptions qualitatively differ across students?

Methods

Context and participants

The study was conducted at a public charter high school located in a large U.S. west coast city. Students were in a year-long introductory computing course, *Exploring Computer Science* (Goode, Chapman, & Margolis, 2012). The class had 38 students, 22 of whom the teacher chose to participate in interviews (14-18 years; 11 female, 11 male; 8 White, 6 Latino/Hispanic, 6 Asian, and 2 African-American). At the time of the interview, they had 10 weeks of Scratch programming experience and this was the only programming experience for most of them.

Data collection and analysis

The first author conducted and video-recorded semi-structured think-aloud interviews (Ericsson & Simon, 1998) where every student was asked to draw and explain their understanding of two different PCS: a sensor-based stoplight and an interactive toy (see Fig. 1)—the former present within a mile radius of the school and the latter, an artifact that students can relate to. Each interview lasted about 10 minutes.

The first author annotated the interview transcripts to capture student gestures and gaze, and drawings to capture related utterances. These were analyzed initially deductively and later inductively (Creswell & Poth, 2016). Deductive analysis involved categorizing descriptions for SBF. Another researcher independently coded 3 student transcripts and drawings (~10% of data), reaching ~90% agreement. After discussing disagreements, the revised codebook was applied, and themes were generated to capture qualitatively differences among descriptions: *simplistic* descriptions that discounted any computation or automated control; *qualified* descriptions that only identified a control mechanism without elaborating on its nature or details, and *constructive* descriptions that involved details about computation such as specific programming constructs. Another researcher then coded 10% of the student responses with the new coding scheme, reaching ~85% agreement. Disagreements were discussed, and the first author coded all the student responses. Each student explanation of every PCS was considered as a unit of analysis in which SBF aspects were identified and a qualitative descriptor was assigned to each, resulting in 6 codes for each student across the two interview artifacts (6 circles per student in Fig. 2).

Figure 1. Interview artifacts: Sensor-based stoplight (left) and an interactive toy bird (right).

Findings

Qualitative variations within student explanations and relationships between SBF aspects revealed three student groups: one with qualified functional descriptions for at least one of the two PCS (n=15; middle group in Fig. 2); another with constructive articulation of computational unit structurally and functionally, and specific programming-related details within behavioral descriptions (n=5; left-most group in Fig. 2); yet another group with simplistic explanations (n=6; right-most group and Jade in Fig. 2).

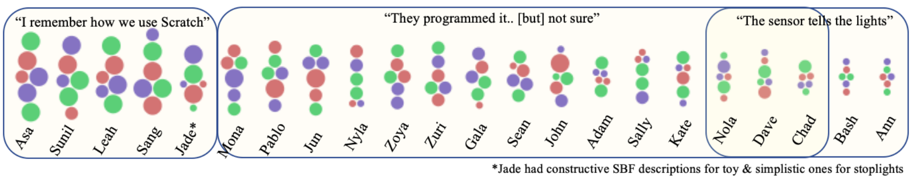

Figure 2. Visualization of student descriptions; red, blue, and green for structural, behavioral, and functional descriptions respectively; small, medium, and large circles for simplified, qualified, and constructive descriptions respectively (all student names are pseudonyms).

"They programmed it…[but] not sure:" Qualified functional descriptions

More than half of the students identified computation in their functional descriptions. They listed an automated mechanism that shaped the overall system functionality (n=15; students with at least one medium green circle, mostly in the middle group in Fig. 2). However, these students struggled to articulate the role of computation in the underlying behavior (medium or small blue circles in Fig. 2). Students identified components such as lights and audio devices as outputs, and the sensors, buttons, and cameras as input devices while describing the system's functionality; most of them (n=9) extended their structural descriptions to acknowledge some form of a computational unit in organizing these inputs and outputs (medium or large red circles in Fig. 2). For instance, Sally identified the control mechanism as a "machine behind [the stoplight]" to coordinate sensors and lights while others acknowledged the presence of a "motherboard," "chip," or a "control panel" structurally.

However, identifying the presence of a computational unit structurally or acknowledging its role functionally did not mean they connected it to system behavior. Many students in this group (first 8 of 13 in the middle group in Fig. 2), informed by their prior Scratch programming experience, thought of computation as distributed across different components such as input/output devices, similar to how sprites are associated with code fragments in Scratch (Maloney et al., 2010). This was evident in Zuri's descriptions of programs as residing in the toy's sensors that will control signals sent to the lights (see Fig. 3, middle). Others (last 5 of 13 in the middle group in Fig. 2) slipped back to simplistic descriptions, barely acknowledging any computation. For instance, Sally, who initially noted the presence of a computational machine controlling the system, dropped it in her behavioral description, and told that the sensors and the lights directly communicate with each other. Overall, students' struggles with articulating the role of computation in system behavior despite identifying its functional presence points to the accessibility of the functional compared to the behavioral or even structural aspects.

"The sensor tells the lights:" Simplistic SBF descriptions

A number of students missed accounting for any computation across their SBF descriptions for at least one of the two PCS (6 out of 22; right-most group and Jade in Fig. 2). The perceptual aspects of the artifacts were the most accessible for learners as they anchored their descriptions around visible inputs (e.g., sensors or buttons) and outputs (e.g., lights and speakers) while leaving out any processing unit. For instance, Bash drew (Fig. 3, left) buttons, a "tape recorder," lights, and wires, and directly connected them to each other without any computing unit. Simplistic structural descriptions led to simplistic functional explanations. In this case, Bash continued to explain buttons as simple electronic switches directly controlling the lights and the "tape recorder." leaving no room for any explanation related to its conditional outcomes based on different degrees of presses.

Simplistic structural and functional descriptions further led to simplistic behavioral explanations. Some students adjusted their simple circuits connecting inputs and outputs to make up for computation-based sensing functionality. For instance, Nola, similar to Bash, thought of the toy in simplistic terms as consisting of buttons, lights, and a microphone connected through wires. When asked about the conditional outcomes, she included computation within her simplistic structural descriptions by adding a set of wires between the buttons and the lights that could send "two different types of signals." She continued to explain the mechanism as one where the button allows for two different kinds of presses and sends different sets of signals for the lights to display patterns. Overall, visible aspects of the PCS such as input and output devices were most accessible to these students, similar to Cederqvist's (2020) observation, and this limited students' ability to see interconnections and computation across the structural, functional, and behavioral aspects of the systems.

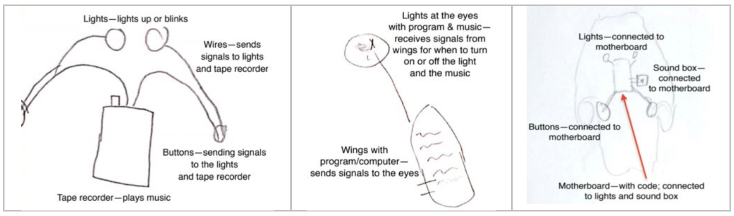

Figure 3. Annotated student drawings: Bash's simplistic connections between the buttons, lights and "tape recorder" (left); Zuri's qualified drawing of wings with computing abilities (middle); Sang's constructive drawing showing "motherboard" connecting the inputs and outputs (right).

"I remember how we use Scratch:" Constructive SBF descriptions

Although most students faced challenges in either identifying or integrating computation into their descriptions, a small proportion of them (5 of 22 in the left-most group in Fig. 2) described specific aspects of computation. They acknowledged the presence of a central processing unit in their drawings and explained its function as receiving inputs and sending signals to respective devices. Further, they drew from their limited prior programming experience to predict probable programming constructs controlling the system behavior. As seen above, Sang's explanation of the "motherboard" connecting the lights, "sound box," and the buttons in the toy bird clarified the connections between microcontroller-like processing, input, and output devices and supported his further functional and behavioral explanations (see Fig. 3, right). He connected the sensor-based interactive functionality to programming constructs by including *if-else* statements to explain conditional outcomes.

Similar to Sang, most of his peers elicited their explanations from their recent and yet limited Scratch programming experience: pointing to *if-else*, *delay*, and *forever* blocks while explaining the underlying behavior. For example, Asa employed these constructs to explain how stoplights work. "You do make a loop where certain things happen then certain activities occur… someone presses the button on the crosswalk, the green light will go a little bit faster," she said describing the loop and conditional constructs mediating interactions between human users and stoplights. Others identified the *forever* loop block in Scratch (e.g., Jade), the *delay* block to count down time for the lights (e.g., Leah), or the *if-else* conditional blocks to manage the input signals and affect outputs appropriately (e.g., Sunil). Though these students' descriptions were relatively advanced compared to their peers, they were limited too in further elaborating on the data and control flow between the computational unit, inputs, and outputs to account for the overall system behavior. In sum, students' initial articulation of different aspects of PCS promises its potential integration with computing teaching while pointing at pedagogical designs to meet where students are to relate computation to everyday PCS.

Discussion

Contexts such as stoplights have a potential to draw from students' user experience. At a functional level, they allow students to make connections to microprocessor-based learning systems such as Arduino construction kits. However, these user-facing PCS intentionally black-box complex underlying connections and this stands in the way of effective utilization of these systems for educational purposes. One way to get around this is to explore the affordances of student-generated drawings in revealing certain underlying aspects. As noted above, student drawings were effective in surfacing structural understanding and mediating functional and behavioral explanations when combined with the "what" and the "how" questions. Teachers can adopt similar practices to highlight the invisible processing unit and the interconnections and facilitate discussions about systems' function and behavior. To surface the invisible program execution that controls the system behavior, teachers can employ notional machines i.e., pedagogical devices to communicate program execution (Sorva, 2013) and be informed by students' prior programming experiences (e.g., Scratch in the examples above). Future research can explore learning activities to integrate everyday PCS with computing education. To conclude, future research, as well as careful pedagogical design can make room for everyday PCS within computing education.

References

Bhatta, S. R., & Goel, A. (1997). Learning generic mechanisms for innovative strategies in adaptive design. *The Journal of the Learning Sciences*, *6*(4), 367-396.

Cederqvist, A. M. (2020). Pupils' ways of understanding programmed technological solutions when analysing structure and function. *Education and Information Technologies*, *25*(2), 1039-1065.

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. Sage publications.

Ericsson, K. A., & Simon, H. A. (1998). How to study thinking in everyday life: Contrasting think-aloud protocols with descriptions and explanations of thinking. *Mind, Culture, and Activity*, *5*(3), 178-186.

Goode, J., Chapman, G., & Margolis, J. (2012). Beyond curriculum: the exploring computer science program. *ACM Inroads*, *3*(2), 47-53.

Maloney, J., Resnick, M., Rusk, N., Silverman, B., & Eastmond, E. (2010). The scratch programming language and environment. *ACM Transactions on Computing Education (TOCE)*, *10*(4), 1-15.

O'Sullivan, D., & Igoe, T. (2004). *Physical computing: sensing and controlling the physical world with computers*. Course Technology Press.

Pancratz, N., & Diethelm, I. (2020). "Draw us how smartphones, video gaming consoles, and robotic vacuum cleaners look like from the inside" students' conceptions of computing system architecture. In Workshop in Primary and Secondary Computing Education, 2020, Virtual Event, Germany. ACM, New York, NY, USA, 10 pages. https://doi.org/10.1145/3421590.3421600.

Przybylla, M., & Romeike, R. (2014). Physical Computing and Its Scope--Towards a Constructionist Computer Science Curriculum with Physical Computing. *Informatics in Education*, *13*(2), 241-254.

Sorva, J. (2013). Notional machines and introductory programming education. *TOCE*, *13*(2), 1-31.

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Characterizing Student Theory Building in Computational Modeling

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Abstract: It is widely agreed that engaging students in authentic science practices is important for science education. Theory building is a central practice of science. Today, many scientists build theory through computational modeling. This paper characterizes the nature of student theory building in the context of computational modeling activities. Using a fine-grained grounded analysis, we identified theory-building moves in one student's goal-directed modeling in a block-based microworld. We present moves enacted during phases of model building, testing, debugging, and sense-making using a segment of transcript from the student's theory-building activity, which was focused on modeling a flu epidemic.

Introduction

It is widely agreed that engaging students in authentic science practices is important for science education (Duschl, Schweingruber, & Shouse, 2007). Theory building is a central practice of science. Many scientists build theory by constructing computational models that, when run, produce outcomes that can be explored and compared with experimental findings (Foster, 2006). A number of research programs have explored ways of engaging students in theory building through computational modeling. diSessa (1995) describes a case where high school students re-invented F=ma through their development of computational models. Wilensky and colleagues have investigated student construction of models of complex systems phenomena such as predator-prey dynamics, using the NetLogo computational modeling environment (Wilensky, 1999; Wilensky & Reisman, 2006). Recent work in this tradition has examined student construction of models using NetTango Web (Horn, Baker & Wilensky, 2020), a block-based interface to NetLogo. The present work builds on this tradition by examining the nature of student theory building in the context of computational modeling activities. It seeks to characterize elements of theory building supported by block-based microworlds.

Theoretical foundations

We define scientific theory building as a family of practices through which scientists and students systematically refine theoretical knowledge artifacts, including laws, models, explanations, constructs, and categories (Swanson, 2019). As these artifacts are refined, thinking is refined. Our perspective aligns with constructivist frameworks that view the construction of new knowledge as a refinement of prior knowledge (diSessa, 1993). It also aligns with constructionism (Papert, 1980), which argues that learning happens best through the construction of public artifacts, such as computational models. In our work, we seek to characterize students' theory building by describing the moves through which they refine their computational models. These are moves through which their ideas are systematized and formalized, and brought into alignment with evidence and observation. We are focused on identifying these moves for two reasons. First, we view them as productive resources that can be leveraged and developed by instruction toward expertise in theory building. Second, we are interested in mapping a gradient from less to more expert theory building, and in so doing, locating student theory building on a continuum with the theory building of scientists. In this paper, we focus specifically on characterizing the *process* of student theory building, leaving the science *learning* that results to other papers.

Methods

We present results from an analysis of data taken from a larger study focused on supporting middle school student engagement in different approaches to scientific theory building, including the construction of computational agent-based models. To make computational agent-based modeling more accessible, we are designing block-based microworlds using the NetTango interface to NetLogo. NetTango makes the computational power of NetLogo accessible to authors by using a block-based programming language curated to a particular phenomenon. NetTango blocks are not a full programming language, but domain-specific blocks relevant to the modeled phenomenon. Previously called *semantic blocks (*Wilkerson-Jerde & Wilensky, 2010) and now called *domain blocks* (Wagh et al., 2017) the blocks are, from a student's point of view, primitive elements of code that represent agents' actions, which can be combined to model a specific phenomenon. We are designing domain-block libraries for simulating complex systems phenomena and studying how children use the blocks to engage in scientific theory building. In this study, we ask the question *"What is the character of student theory building in the context of computational modeling?"*

To address this question, we tested NetTango modeling microworlds with middle school students (ages 12-14) during one-on-one 1.5-hour task-based interviews. During each interview, the student had full command of a laptop featuring an agent-based microworld. The interviewer guided them through tasks and questions from a semi-structured protocol, which introduced the features of the microworld and then prompted the student to model a particular phenomenon. This study focuses on an interview with Sage, a 13-year-old who had just started 8th grade at a public school in her small Midwestern city. Sage explored the *Spread of Disease* model, shown in Figure 1, below. Figure 1 shows the microworld with a model of Ebola built by Sage. The black box to the left is the *world* which depicts the activity of the agents that are programmed to behave according to the rules specified by the model. The *setup* and *go* buttons are controlled by procedures (red blocks) that the user must drag from the block library (far right) into the modeling field (middle) and then define by connecting with blocks (purple, grey, and green), such as *move*, *if contact person*, and *infect*.

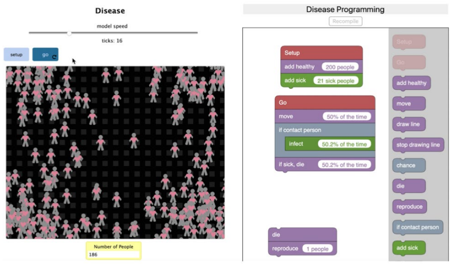

Figure 1. The *Spread of Disease* microworld featuring Sage's model of Ebola.

Sage's interview was recorded using video, audio, and screencast technology. The audio recording was transcribed. A fine-grained grounded analysis was applied to both the screencast and transcript to identify theory-building moves that Sage enacted (Glaser and Strauss, 2017). First, the screencast of Sage's interview was reviewed and times were noted during which she engaged in building models for particular diseases, namely Ebola, the flu, and a zombie apocalypse. These episodes were then marked on the transcript, which was read for evidence of theory-building moves, which were named and organized into phases of model building. These were: 1) building, 2) testing, 3) debugging, and 4) sense-making. For the purposes of illustrating the moves she enacted, the moves were used to characterize the episode of Sage's modeling in which she tried to model a flu epidemic. The episode was temporally decomposed into steps of model building, testing, debugging, and sense-making. The episode is presented in the Findings section as a piecewise trajectory. The transcript associated with each step is followed by a description of the smaller theory-building moves in which Sage engaged, highlighted in italics.

Findings

The grounded analysis of the three episodes revealed 46 theory-building moves across the four phases. We present a narrative account of a segment of Sage's modeling activity to illustrate how she engaged in building, testing, debugging, and making sense of her model. We offer a temporal decomposition of the first three minutes of the 10-minute trajectory through Sage's flu modeling activity, highlighting her theory-building moves in italics.

Modeling the spread of influenza

Sage is seated at a desk in an office, the interviewer sits at her left. She is looking at a laptop screen on which the *Disease Spread* modeling microworld is open. She has been exploring the microworld for the last 40 minutes. Her exploration began by trying out combinations of blocks and watching the resulting activity in the *world*. She then built and refined a model of Ebola (Figure 2), at the interviewer's request. Following this, the interviewer asks Sage how she would modify the code in the Ebola model, to model the flu.

Step 1: Building the initial flu model

Sage looks at the model of Ebola and considers how she might modify the code to represent the flu.

> Sage: If it was flu, hmm, it's less deadly [...] Like, I don't know, like 10%.

To match her understanding of the flu, Sage *purposefully selects a parameter value*, decreasing the probability that a sick agent will die, from 50.2% to 10%, and then to 5.5%. She appears to be *drawing on prior knowledge* she has about the difference in deadliness of the flu *as compared* with Ebola. She *approximates the parameter value* and shows an *awareness of the limits of her knowledge*, qualifying her choice with the words “I don’t know.”

Step 2. Testing the initial flu model

The interviewer asks Sage how she thinks her modification is going to influence the model outcome.

> Sage: I think the epidemic is going to spread like much further because, um, people like when people are moving around and infecting people, they're like, they're, they're not, they don't have like a 50% chance of dying every time. [...] And so people weren't, people were dying faster than they were coming in contact with people instead of-

Sage *makes a prediction for the outcome of the model run*, and *explains her prediction* by *comparing her expectation with results of previous runs* of her model of Ebola. She *explains the aggregate-level outcomes of those runs as the result of agent-level interactions*. Her reasoning is that for Ebola, “people were dying faster than they were coming in contact with people,” and the disease disappeared from the world before it could turn into an epidemic. For the flu, she reasons that the epidemic will spread because it is less deadly and therefore sick people will be in the world long enough to infect healthy people. She appears to be *drawing on knowledge* she constructed while modeling Ebola, that if the disease is deadly to infected individuals it will kill them off before they can spread it and decimate the population. Sage presses “go,” running the model to *test the effect of her new parameter* and *observing* as the model runs. She watches as the number of people in the world decreases as healthy people become infected and sick people die. This outcome stands in contrast with her Ebola model, where all of the initially sick people died in the first few ticks.

Step 3: Making sense of the initial flu model

The interviewer asks Sage if she thinks this model looks different from her model of Ebola.

> Sage: Yeah. Um, I think the percentage of population is like going down as you can see.
>
> Interviewer: Ah, so what did you change in the um, the flu case?
>
> Sage: Well, people died less and it spread less. And so, we went from like 221 people, 41 people because it's, um, it's very infectious, but it's like, like people don't die a lot. But when there are a lot of people then people start dying. [...] And so just people keep dying and then eventually [...] So, because no one's recovering, you can't, I didn't have it set to recover.

Sage tests the model and *describes its outcome*: that the population is decreasing over time. She *compares the results of this run with results of the previous runs* of the Ebola model, where fewer people died, because the sick people died before the disease could spread. She turns to the flu model-run results, *referencing numerical data* that she *calculated* by subtracting the value given in the box titled “number of people” from the total initial population (the population has decreased by 41). She *explains the aggregate-level outcome of the flu model in terms of agent-level behavior*. She explains that the flu is very infectious but less deadly to those infected. If there are a lot of people, some percentage of the population will die, so the population decreases. Through her sense-making, Sage *arrives at a powerful conclusion about complex-systems dynamics*: when a disease is less deadly to infected individuals, infected people die less and the disease spreads to more of the population. If there are enough people in the population, many people will ultimately die. Sage acknowledges that the population may have decreased too much in her model, because the only option for sick people is to eventually die, as she left out the “recover” block. Sage *connects the agent behavior with the model code* and engages in debugging, identifying this as a *problem with the model*.

Step 4: Debugging the initial flu model

The interviewer asks Sage if she thinks as many people die in a flu epidemic as shown in her model.

> Sage: Probably not. It's probably because I have the infectivity high and people aren't recovering. But let's say you recover like, I don't know, 50%? No, like 75 but that's going to be way too high. Yeah, 75 and less infectious, and this will be hard to start your... Wait, no, that's recover, wait. Yeah. Infect like 10%.

At the interviewer's prompting, Sage *assesses the reasonableness of her model's results*. She explains the unexpected *outcome at the aggregate level as the result of both an incorrect parameter setting* and *incorrect agent behavior*. She engages in debugging, *modifying the code to address the problem* by adding the "recover" block to the model and setting the probability of recovery to 73.1%. She also debugs the model by *modifying a parameter to address the problem*, reducing the probability of infection from 50% to 10.5%. Following this, Sage continues to work on her model for another 7 minutes, working through an additional 18 steps of testing, making sense of, and debugging the model. All the while her goal was to find a way to get the epidemic to sustain itself and work more like her image of the flu epidemic. Over the 10 minutes of the activity, Sage demonstrated many moves that may be productive foundations for developing expertise in areas of theory building, including model building, testing, debugging and sense-making.

Discussion

This study characterizes student theory building in the context of computational agent-based modeling. Working in the microworld with the support of the interviewer, Sage engaged in theory building by constructing, testing, debugging, and making sense of a computational model. By identifying and characterizing Sage's theory-building moves, we identified resources she brings to her learning that may serve as foundations for developing expertise in theory building. In this way, we make a contribution to literature concerned with identifying the resources novices bring to their learning that can be foundations for the development of scientific expertise. The work makes a contribution to the larger project of characterizing the nature of student engagement in different forms of scientific theory building by characterizing student engagement in computational agent-based modeling. By identifying the smaller moves of which this approach to theory building is composed, our findings are foundational for the development of science curricula and assessments that promote and capture rich student engagement in scientific theory building.

References

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and instruction*, *10*(2-3), 105-225.

diSessa, A. A. (1995). Designing Newton's laws: Patterns of social and representational feedback in a learning task. In R.-J. Beun, M. Baker, & M. Reiner (Eds.), *Dialogue and Interaction: Modeling Interaction in Intelligent Tutoring Systems.* Berlin: Springer-Verlag, 105-122.

Duschl, R. A., Schweingruber, H. A., & Shouse, A. W. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8* (Vol. 500). Washington, DC: National Academies Press.

Foster, I. (2006) 2020 computing: a two-way street to science's future. Nature 440(7083):419

Glaser, B. G., & Strauss, A. L. (2017). *Discovery of grounded theory: Strategies for qualitative research*. Routledge.

Horn, M.S., Baker, J. & Wilensky, U. (2020). NetTango Web [Computer Software]. Evanston, IL: Center for Connected Learning and Computer Based Modeling, Northwestern University. https://netlogoweb.org/nettango-builder

Papert, S. (1980). Mindstorms: Computers, children, and powerful ideas. *NY: Basic Books*.

Swanson, H. (2019, April). *Cultivating a theoretical turn-of-mind.* Paper presented at the annual meeting of the American Educational Research Association, Toronto, Canada.

Wagh, A., Cook-Whitt, K., & Wilensky, U. (2017). Bridging inquiry-based science and constructionism: Exploring the alignment between students tinkering with code of computational models and goals of inquiry. *Journal of Research in Science Teaching*, *54*(5), 615-641.

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—an embodied modeling approach. *Cognition and instruction*, *24*(2), 171-209.

Wilkerson-Jerde, M., & Wilensky, U. (2010). *Restructuring Change, Interpreting Changes: The DeltaTick Modeling and Analysis Toolkit*. Paper presented at the Constructionism 2010 Conference, Paris.

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Student Perceptions in a Formal Makerspace: A Case Study of Two High School Senior Students and their Collaboration on a Computer-Aided Design Project

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Abstract: While collaboration is a major theme across makerspace studies (Papavlasopoulou et al., 2017), few studies consider how students perceive collaboration within makerspaces. This single case study explores secondary students' perceptions of their collaborative experiences while working on a computer-aided design project in a formal makerspace. Survey, observation, and interview data were collected and qualitatively coded. Findings demonstrate how a student with technical expertise can take on increasing ownership of a peer's project and limit learning opportunities for the partner student. Implications include how teachers can orchestrate and monitor collaborative relationships to support students' success and agency in formal makerspaces.

Background and significance

Many school systems are incorporating technology-enhanced learning environments as formal makerspaces (Peppler et al., 2015) to connect curriculum-based content to professional skills and engage students in communities of practice that cater to their personal interests. While collaboration is a major theme across makerspace studies (Papavlasopoulou et al., 2017), there is little consideration of the students' perceptions of collaboration or how passion-based learning may affect students' experiences within the makerspace. Our research seeks to privilege student voice by considering two secondary students' perceptions of their collaborative experiences while working on a computer-aided design (CAD) project in a formal makerspace. We consider: How do students collaborate within a formal makerspace and to what extent do students' perceptions of these collaborations affect their experiences within the makerspace?

All students should be supported in gaining the skills needed to engage in the professional communities of their interests and choice. Our findings can provide insight into student perspectives for educators toward better understanding the support that students need to actively engage in positive, collaborative learning experiences within a formal makerspace and creating equitable learning experiences for all students.

Collaboration and equity in makerspaces

Papavlasopoulou and colleagues (2017) suggest that collaboration is a major theme across makerspace studies. Prior research shows that students in makerspaces use collaboration to create relationships in which they work together for access to skills and a diversity of knowledge (e.g., Gutiérrez et al., 2014) by recognizing the skills and interests of their peers. The ability of a peer group to negotiate roles, allocate responsibilities, and build a collective product from individual work is called collaborative agency (Kafai et al., 2012). Additionally, makerspaces emphasize learning through doing where students build upon their existing resources, learn practices that are authentic to professional communities within their areas of interest, and develop their own identities through collaborative interactions (e.g., Baker & Lattuca, 2010). Thus, collaboration may be critical to helping students develop an identity as a member of a makerspace learning environment.

Formal makerspaces may offer an asset-based approach to help traditionally marginalized youth engage in passion-based learning. However, while formal makerspaces offer the opportunity for marginalized youth to engage in passion-based learning at school, collaborations within makerspaces can also hinder equitable participation in learning. For example, a student who needs help may begin to collaborate based on helplessness or replication (Sheffield et al., 2017). Similarly, when makerspace participants feel knowledgeable, they may choose to share their knowledge or either take over the work or refuse assistance (Maltese et al., 2018). While equitable collaboration on long-term projects increases the opportunities for marginalized youth to build supportive social networks, if collaborative roles remain consistent and become part of students' identities in the makerspace then hierarchies may develop that negatively affect future collaboration (Barton et al., 2017). Collaboration can then also promote inequity (Maltese et al., 2018). Thus, more research is needed to understand how students perceive collaboration in makerspaces to increase the likelihood for equity in collaborations.

Study context

In this holistic, single case study (Yin, 2018), we consider two students (Theodore and Joseph) who worked together on a CAD project in a formal makerspace, Maker High, over a two-week period. Maker High was available for high school seniors across a public school district to attend during the second half of every other school day and receive course credit. Although there were two teachers at Maker High, a preliminary review of Theodore and Joseph's surveys showed that their passion-based interests of using computers to create designs were outside of the teachers' range of expertise. Further, Theodore's survey included his plan to begin work on a CAD project that involved technology that he had never before used but that Joseph had promised to help him learn. The opportunity to focus on a student who may not have been able to seek help from a teacher but was seeking a collaborative relationship with a peer led to our decision to study Theodore and Joseph.

Methods

Over the course of two weeks in the spring, the two students were observed working on the design portion of their CAD project for four days, for four hours each day. Audio recordings of the students' discussions were collected and transcribed and the observing researcher wrote daily analytic notes in a reflexive journal. Immediately prior to and following each observation, semi-structured interviews were conducted with the students to understand their goals, challenges and successes, and perceptions of collaboration while working on the project that day. Data from surveys conducted at the beginning of the school year, mid-year, and at year-end, asking students questions regarding prior collaborative experiences in non-traditional learning environments and their current collaborative experiences at Maker High, were included in the analysis to increase construct validity using data triangulation (Yin, 2018). Two researchers coded 20% of the data from all of the sources with first-level codes in 5% increments, discussing and reconciling any disagreement after each set of 5% increments to obtain an inter-rater reliability above 80% (Miles et al., 2020). These codes included descriptive coding to summarize when students discuss different settings in which they have experienced collaboration and their perceived success and challenges of collaboration; concept coding, using a symbolic word or phrase that suggests an idea; and emotion coding, when participants recall emotions, to consider when and how students perceive emotional support. The researchers then divided and coded the remaining data separately, discussing any uncertainty. The researchers separately engaged in a second-level method of pattern coding to categorize potential themes and compared their analyses to reach consensus.

Results

Theodore and Joseph's collaborative roles

Joseph's prior experiences in four different CAD courses at his base school led him to have an expertise that no one else at Maker High (including the teachers) had. Theodore approached Joseph for help prior to beginning his project because he was aware of Joseph's expertise. For Theodore, this was an affordance of attending Maker High: "I have plenty of ideas but I have no idea how to do them and [Maker High] helps make my ideas happen." Through the two weeks spent working on the CAD design, Joseph took on a mentoring role that surpassed occasional help. As Theodore had questions, Joseph would leave his nearby computer station to provide help. By the second observation, Joseph had made the choice to abandon his project to sit by Theodore for the remainder of our observation period. He began to step into the role of a more constant mentor for Theodore. For example, he said "Theodore got past a mental barrier of not being able to get work done on it. Certain functions of CAD get annoying, but Theodore worked so hard and had a breakthrough today." Initially Joseph also focused on leading Theodore through the process of making design choices. However, as the project progressed, Joseph sometimes took the computer mouse from Theodore and edited the design himself. At times Theodore was receptive saying, "I see what you're doing. That looks good." But other times, he reminded Joseph that it was his project. For example, in the final observation, Joseph went even further in his contributions to the project by making a design change as he continued to work on the project while Theodore went to the bathroom. WhenTheodore returned, he said, "I said wait, I don't want you to do it for me."

After abandoning his own project to more closely help Theodore, Joseph began to express ownership of Theodore's project. This may have led him to begin to manage not only the project but also Theodore himself. Particularly, Joseph tried to keep Theodore on track and was concerned about his productivity. At first this involved checking in on the completion of goals without statements of judgement regarding progress. As they continued to work together, these statements became more critical. For example, as another group finished a project, Theodore suggested, "We should take a break and see what they're doing." Joseph replied, "Stop, you constantly want to take a break. You take too many breaks." These corrections then took on a more negative tone.

Joseph's perspective

Joseph's willingness to step into a helper role was surprising since, when asked at the beginning of the year who he hoped to work with during his time at Maker High, Joseph had written "a person that already has a ton of background knowledge because I'm not a fan of teaching other people something and would like to have a person I can work with, with the same sort of mindset". However by mid-year, he reported feeling that he did not have equals in terms of technical knowledge or even peers working in the same area of interest, writing, "I don't have many people doing engineering so I probably can't find someone to work with." When asked about helping Theodore manage his time and stay on task, Joseph stated that he was "looking to help to figure out what [Theodore's] next steps are because he gets sidetracked a lot which isn't always a bad thing but he needs sometimes someone to tell him what he should be doing next." Joseph's investment in the successful completion of Theodore's project went past simply finishing the CAD design. He offered to help Theodore use technology at his base school, unavailable at Theodore's, and use 3-D printers, CNC routers, and welding to build Theodore's project outside of Maker High.

Theodore's perspective

Throughout the project, Theodore seemed receptive and appreciative of Joseph's help. He believed that he needed help to stay motivated, and he stated appreciating that Joseph helped him to increase productivity. Yet, Theodore also showed a dependency on Joseph's help. This made him feel insecure in his lack of knowledge despite his recognition that he was doing this project as a way to learn more about CAD. Particularly, he felt that Joseph could be condescending and was not always willing to explain concepts. Theodore stated that Joseph is "… good at helping when he's good at helping. He won't explain what he's talking about, he'll say do it. And I want to know the reason behind it. When I ask him to explain sometimes he does, sometimes not." This was supported in observation:

Joseph:	I just made it for you
Theodore:	Yeah but you weren't explaining it.
Joseph:	Alright just ask questions if you need it.
Theodore:	I don't know what's happening.
Joseph:	Well now you do the work. Make a hole, is that what you want to do? It's your project, take control.

Other times, Joseph appeared to attempt to scaffold Theodore's understanding by asking questions. But Theodore showed signs of frustration, asking what Joseph would do next instead of thinking through the process. For example:

Joseph:	Make everything else wood, that doesn't make sense. What else could you do?
Theodore:	Do you have an idea? Are you trying to encourage me toward an idea? That could take a while.
Joseph:	First off, I think you should make this plate a little rounder. This could come down, you'll have a bolt. You're going to need washers especially with metal and wood it gives it a metal surface to attach on.

Discussion

In this study, two students formed a close collaborative relationship within their makerspace that enabled them to work on solving the problems of a project that were relevant to them (e.g., Sheffield et al., 2017). Theodore leveraged the expertise of his peer, Joseph, who became a mentor in CAD as well as a delegator of tasks and reminder of time management. We propose that collaborative roles of "helper" and "student-in-need-of-help" may be complicated in a formal makerspace. For example, in this data, the student in need of help is also the leader of a project asking a peer for help based on their valuing of that individual's expertise. As a helper, Joseph is then working for the student leader on their project, although at times it may seem that this helper student is taking on a leader role in the project by assigning tasks to Theodore. Although not necessarily a negative role, if students are always in the same collaborative role, as Theodore and Joseph seem to be within this project, then they may be missing out on opportunities to use their own expertise or receive help on their own project.

For these two students, support and collaboration during this project was limited to their partnership. Theodore was seemingly dependent on Joseph's prior experience to complete his CAD project. Although working at Maker High allowed him opportunities to engage in professional practices, his dependency and, at times, learned helplessness within the collaborative relationship may affect the development of his identity (e.g., Baker & Lattuca, 2010) as a CAD operator. Further, Joseph's perceptions of isolation due to a lack of surrounding resources throughout the school year may have led him to work with Theodore despite Joseph's statement of not wanting to be in a teaching role. Within this partnership, the students did not have support in using their collaborative agency (Kafai et al., 2012) to delegate work. Thus, without explicit structure or support, students may not be able to draw upon or develop individual expertise, which has the potential to reinforce traditional school roles and identities in formal makerspaces.

Implications and conclusions

At Maker High, there were opportunities for rich, sustained collaboration between students that fulfilled the promise of makerspaces as environments for collaborative learning (e.g., Peppler et al., 2015). Yet, despite the idea that students can find success in makerspaces if they have access to expertise and resources through collaboration (Gutiérrez et al., 2014), care needs to be taken to avoid putting undue mentoring responsibility on students. Further, the students who are helping their peers may not support the other students emotionally or mentally despite their content or technical knowledge. Collaborative relationships, as critical as they are for students' success in makerspaces, may then need to be more carefully facilitated in formal makerspaces to avoid creating too much burden for the helping student or feelings of dependency for the student receiving help. Preferably, partnerships can be formed where students support each other more equitably or students would engage in a variety of partnerships with different collaborative roles. Teachers could then help students to manage their time and learn to manage the progress of their projects. Student partnerships could be based more on the offering of expertise and learning from a peer's skills rather than being in charge of a peer's productivity. Teachers then may need support to put into place protocols and norms of collaboration to enable more equitable collaboration opportunities in formal makerspaces.

References

Baker, V. L., & Lattuca, L. R. (2010). Developmental networks and learning: Toward an interdisciplinary perspective on identity development during doctoral study. *Studies in Higher Education*, *35*(7), 807-827.

Barton, A. C., Tan, E., & Greenberg, D. (2016). The makerspace movement: Sites of possibilities for equitable opportunities to engage underrepresented youth in STEM. *Teachers College Record*, *119*(6), 11-44.

Fields, D., Vasudevan, V., & Kafai, Y. B. (2015). The programmers' collective: fostering participatory culture by making music videos in a high school Scratch coding workshop. *Interactive Learning Environments*, *23*(5), 613-633.

Gutiérrez, K. D., Schwartz, L., DiGiacomo, D., & Vossoughi, S. (2014). Making and tinkering: creativity, imagination, and ingenuity as a fundamental human practice. In *AERA (American Educational Research Association) conference, Philadelphia*.

Kafai, Y. B., Fields, D., & Burke, W. Q. (2012). Entering the clubhouse: Case studies of young programmers joining the online Scratch communities. In *End-User Computing, Development, and Software Engineering: New Challenges* (pp. 279-294). IGI Global.

Maltese, A. V., Simpson, A., & Anderson, A. (2018). Failing to learn: The impact of failures during making activities. *Thinking Skills and Creativity*.

Miles, M.B., Huberman, A.M., & Saldana, J.M. (2020). *Qualitative data analysis: A methods sourcebook, 4th Edition*. Thousand Oaks, CA: SAGE.

Papavlasopoulou, S., Giannakos, M. N., & Jaccheri, L. (2017). Empirical studies on the maker movement, a promising approach to learning: A literature review. *Entertainment Computing*, *18*, 57-78.

Peppler, K., Maltese, A., Keune, A., Chang, S., Regalla, L., & Initiative, M. E. (2015). Survey of makerspaces, part II. *Open Portfolios Maker Education Initiative*.

Sheffield, R., Koul, R., Blackley, S., & Maynard, N. (2017). Makerspace in STEM for girls: a physical space to develop twenty-first-century skills. *Educational Media International*, *54*(2), 148-164.

Yin, R.K. (2018). *Case study research and applications: Design and methods, 6th Edition*. Thousand Oaks, CA: SAGE.

Collaborative Data Engineering: Strategies to support Macro-level Exploration of Youth Learning Ecosystems

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Abstract: The time has come for the learning sciences to expand design and research methods in order to understand access and participation to learning opportunities at a macro level. Advances in technology allow networked social systems (such as out-of-school providers) to crowdsource and combine the data they collect and interpret collectively through data representations. Learning sciences can leverage networked data as a way to stress test theories based on ethnographic research with individuals or small groups and offer learning science perspectives to how we understand and address power-related infrastructure and historic racism. In this paper, we share a process for designing technical systems, refining data models, visualizing learning landscapes, and working with decision makers to impact change using an investigation of the 2019 Chicago summer learning landscape as a case example.

Keywords: learning ecosystems, out-of-school time, data engineering, equity

Introduction

The learning sciences practice of weaving design, cognition, and context together to investigate learning has birthed new ways of understanding how people learn and how environments influence what happens. Research and design efforts most frequently use person-centered units of analysis, including what we describe as micro- (individual, family) and meso- (e.g., program, classroom, affinity group) levels. Studies have generated powerful frameworks and models of learning ecosystems with youth at the center. These egocentric models show how youth learn across places and time, illustrating how social networks and events are critical development and identity shapers and identifying potential barriers and sparks that can influence participation and persistence (e.g., Barron, 2006; Ito et al., 2013). These models have advanced understanding of how youth learn out of school, and the interconnected relationships between home, virtual spaces, school, and other learning environments. For over a decade, our own design-based research has been grounded in these egocentric learning frameworks, meaning we spent many years at the meso level of classroom and program design and study. But there are limitations to designs based on understandings that hinge on small-scale studies of specific programs or organizations or synthesis of individual ethnographies (Hect & Crowley, 2019). In the past few years, we have expanded our research beyond individual programs intended to bolster youth and family participation in computational making to consider inequities in STEAM opportunities across geographic landscapes at a macro level (e.g., cities and communities) (Pinkard, 2019). There is a lack of attention in the field to this level of study and design and as such, research to understand neighborhood or city patterns of informal learning are rare or non-existent. Addressing this vacuum is urgent in order for American communities to establish equitable learning systems informed by a shared awareness of the historic systematic racism embedded in the placement and practice of civic learning, leisure, and performance institutions (i.e., schools, parks, libraries, museums, community-based organizations). Current tools and organizational connections make this work possible (Akiva, Delale-O'Connor, & Pittman, 2020).

In this paper, we illustrate how we are engaging in research and design at a macro level. We describe a process for operationalizing landscapes at a citywide level, a direct expansion of our earlier methodology to understand learning across formal and informal spaces at smaller scales. We ask questions about distribution of opportunities at a macro level to reveal issues of access related to: places (where are the locations where learning happens?), people (who designs and offers youth programming?), and opportunity (what programs and events are available for youth to participate in?). We also share how stakeholders have been engaged in data collection and interpretation to translate understanding macro-level data to actionable design intended to (re)allocate resources for more equitable distribution and youth participation.

Building blocks from micro-level analysis

We consider our earlier methods to be the building blocks for our current work. To understand interest and development over time for middle school students participating in a series of after school digital arts opportunities, individual learning timelines were developed that linked events across time (y-axis) and environment (x-axis) and social network connections (Barron, Gomez, Pinkard, & Martin, 2014). Researchers and practitioners used understandings about key events (such as interest-driven projects, parent collaboration, and showcase opportunities) and challenges (such as limited opportunities for advancement, competing interests, perceived identities or stereotypes, transportation, or costs) to design programs and opportunities to better serve youth learning trajectories, with special attention to equitable engagement. These types of micro-level representations of unique learners and their pathways over time and across places can help to conceptualize the importance and interconnectedness of key events in youth learning and development, and how they fit into different spatial (school, home, community, and online), social (parents, mentors, teachers, and peers), and temporal (grades, ages) dimensions. Representations can be shared with practitioners and youth and families, yielding new insights and ideas for design, but are often time consuming and crafted individually based on qualitative data. In the remainder of this paper, we reveal how we utilized these micro-level building blocks about where, who, and what is going on in the lives of young people that influenced their learning journeys over time to investigate similar questions at a larger scale, utilizing current powerful technologies and analytical strategies while staying grounded in person-focused understanding about learning and development.

Methods

Given the lack of methodology for citywide understanding of youth learning ecosystems, including opportunities and participation, the methods utilized in this work emerged from a collaborative data engineering design process, including the design and implementation of a sociotechnical data collection system, and corresponding processes of input, collection, and interpretation.

Developing a platform for collaborative input about OST opportunities

Agreement that out-of-school time (OST) learning is important is common but understanding what opportunities are available, accessible, and at the right level, especially in science, engineering, and computational disciplines, often remains a black box. This lack of visibility confronts multiple stakeholders, including youth, parents, organizations who offer programs, and city and community leaders who want to ensure equitable opportunities across the geographic areas they serve. In 2013 a multi-year collaboration was established between researchers, practitioners, and city leadership, with support from philanthropic funding, to address this issue. Our team developed a technical platform and invited OST providers to input their program information and key metadata as well as youth participation data. Providers can upload a batch of programs through a .csv file with required fields (common for larger agencies and organizations) or manually enter each program. Fields captured for each program have evolved over time, prioritized by those that are (a) important for families who want to participate, (b) feasible for practitioners to easily access and report, and (c) allowing inquiry in terms of access and equity, connected to our micro-level building blocks used to explore the individual-level learning events over time.

The dataset shared in this paper included programs for youth (ages 0-18) available during the summer of 2019, including 5,583 unique program records contributed by 166 Chicago youth-serving organizations.

Constructing data models from theoretical models

A first phase in the macro-level analysis is cleaning and transforming the provider-entered data into formats that are easy to manipulate and represent the networked connections (e.g., social groups, participation trajectories, content and activity relationships) and metrics that we have identified as important from our explorations of youth ecosystems and from related research. Examples include the number of locations that youth have access to that offer informal learning opportunities (related to youth connection with physical community spaces, each with cultural and place-based resources and facilities (e.g., Barron et al., 2014)), the number of organizations or agencies who offer those programs (related to connections with various types of organizational and adult mentorship, expertise, and human capital (e.g. Ching et al., 2015)), the breadth and depth of learning opportunities in different content areas (related to engagement and interest development and deepening (e.g., Ito, et al., 2013)), and proportions of opportunities with additional supports (related to participation equity (e.g., Pinkard, 2019)).

Because ecosystems evolve over space and time, the information that we collect needs to be stored in a manner that represents our theoretical perspective, maintains longitudinal coherency, and is flexible enough to facilitate a variety of analytical approaches. To achieve this goal, we implemented a data warehousing initiative. In the field of computer science, data warehousing refers to the computing architecture used to store analytical data and the way to design data models to support analytical processes (e.g., dimensional modeling, data marts, data vaults). Going into the specifics of these technologies are beyond the scope of this paper, but we do want to identify the design approach we have taken to create an effective data warehousing initiative. Our collaborative design process as a team of researchers, designers, and data scientists is as follows: (1) *articulate and synthesize* *theoretical goals* by generating and documenting new and existing research questions, (2) *information linking* to develop metric naming protocols, information relationships, and the interpretation of metrics, (3) *ideation & feedback* as prototype data models (including relational diagrams and sample data worksheets) are presented for testing and feedback, (4) *implementation* of selected data models in the data warehouse (e.g. AWS Redshift), and (5) *access* allowing researchers to pull data into visualization tools to construct publicly shareable representations.

Connecting and visualizing data for stakeholder interpretation

Our interpretive level for this work is the city of Chicago, while the analytical level is the community boundary. Chicago's 77 community areas have clearly defined borders that do not overlap and that are recognized by the people who live within them (unlike other Chicago geographic regions, like neighborhoods, that are less defined and open to individual interpretation). Summaries of the platform data are tabulated by community area to reveal dimensions of the learning ecosystem. We consider these to be macro-level representations of the individual learning ecosystems of the youth in these geographic areas. ArcGIS is used to develop static maps and online apps that allow presentation and exploration with stakeholder groups during citywide meetings hosted by the mayor's office and smaller community meetings organized by local community organizations (Erete et al., 2020). Importantly, these maps are automated and can draw from live data, allowing comparisons of different time periods. Maps are integrated with other data sources, such as city crime data and census data, as well as youth-collected data from organizational partners classifying the types of providers surveying features of unique learning hubs (e.g., asset maps of makerspaces, instructional kitchens, recording studios, and places to hang out).

Findings

In this section we show examples of the kinds of visualizations that help to reveal distribution of opportunities at a macro level, how this illustrates both richness and gaps in opportunities across Chicago communities, and how these visualizations can be utilized to promote deeper conversations about resources, design, and interpretation.

Learning hubs and human capital

Physical spaces where informal learning opportunities are offered are not necessarily the location where agencies or providers who offer those programs are located. For instance, the location of a science museum is different from the school location where that museum offers after school programs. This type of outreach programming is relatively common, but organizations infrequently have ways to look at the holistic distribution of where opportunities are offered in ways that can support understanding of learning landscapes and providing access to opportunities where they are needed. During the summer of 2019, our dataset revealed all but two of Chicago's 77 community areas included locations that offered programs. However, there was variability between communities. Communities with the highest abundance of locations were clustered around the vertical middle of the city (figure 1a). Stakeholders noted this was possibly due to the city's public transportation system and driving infrastructure which make it notoriously difficult to move east to west and to cross the vertical midline, separating the north and south sides. Similar maps with comparative abundance of providers were created to engage stakeholders in conversations about the human capital related to OST within and flowing into community areas. Maps, importantly, encourage stakeholders to take not just a deficit perspective on historically marginalized communities, but an asset model that sees richness of opportunity and assets using these alternative indicators.

Availability of opportunities

Looking at program content areas can help reveal yet another measure of learning landscapes, yielding portraits of communities who may have valuable knowledge or depth of experiences in particular areas. It can also drive conversations about what is offered in reality compared to what is desired, including how it matches youth interests and community perceptions about what their youth need in informal learning spaces outside of school time. Figures 1b & 1c show counts of programs in two different content areas by community. While both are present in community areas distributed throughout the city, the concentration of distribution looks different.

Coverage is related to historical infrastructure and intentional funding strategies, recognized by stakeholders who act as interpreters. One example is the equitable distribution of Chicago's parks, and physical infrastructure stemming from community-driven legislation for regional parks commissions in the late 1800s. Today the distribution and abundance of sports is tightly connected to the system (in our data, park sites accounted for 97% of sports programming reaching 75 communities). Another example is the distribution of computational opportunities. Although depth of coding opportunities is significantly less than sports, the breadth of communities in which computational opportunities are offered is tied to library infrastructure and research-practice partnerships formed and funded in the past few years to create a community of practice around coding in libraries. In our data sample, 45% of the programs classified as *coding* were located in public libraries, a significant change from earlier analysis when these opportunities were tied to universities clustered downtown (Pinkard et al., 2016). These visible infrastructure patterns and changes over time show how changes in policy and collaborative interventions directly impact learning landscapes and how successes and opportunities can be made visible to stakeholders.

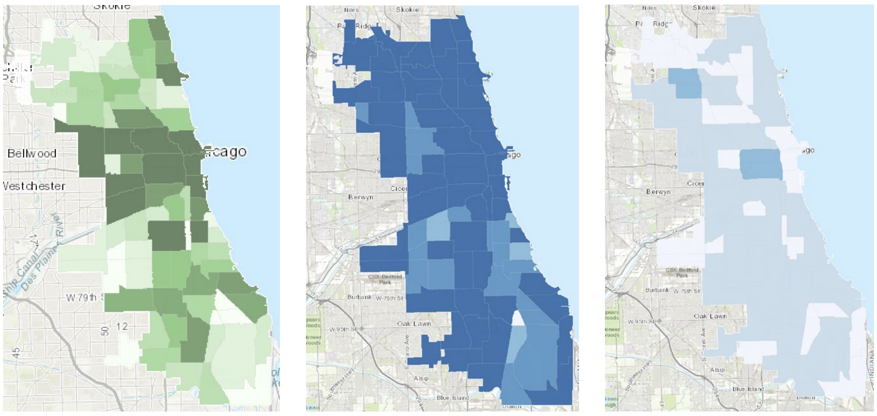

Figure 1. (a) Counts of unique *learning hubs*, and *density of programs* in the content areas of: (b) Sports and (c) coding and computational thinking (for all three maps, darker colors indicate higher counts)

Discussion and invitation

In this paper, we articulate the need for more approaches and frameworks to look at learning ecosystems at a macro level and share our collaborative multi-year effort to work at this scale. Our development of a citywide data system around OST opportunities and collaboration with stakeholders in the data collection (e.g., providers entering program data and metadata) and interpretation (through citywide and community meetings) is supporting conversations toward actionable design to (re)allocate resources for more equitable distribution and youth participation. Stakeholders can interpret patterns to consider where to offer (providers), invite (community leaders), study (researchers), or fund (city and philanthropic organizations) programming. We invite the community to utilize our platform, frameworks, and methods to support OST providers and decision-makers interested in reimaging their community's opportunity landscape. We consider this to be an ideal time for the learning sciences to expand the scope of study to a macro level in support of building a more just society.

References

Akiva, T., Delale-O'Connor, L., & Pittman, K. J. (2020). The Promise of Building Equitable Ecosystems for Learning. *Urban Education*, 0042085920926230.

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective. *Human Development*, *49*(4), 193–224. doi:10.1159/000094368

Barron, B., Gomez, G., Pinkard, N., & Martin, C.K. (2014). *The Digital Youth Network: Cultivating digital media citizenship in urban communities*. Cambridge, MA: MIT Press.

Ching, D., Santo, R., Hoadley, C., & Peppler, K. (2015). On-ramps, lane changes, detours and destinations: building connected learning pathways in hive NYC through brokering future learning opportunities.

Erete, S., Dickinson, J., Martin, C., Bethune, A., & Pinkard, N. (2020). Community Conversations: A Model for Community-Driven Design of Learning Ecosystems with Geospatial Technologies. In Gresalfi, M. and Horn, I.S. (Eds.), *14th International Conference of the Learning Sciences 2020, Volume 3* (pp. 1629-32).

Hect, M. & Crowley, K. (2019). Unpacking the learning ecosystems framework: Lessons from the adaptive management of biological ecosystems, *Journal of the Learning Sciences*, doi: 10508406.2019.1693381

Ito, M., Gutiérrez, K., Livingstone, S., Penuel, B., Rhodes, J., Salen, K., Schor, J., Sefton-Green, J., Watkins, C. (2013). Connected learning: An agenda for research and design. BookBaby.

Pinkard, N., Penuel, W. R., Dibi, O., … (2016). Mapping and modeling the abundance, diversity, and accessibility of summer learning opportunities at the scale of a city. Paper presented at the AERA, Washington, DC.

Pinkard, N. (2019). Freedom of Movement: Defining, researching, and designing the components of a healthy learning ecosystem. *Human Development*, *62* (1/2), pp. 40-65.

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From "Uh oh" to "I'm Curious If": Changes in Teachers' Stance over Time

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Abstract: If teachers are to adapt lessons based on students' ideas, they must first make sense of students' ideas. In fact, a range of research has shown the importance of teachers taking an interpretive stance when discussing students' thinking in order to position teachers to promote opportunities for students' learning. Here we look at the extent to which teachers developed an interpretive stance toward students' mathematical ideas when tagging moments of classroom video in an online system. We also examine key characteristics of teachers' interpretive tags and shifts in the frequency in which these characteristics appeared in teachers' interpretive tags over time.

Background

Effective teaching requires close attention to students' ideas in order to make in-the-moment decisions that are responsive to students' strengths and needs (Richards et al., 2020). A range of research suggests that the development of teachers' ability to notice can help teachers effectively navigate this challenge during instruction (Sherin et al., 2011). Furthermore, video-based professional development has been successful in supporting teachers in learning to notice (Erickson, 2011; Sherin, 2007). In previous work, we found that a video annotation tool, what we refer to as the "tagging tool," supported teachers in attending to students' mathematical thinking while engaging with video artifacts (Larison, et al., 2019). In particular, teachers became more attuned to students' thinking over time while using the tool. Here, we expand that work by exploring changes in *how* teachers made sense of students' mathematical thinking as they noticed their thinking more routinely over time.

Examining how teachers notice has contributed nuanced understandings of teacher thinking and learning. When teachers notice they use varied lenses that influence how they interpret what they observe (Sherin & Russ, 2014). For example, when teachers notice students' thinking, they may do so from a deficit-orientation, searching for how to fix mistakes or fill "gaps," while overlooking strengths and logic in students' ideas (Jilk, 2016). Similarly, teachers tend to notice complete and coherent thinking and have more difficulty noticing students' thinking-in-progress (Diamond et al., 2018). Recent studies have shown that wider-held deficit ideologies along the lines of race and gender can also mediate teachers' noticing (Adiredja, 2019; Louie, 2018; Shah et al., 2020). These studies suggest that it may be particularly difficult for teachers to notice rich and varied types of student thinking, especially those that do not align with their expectations or that are in tension with their implicit biases. Both what teachers notice and how they notice set the stage for how they respond, and whether and how opportunities for learning are opened for students.

One approach to examining how teachers analyze classroom interactions involves characterizing the stance teachers apply in this context. By stance we refer specifically to whether teachers *describe*, *evaluate*, or *interpret* what they notice (van Es & Sherin, 2008). If we believe that students' thinking is the foundation from which teachers should adapt lessons, then we must better understand how teachers make sense of students' varied ways of thinking. For instance, we can examine how teachers seek to understand students' thinking that is not yet clear to them, or that perhaps that challenges what they expect to see and hear. Of particular importance is the assumption that when teachers seek to interpret, rather than evaluate or describe what they see and hear, they are actively working to make sense of what might not be initially obvious to them. In this study, we explore the stance teachers take specifically in discussing elementary students' mathematical thinking in classroom videos and ask three interrelated questions, (a) When using a tagging tool to mark moments of students' thinking in video, how did teachers' stance change over time? (b) What were characteristics of teachers' interpretive tags? And (c) How did teachers' interpretive tags shift over time?

Methods

The data from which we draw come from a six-week online professional development course adapted from Lomax and colleagues (2017). One goal of the course was to support teachers in strengthening their skills in noticing student mathematical thinking when watching and reflecting on their own and their peers' videos of instruction. Ten K-2 teachers from a suburban Midwestern school district participated in the course. Each week, teachers were asked to try a practice or routine designed to engage students in mathematical argumentation, video-record their lesson, and trim and upload a clip of their video to the platform to share with peers. Here we investigate teachers' use of the tagging tool to engage with videos.

Teachers were prompted to notice and mark interesting moments of students' mathematical thinking in their own and one another's videos using a tagging tool. The tool was integrated with the video itself, and teachers could press a button to pause the video at any moment. Doing so would pause the video and open a text box indicating the moment at which the video was paused, allowing teachers to make a note, or "tag," and then resume the video.

To analyze contributions teachers made using the tagging tool, we first segmented tags into idea units (Jacobs & Morita, 2002) which were then coded along the dimensions of actor, topic, and video-based. Each tag unit in which actor was coded as *student*, topic was coded as *mathematics*, and video-based was coded as *yes* were further defined as SMTV (students' mathematical thinking related to the video) tag units and serve as our variable of interest (n= 200). Next we coded the stance of all SMTV tag units as either describe, evaluate, or interpret. We characterize a tag unit with an interpretive stance as one in which the teacher sought to make an inference or hypothesis about what she observed in the video (van Es & Sherin, 2008), or explicitly surfaced a question or confusion. We believe that the latter part of our definition is important to capture how teachers grapple with the moments that are in tension with or different from their expectations. Of the 200 total SMTV tag units, 84 were coded as interpretive.

Finally, we used a bottom-up approach to coding (Miles et al., 2014) and a constant comparison method (Glaser & Strauss, 1967) to identify characteristics of teachers' interpretive tag units that were not captured by the interpretive stance code alone. In particular, we examined the ways in which teachers engaged with students' thinking as they attempted to make sense of what they noticed. This resulted in the identification of four approaches to interpreting students' mathematical thinking. The 84 interpretive SMTV tags were then coded along these four approaches, with 5 tags coded as "other." We also examined teachers' use of the four approaches over time.

Findings

We found that over time the teachers generally enacted a more interpretive stance when noticing students' mathematical thinking in videos (see Figure 1). In week 1 of the course, only 14% (3/22) of teachers' SMTV tag units took an interpretive stance. In week 2, interpretive tag units accounted for 31% (12/39) of SMTV tags. By week 3, 51% (34/67) of SMTV tag units were coded interpretive. The proportion of interpretive SMTV tag units decreased slightly in week 4, to 47% (34/72), yet remained significantly higher than in weeks 1 and 2 of the course.

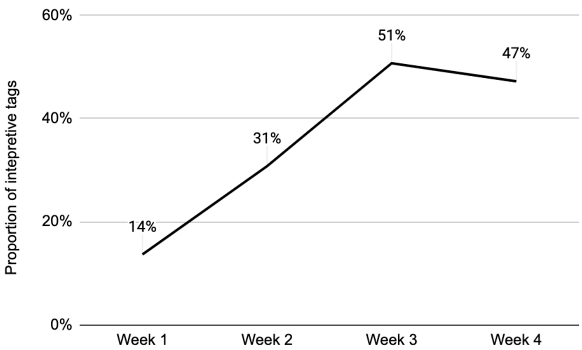

Figure 1. Percent of SMTV tag units coded as interpretive stance over time

Analysis of the nature of teachers' interpretive tag units resulted in the identification of four characteristics: fascination, curiosity, imagination, and hesitancy (see Table 1). Interpretive tag units that involved fascination were specific about what aspect of students' thinking was interesting or included inferences about why students knew, said, or did something. For instance, in a video of students solving "2 + 3 = __ + 1," a teacher tagged, "Here she is trying to rearrange the equation. She thinks that the equal sign should go after the 2 + 3 + 1. That's how she is getting to box being 6." Here, the teacher suggested that the student thought the blank space equaled six because she was trying to add 2, 3, and 1, rather than solve to make both sides equal.

When teachers' interpretive tag units were characterized as curious, they indicated that students' thinking challenged their own thinking or expectations, or surfaced an unresolved or rhetorical wondering. For instance, a teacher tagged, "I was mad the video ended... I'm curious if she then understood why 6 was not the correct answer." This tag makes clear that the teacher was unsatisfied by what she saw in the video and wanted to know more about the situation and what became of the student's thinking. Often tags that display teachers' curiosity explicitly included phrases like "I'm curious…" and "I wonder…" Further, teachers often made explicit when the things students knew, said, or did that did not align with what they were expecting.

Sometimes teachers' interpretive tag units were characterized as imaginative. In these cases, teachers considered moments prior to the video that were not visible, or a possible future moment(s). For example, a teacher noticed, "He recognizes that both sides of the equal sign have to be 'the same numbers,'" then subsequently imagined, "I wonder what they would think if they were given the equations with letters." Here, the teacher drew from what happened in the video to think about a specific, imagined future.

Finally, we found that a portion of teachers' interpretive tags were hesitant in nature. That is, teachers conveyed their understanding of students' thinking in tentative ways. For instance, a teacher tagged, "I had to re-watch this several times to understand why she put a one in the box. I think she was trying to express that the expression is counting on toward 7." The teacher explicitly notes that she was unsure of what was going on and therefore re-watched the video. Seemingly still unsure, she notes "I think she was trying to express…" as she interprets the students' thinking. A single interpretive tag could be coded as relating to more than one of these aspects.

Table 1: Characteristics of teachers' interpretive tags.

	Definition	**Examples**
Fascinated	Teachers focused on what they found interesting about student thinking or their inferences about why students thought what they did.	I was really intrigued by her thinking here. She is confident that this is incorrect because of how the equation is backwards.
Curious	Teachers indicated that students' thinking challenged their own thinking or expectations, or surfaced an unresolved or rhetorical wondering.	This explanation was a surprise to me since we talk about doubles + 1. He obviously understands making a group of ten and then counting on. He challenged himself without me asking him to.
Imaginative	Teachers considered moments prior to the video that were not visible, or a possible future moment(s).	…It's so interesting how one student sees a cupcake and the other a hexagon. *I wonder about how that translates to the way they see other things in the real world.*
Hesitant	Teachers conveyed their understanding of student thinking in tentative ways.	I was really excited when she said it was like two equations stuck together. *I thought that maybe she was seeing the equal sign in the middle and that the two sides should equal the same thing.*

When we looked closely, we found shifts in the appearance of these features in teachers' interpretive tags over time (see Table 2). Across all four weeks, the teachers' interpretive tags reflect their fascination with students' thinking. Over time, however, they became increasingly curious, imaginative, and hesitant in interpreting students' mathematical thinking. In part, this may be due to the increased number of interpretative tags that the teachers made leading to more variety in their interpretations. Yet in addition, we think these findings suggest that as teachers more routinely interpreted students' thinking using the tagging tool, teachers also routinely engaged with students' thinking in more nuanced ways.

Table 2: Frequency of characteristics of teachers' interpretive tags over time.

	Week 1	**Week 2**	**Week 3**	**Week 4**
Total interpretive SMTV tags	**3**	**12**	**34**	**34**
Fascinated	67% (2)	58% (7)	68% (23)	59% (20)
Curious	0% (0)	0% (0)	18% (6)	29% (10)
Imaginative	0% (0)	25% (3)	9% (3)	24% (8)
Hesitant	0% (0)	8% (1)	18% (6)	18% (6)
Other	33% (1)	8% (1)	6% (2)	3% (1)

Discussion and implications

In our analyses, we noted three main findings. First, teachers' SMTV tag units became more interpretive over time. This aligns with prior work that showed that teachers can learn to interpret student thinking as they attend to students' comments and ideas via video. Furthermore, related work (Walkoe, et al., 2020) suggests that a tagging tool such as the one used here may have aided the teachers focusing on sense-making around the students' thinking in the videos. Our second finding elevates the nuance in teachers' interpretations in their SMTV tags. Teachers demonstrated four characteristics in their tags: fascination, curiosity, imagination, and hesitancy. While tags that focus on fascination with students' ideas were most common, we believe particular attention should be paid to the other approaches. In particular, tags that reveal curiosity about and hesitancy towards student thinking may reflect teachers becoming more attuned to the ways that students' thinking surprises them or raises questions for them. This sense of oneself as a teacher-learner has been shown to be a powerful mechanism for change in teacher practice. Future work will examine the nature of the videos that seem to prompt these characteristics of tags. In addition, we will explore the potential value in sharing these approaches with teachers as they use the tagging tool.

References

Adiredja, A. P. (2019). Anti-deficit narratives: Engaging the politics of research on mathematical sense making. *Journal for Research in Mathematics Education*, *50*(4), 401-435.

Diamond, J. M., Kalinec-Craig, C. A., & Shih, J. C. (2018). The Problem of Sunny's Pennies: A Multi-Institutional Study about the Development of Elementary Preservice Teachers' Professional Noticing. *Mathematics Teacher Education and Development*, *20*(2), 114-132.

Erickson, F. (2011). On noticing teacher noticing. *Mathematics teacher noticing: Seeing through teachers' eyes*, 17-34.

Glaser, B., & Strauss, A. (1967). The discovery of grounded theory. *Weidenfield & Nicolson, London*, 1-19. Jacobs, Jennifer K., and Eiji Morita. "Japanese and American Teachers' Evaluations of Videotaped Mathematics Lessons." *Journal for Research in Mathematics Education* 33, no. 3 (May 2002): 154.

Jilk, L. M. (2016). Supporting teacher noticing of students' mathematical strengths. *Mathematics Teacher Educator*, *4*(2), 188-199.

Larison, S. Richards, J. & Sherin, M. G. (2019). *Analyzing designs for teacher online discourse around videos of primary students' mathematical thinking*. Proceedings of the forty-first annual meeting of the North American Chapter of the International Group for the Psychology of Mathematics Education. St. Louis, MO: University of Missouri.

Lomax, K., Fox, A., Kazemi, E., & Shahan, E. (2017). *Argumentation in Mathematics*. An online course developed in partnership with the Teaching Channel.

Louie, N. L. (2018). Culture and ideology in mathematics teacher noticing. *Educational Studies in Mathematics*, *97*(1), 55-69.

Miles, M. B., Huberman, A. M., & Saldana, J. (2014). Qualitative data analysis: A methods Sourcebook. Richards, J., Elby, A., Luna, M. J., Robertson, A. D., Levin, D. M., & Nyeggen, C. G. (2020). Reframing the Responsiveness Challenge: A Framing-Anchored Explanatory Framework to Account for Irregularity in Novice Teachers' Attention and Responsiveness to Student Thinking. *Cognition and Instruction*, *38*(2), 116-152.

Shah, N., Herbel-Eisenmann, B., & Reinholz, D. (2020). Why Mrs. Stone Never Calls on Debra: A Case of Race-Gender Ideology in Practice.

Sherin, M. G. (2007). The development of teachers' professional vision in video clubs. *Video research in the learning sciences*, 383-395.

Sherin, M., Jacobs, V., & Philipp, R. (Eds.). (2011). *Mathematics teacher noticing: Seeing through teachers' eyes*. Routledge.

Sherin, M. G., & Russ, R. S. (2014). Teacher noticing via video. *Digital video for teacher education: Research and practice*, 3-20.

van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and teacher education*, *24*(2), 244-276.

Walkoe, J., Sherin, M., & Elby, A. (2020). Video tagging as a window into teacher noticing. *Journal of Mathematics Teacher Education*, *23*(4), 385-405.

Spatial Negotiation of Graffiti Artists: Pedagogical Actions in the Interest of Publicness

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Abstract: This paper examines pedagogical actions and events practices by graffiti artists in different parts of the world. We examined their work through the lens of public pedagogy and based the literature on street art and graffiti, in terms of how their pedagogical actions are always forming and evolving, demonstrating how public spaces could look and be experienced differently. We examined five graffiti artists' work using the digital records of their work and online interviews. We argue through the examples of graffiti artists' practices that our design of learning environments should work toward learners' becoming public that embodies notions of plurality and difference.

Introduction

Learning sciences scholars have been advancing knowledge about how people learn and how we design learning environments in formal and informal contexts. Most recently, numerous efforts were made to critically examine and address equity and justice in public education, and the learning sciences scholars continue to find what has been relatively neglected in our field (Erickson, 2021), including our space, publics, and civic engagement. In this paper, we propose to bring public pedagogy, which concerns "the public quality of human togetherness" and "actors and events becoming public" (Biesta, 2012, p. 693), into the conversations in the learning sciences by examining the work of graffiti and street artists. Public pedagogy is about emergent forming and evolving of the public sphere, sustaining plurality and difference of human experience and interpretations (Biesta, 2012; Schuermans et al., 2012). Art on the public spaces could specifically open up "new ways of seeing, feeling, experiencing, and describing the world" (Schuermans et al., 2012, p. 677). The arts in formal learning spaces have often been a subject of token integration for gaining learners' interest toward other disciplines, especially STEM (Science, Technology, Engineering, Mathematics) (Kim et al., 2019). In this paper, we hope to show how pedagogical actions and events could look like when we demonstrate concern for publicness.

Graffiti art and public pedagogy

Graffiti and street art can be considered a "tacitly sanctioned" expressive form (Pennycook, 2010) when the street art scene contributes to the narratives and life as part of the urban landscape to the eyes of the public. Some scholars and art educators made efforts to recognize and include graffiti as legitimate art form within art education (e.g., Christen, 2010; Eldridge, 2013; Pennycook, 2010; Hampton et al., 2013), to incorporate youth's and young adults' values, subcultures, and activisms as important aspects of their learning, such as hip-hop and graffiti subcultures (Gosine & Tabi, 2016). Graffiti and street artists' practices of resisting power and existing structure have the resemblance to pedagogical approaches with criticality: the practice of "a constant unveiling of reality" (Freire, 1970/2002, p. 81) through problematizing what seems natural or inevitable in our world (Giroux, 2011). In fact, graffiti and street artists create the subcultures that constantly disclose and problematize the politics of urban spaces. Biesta (2014) describes public pedagogy as the collection pedagogies in the interest of publicness, which are activist, experimental, and demonstrative. They are activist pedagogies by resisting the private sphere and creating alternative ways of being in public relationships in plurality; they are experimental pedagogies by generating numerous ways and outcomes of actions that emerge from their socio-cultural interactions; and they are demonstrative by showing the possibilities of doing things differently (Biesta, 2014; Cooper & Sandlin, 2019). In this paper, we explore how the work of contemporary graffiti and street artists demonstrates activist, experimental, and demonstrative pedagogies in the interest of publicness and how we might consider public pedagogy as part of our scholarship and practices.

The study

This paper examines the practices of five active graffiti and street artists as a phenomenological reflection (van Manen, 2003) of their lived experience. The second author led the study and started by contacting the artists through Instagram, which is the artists' popular means of sharing their work. Data was collected through written interviews to questions (e.g., What are some of the significant moments in your artistic journey?), Instagram chats and posts, and other websites. The analysis was focused on this phenomenon of the artists' claiming their presence and voice on the walls of their cities. The approach is interpretive as we reflect on their personal narratives, practices, and artifacts. We considered their shifts in practices, their use of space, and how they reconfigure and appropriate the urban space. In doing so, we uncovered how their interventions diversify, alter and destabilize the narratives of the visual urbanscape that is monopolised by establishments of authority (hegemonic values) and how their practice resembles public pedagogy. We chose artists who engaged in legal and/or illegal graffiti and practising in non-US cities for this paper. We also foreground the practices and views of female graffiti artists.

Findings: Spatial contestations and plurality of practices

The manifestation of graffiti is regarded as a sign of societal inequalities, it is indicative of contrasting perspectives of what urban space should be and its meaning is negotiated and disputed (Zieleniec, 2017). Drawing from Harvey (2001, 2007, 2012), Zieleniec (2016) argues that the neo-liberalist economic model that decides the planning of space in urban cities champions efficiency and uniformity, but suppresses diversity. Surveillance is also one of the features of the neo-liberalist approach to spatial and social control. Existing in conflict, graffiti is often positioned within the contested notion of "destruction vs creation" (Dovey et al. 2012, p.22). Young (2012) observed that in more extreme cases, this resulted in "over-criminalisation" (p.2) of graffiti artists being handed down with harsh penalties. SeronMoon, a legal female graffiti artist from Hatay, Turkey shares that: "*There are more dangerous things in the world. Terror, war, murders, hunger, migration etc. but everyone thinks our art is dangerous. It is too silly. Laws must protect poor people but it does not protect them. It protects walls only.*"

SeronMoon's views question the rationale of the laws against graffiti artists, wall ownership and the right to participate in contributing to the visual landscape of the city. Further, the visual noise generated by corporations' billboards and advertisements are produced without consulting the residents residing in the urban space (Pennycook, 2010). This exposes the extent of control that corporations have over the urban visual scape (Christensen & Thor, 2017). Law and policing can affect the act of graffiti writing. Xiang201 from Keelung, Taiwan shares his experiences that contravene the strict enforcement of laws that persecute graffiti artists: "*the police in Keelung are relatively lax in enforcing the law because they also understand the beauty of graffiti art, this is very magical. But in Taipei, it may legally limit the creative space of graffiti artists, and I think it affects the artists who want to convey the meaning… I'm very lucky. I've met the police many times but they only told me to stop or let me continue to create.*"

Figure 1. PESKO's graffiti murals.

Xiang201 prefers to work on legal walls as it affords him the time to perfect his work without the pressure to complete his work quickly. In a study by Halsey and Young (2002), city councils demonstrating leniency allowing graffiti artists to work on local walls offered a bridge for them to communicate with the local community through their artistry. PESKO from Sfax, Tunisia is a typography street artist who juxtaposes graffiti-influenced lettering with typography advises that permission is absolutely needed to paint on any walls in Tunisia. His unique lettering style (see Figure 1) is a sharp and refreshing contrast to the drape and uniform architectural landscape that dominates north African cities. It may seem that legal graffiti is constrained by strict local regulations, but PESKO's creations do not conform to the aesthetics of a typical northern African city and transform the visual landscape populated with rectangular-structured buildings. There is no critical theme in PESKO's graffiti, but we see how his benign art adds to the city's visual narrative with bold and pastel palette along with peaceful messages.

Drawing from Lefebvre, Zieleniec (2016) argued that the inhabitants of streets have the right to the city's urban space, and that graffiti and street art show "the possibility of refashioning, recreating, reclaiming the city and the urban for people and not just for profit" (p. 4). PESKO's work demonstrates to the public how the city space could look different when embracing plurality of human actions (Biesta, 2012).

In emphasizing plurality in public pedagogy, Biesta (2012) suggested "[a]s soon as we erase plurality we deprive others of their actions and their freedom, and as a result we deprive ourselves of our possibility to act, and hence of our freedom" (p.688). Working on a very broad spectrum of materials and tools, Nemo, a Barcelona-based female graffiti artist who practises both lawful and unlawful graffiti shows that one need not be bound by the parameters established by those who set it. Nemo refuses to homogenize the urban space as well as the work of graffiti art. In the interview, Nemo mentioned, "*Graffiti is total freedom…I always avoid copying. I experimented a lot even if people couldn't understand me… I'm making my own DIY tools, combining ideas and get inspired by improvisation directly in the streets.*"

She tested and developed the graffiti-form using computer and video technology to project graffiti images on the wall, called graffiti mapping. Crossing over to the non-digital realm, she invented ways to create graffiti-tags (quick rendering graffiti artist's signature on street wall) using paint rollers and flip-flops to make imprints of her graffiti name on street surfaces (see Figure 2). Graffiti-tags are often produced by using markers, and Nemo contributed new techniques to the existing graffiti forms using banal items drawn from daily life. Through her experimental actions, she re-interprets how the graffiti-tag may be executed and manifest visually.

Figure 2. Nemo's walk tagging flip-flops.

Figure 3. Ladies on Wall group's graffiti mural painting.

Bunga, a female graffiti artist from Indonesia who now paints on legal walls, must deal with the disparaging comments from the graffiti community made up of men. She recalled that, *"one day I've found that my graffiti buddies are making fun of my endeavours searching my 'identity', I've been judged that my skill sucks but I've got lots of job and opportunities from it and they thought that I don't deserve that much. It hit me hard"* (Bunga, Interview 1). Male members within her graffiti circle have the assumption that, *"females can't do better artwork than males"* (Bunga, Interview 2). Working within this male-dominant subcultural art form, women are often met with biases that discredit their capabilities (Pabon, 2017). Bunga later started, "Ladies on Wall" (LOW) group (see Figure 3) to recruit women of Muslim and Hindu backgrounds to support them for graffiti mural painting skills. Not totally free from male criticism of their creations, the emergence of this legal female graffiti crew, however, signifies the aspiration to develop a system separate from an established one monopolized by men. Further, it acts as a competing voice that seeks to assert a spot in the urban space where women express themselves in solidarity. LOW group's street artwork shows their actions of becoming public (Biesta, 2012), practicing activist and demonstrative pedagogies of encouraging young women with artistic talent to express themselves and showing others in public new possibilities of being as religious women.

Discussion and conclusions

As urban spatial expressions, legal and illegal graffiti reflect multifaceted perspectives and practices as demonstrated by the graffiti and street artists in our paper. Working in different contexts, the artists navigated a complex terrain, most of them pushing boundaries implicitly or explicitly, contesting the obstacles that are constructed to subdue their voices. For instance, SeronMoon resisted and disputed the grounds of the law that persecutes graffiti artists who pursue to decorate city surfaces. Introducing new visual elements to the Tunisian cityscapes, PESKO paints graphic and calligraphic letterings on surfaces that clash and invigorate the space. Challenging the practice of graffiti, Nemo implemented new ideas using mundane objects like flip-flop sandals as a tool to execute graffiti tags. Operating in a patriarchal environment, Bunga led a collective effort for women artists to occupy the walls with their graffiti murals. Working in exceptional circumstances where authorities demonstrated leniency towards graffiti, Xiang201 experiences freedom to express and hone his craft to communicate with the public. These examples of graffiti artists' practices evince a world depicted by Biesta (2014) that centers on public pedagogy and plurality that serves the community, providing experimental, activist and demonstrative approaches to spatial and visual politics. The artists introduced in this paper might be practicing the same art form, sometimes prohibited and other times sanctioned. On the other hand, each of them engages in spatial negotiation differently within their own sociopolitical situations. In the interest of publicness, their pedagogical actions are deeply ingrained within their communities, while considering and challenging the existing power structures, hegemonic values, and dominant practices. We suggest that bringing public pedagogy into the conversations in the learning sciences is an important step in exploring how we might centralize publicness in our scholarship and practices.

References

Biesta, G. (2012). Becoming public: public pedagogy, citizenship and the public sphere. *Social and Cultural Geography*, *13*(7), 683–697.

Biesta, G. (2014). Making pedagogy public: For the public, of the public, or in the interest of publicness? In J. Burdick, J. A. Sandlin, & M. P. O'Malley (Eds.), *Problematizing public pedagogy* (pp. 15–25). Routledge.

Christen, R. S. (2010). Graffiti as a public educator of urban teenagers. In J. Sandlin, Jennifer A., Schultz, Brian D., Burdick (Ed.), *Handbook of public pedagogy: Education and learning beyond schooling* (pp. 233–243). Routledge.

Christensen, M., & Thor, T. (2017). The reciprocal city: Performing solidarity—Mediating space through street art and graffiti. *International Communication Gazette, 79*(6-7), 584-612.

Cooper, J., & Sandlin, J. A. (2019). Intra-active pedagogies of publicness: exploring street art in Melbourne, Australia. *Pedagogy, Culture & Society*, 1–23.

Dovey, K., Wollan, S., & Woodcock, I. (2012). Placing graffiti: Creating and contesting character in inner-city Melbourne. *Journal of Urban Design*.

Eldridge, L. A. (2013). An unselfish act: Graffiti in art education. *Art Education*, *66*(5), 21–29.

Erickson, F. (2021). Waldo, blind inquirers, and an elephant: Locating learning in social movements. *Journal of the Learning Sciences.* Advanced online publication.

Freire, P. (1970/2002). *Pedagogy of the oppressed*. Continuum.

Giroux, H. A. (2011). *On critical pedagogy*. Continuum.

Gosine, K., & Tabi, E. (2016). Disrupting neoliberalism and bridging the multiple worlds of marginalized youth via Hip-Hop pedagogy: Contemplating possibilities. *Review of Education, Pedagogy, and Cultural Studies*, *38*(5), 445–467.

Halsey, M. and Young, A. (2002). The meanings of graffiti and municipal administration. *Australian and New Zealand Journal of Criminology* *35*(2), 165–186.

Hampton, R., Dare, Hyke, & Juice. (2013). Graffiti and art education: "They don't understand how I feel about the funk." *Art Education*, *66*(5), 51–55.

Jurow, A. S., & Shea, M. (2015). Learning in equity-oriented scale-making projects. *Journal of the Learning Sciences*, *24*(2), 286–307.

Kim, B., Rasporich, S., & Gupta, D. (2019). Imagining the sustainable future through the construction of fantasy worlds. In P. Sengupta, M. Shanahan, & B. Kim (Eds.), *Critical, transdisciplinary and embodied approaches in STEM education* (pp. 61–82). Springer.

Kincheloe, J. L. (2008). *Knowledge and critical pedagogy*. Springer.

Lefebvre, H. (1974/1991). *The production of space*. Blackwell.

Pabón, J. N. (2016). Ways of being seen: Gender and writing on the wall. In J. I. Ross (Ed.), *Routledge handbook of graffiti and street art* (pp. 78-91). Routledge.

Pennycook, A. (2010). Spatial narrations: Graffscapes and city souls. In A. Jaworski & C. Thurlow (Eds.), *Semiotic landscapes: Language, image, space* (pp. 137–150). Continuum.

Schuermans, N., Loopmans, M. P. J., & Vandenabeele, J. (2012). Public space, public art and public pedagogy. *Social and Cultural Geography*, *13*(7), 675–682.

van Manen, M. (2003). *Writing in the dark: phenomenological studies in interpretive inquiry*. The Althouse Press.

Young, A. (2012). Criminal images: The affective judgment of graffiti and street art. *Crime, Media, Culture*, *8*(3), 297–314.

Zieleniec, A. (2016). The right to write the city: Lefebvre and graffiti. *Environnement Urbain / Urban Environment*, *10*. http://journals.openedition.org/eue/1421

Scientific Modeling Practices Through Perspective Taking in a Mixed Reality Embodied Learning Environment

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Abstract: We present a study for first grade students engaging in Science through Technology Enhanced Play (STEP) – a mixed reality embodied learning environment which tracks student movements as they act as honeybees collecting nectar. We attend to how students take up first and third-person perspectives as they work to communicate the location of flowers to their peers through the design of a "waggle dance" and collaboratively make sense of agent behavior in complex systems through embodied modeling. We discuss patterns in students' perspective-taking and its intersection with iterative modeling practices and report on how facilitating these shifts allows students to be positioned as the designers and subjects of their own models while fostering the synthesis of abstract and concrete ideas.

Keywords: perspective-taking, modeling, mixed-reality, science education

Introduction

Developing scientific models is a core practice in K-12 science education. In previous research, we've explored how embodied play can serve as a tool to help young children develop these scientific models (Tu et al., 2019). However, we often see gaps and obstacles in how students conceptualize elements of their models across perspectives and contexts. For instance, we notice that students often struggle to make associations between their movements and the abstract concepts they are representing upon embodying their dances. Therefore, in this research, we use two episodes to illustrate the ways in which students embrace first and third-person perspectives within their modeling and sense-making to answer the following three research questions:

1. What does the taking up of first and third-person perspectives accomplish for students?
2. What leads students to shift between perspectives?
3. How does perspective-taking foster students' engagement in modeling practices?

Theoretical framework

We build on sociocultural theories of learning, which note the importance of social and interactional contexts for shaping and defining learning (Danish & Gresalfi, 2018). Researchers have noted that the ways individuals position themselves or are positioned within social contexts can influence how they interact, how they perceive the world around them, and what they take out of the social situation (Goodwin, 2017). In our work, we also build on theories of embodied cognition, which note the important role of the body in learning. A sociocultural approach to embodied cognition combines these two strands, noting how physical movement can simultaneously support cognition and perception, while also drawing upon and helping to reify the social context in which it occurs (Danish et al., 2020). In the present study, we are interested in how students' draw on these shifting embodied social perspectives while creating scientific models, to better understand how embodiment may support modeling in unique ways.

The present study builds on our prior work on the Science through Technology Enhanced Play (STEP) project (Danish et al., 2020). In STEP, students collaboratively develop an embodied model of a phenomena; in this case, student are modeling how bees communicate the location of flowers with nectar to other bees in the hive using a "waggle dance" as they collect nectar. Students act out how they believe bees will behave as the STEP software environment tracks their movement using computer vision. Their movement is used as input for the computer simulation and students see a honeybee avatar on a shared screen which moves virtually as they move physically.

As students embody the bees, they are engaging in the process of creating and refining models of how honeybees collect nectar. While modeling is an underutilized practice in elementary education contexts, research has demonstrated that such practices have merit for young learners' science education (Louca & Zacharia, 2015). We use Fretz et al.'s (2002) modeling practices taxonomy to conceptualize modeling as an iterative process of planning, searching, synthesizing, analyzing, explaining, and evaluating. These classifications, alongside understandings of modeling and play that define each as rule-based activities and position play as means to introduce scientific modeling to young learners (Tu et al., 2019), offer a theoretical grounding for understanding how students collectively negotiate meanings in practice and understand the underlying phenomena.

In the context of an embodied model using STEP, students coordinate their motion as part of the modeling process, shifting between roles as they move from a first-person perspective of embodying a bee, to a third-person perspective of describing how bees behave. We know that first and third-person perspectives utilize the body in distinct ways (Stec, 2012); however, it is less clear how moving between these viewpoints be conducive for model development and revision, particularly in a fully embodied context such as STEP. The present analysis aims to build on this prior literature by examining how students develop and shift between these two viewpoints while creating embodied models, and how this process supports their engagement with the underlying phenomenon being studied.

Methods

Participants

Twenty-three first grade students from a Mid-western classroom in the United States participated in an eight-session activity to learn about honeybee nectar collection from a systems perspective. Each session consisted of a 30-minute STEP activity where students explored how honeybees collect nectar by embodying the role of honeybees within the STEP environment. While students physically moved around the classroom, the STEP system tracked their motion as input into a computer simulation that was projected at the front of the room. Thus, as a student moved to the front of the room, they might see their bee avatar moving away from the hive and towards a flower, helping them explore how bees collect nectar from the flowers. All classroom activities with the simulation projected on the screen were videotaped for further video analysis.

Analysis

In this study, we attended to how shifting between first and third-person perspectives foster students' science modeling practices in the STEP environment (Danish et al., 2020). We applied Mediated Discourse Analysis (MDA, Scollon, 2001) to identify students' perspectives in video data, and to construct explanations for how these perspectives supported their modeling practices. Our team co-watched videos of students using the STEP environment while iteratively constructing and refining our account of how varying perspectives were present and what they accomplished for students. We then worked to identify key characteristics of first and third-person perspective–taking within the dataset.

While taking up a third-person perspective, students 1) used iconic gestures to communicate ideas to their peers, 2) oriented their attention towards facilitators, and 3) made small modifications to the design through a back-and-forth with facilitators or peers. This often takes the form of a cyclical questioning and revision of designs by facilitators and students. Moments of first-person perspective taking manifested as students' 1) full-embodiment of the target agents (in this case, bees), 2) attending towards one's own movements as represented on the projection, and 3) immediate modifications of designs triggered by real-time failure. Using these markers, we revisited these episodes to determine if and how these perspectives supported distinct modeling practices. We coded each group participating in the waggle dance activity using Fretz et al.'s (2002) modeling practices coding scheme in addition to isolating moments of first and third-person perspective taking using the criteria above. We present two episodes to illustrate how students shift between perspectives in response to the needs of the moment.

Findings

Question 1: What does perspective-taking accomplish for students?

Students engaged in collective, iterative design and refinement of their models. They typically started an episode with a question such as: "how do bees communicate to each other about nectar quality so that they know to visit the best flowers?" and then iterate between discussing and testing their theories.

The planning phase of the activity involves students adopting third-person perspectives as they propose an initial design that is challenged as facilitators and peers introduce new pieces of information. We see the collection and merging of new and old information into a single design as students define and articulate the core requirements and constraints. For example, when trying to understand how bees might indicate nectar quality in their "waggle dance," Abigail and her peers planned a dance that would include walking in a circle. The plan included discussion with peers, references to prior knowledge and naïve understandings, and the interweaving of novel design considerations by facilitators

Students adopted a third-person perspective while discussing how bees might behave in the model, allowing for valuable back-and-forth between students and facilitators. When ready to embody and demonstrate their ideas publicly, students shifted into a first-person perspective. This exploration allowed students to test and evaluate the efficacy of their dances while being exposed to new challenges to their design. For example, when Abigail embodied her proposed dance by walking in a large circle, and a constraint of her design became apparent to the group: the inability to use the full classroom space while one's bee must remain stationed in the simulated hive. This realization allowed for the final iteration of the dance: the replacement of the large circles with spinning in place. This design satisfied all the requirements of the waggle dance and the concerns raised by observers.

Question 2: What leads to students shifting between perspectives?

Students routinely adopted third-person perspectives early in the lesson as they planned their dances. Further analysis illustrated that students' shifts to first-person perspectives were prompted by circumstances in which teaching, clarification, testing, and/or evaluation of the design was needed. Earlier in Abigail's episode, the discovery that her design cannot be sufficiently conveyed through iconic gesture alone prompts a shift into a fully embodied first-person perspective. Abigail's design becomes a public representation of her naïve assumptions around the waggle dance and opportunities for iterative feedback.

Students frequently shift back to a third-person perspective when they acknowledge the need to debug and revise their designs based on newly realized constraints, requirements, or shortcomings of the original design. In a separate episode, Camille – a dancing student – attempted to communicate the location of the target flower to an observing student – Josie. Camille's first demonstration resulted in a failed attempt by Josie to locate the flower, prompting a revision of the dance to account for this miscalculation. Josie returned to 'the hive' and shifted into a third-person perspective to narrate and represent Camille's second performance via gestures. This second attempt was successful.

Question 3: How does perspective-taking foster students' modeling practices?

To understand students' perspective-taking within the context of scientific modeling, we coded episodes using Fretz et al.'s (2002) modeling practices coding scheme which decomposes modeling processes into *planning*, *searching* (for information), *synthesizing*, *analyzing*, *explaining*, and *evaluating* practices. As illustrated in Table 1, we see patterns in which modeling practices were present and were leveraged. Earlier in Abigail's episode, she drew upon naïve understandings of bee anatomy to develop an initial draft of the dance, defended her design to critical observers, but eventually conceding and produced a second iteration of her plan based on newly gathered information. This episode is representative of a larger pattern of perspective-taking intersecting with student engagement in scientific modeling practices; we see third-person perspectives promoting *planning*, *searching*, and *evaluating* within iterative model design.

Camille and Josie's episode exemplifies how the first-person perspective can be leveraged to instigate other scientific modeling practices – namely *analysis* and *evaluation*. Camille's first version of the dance was only revealed to be inadequate and in need of revision when Josie fails to locate the flower while embodying in a first-person perspective. This prompts Camille to reassess their dance and revise based on inconsistencies between her and Josie's interpretations of her instructions.

Table 1: summarizing affordances of perspective-taking & shifting for scientific modeling practices

	First-Person	**Third-Person**	**Cycling Between Both**
What does this perspective afford students?	Testing & Evaluation ▪ *revealing new design requirements & constraints* ▪ *making naïve understandings visible through direct action*	Explanation & Revision ▪ *defining requirements & constraints* ▪ *allowing for critical reflection and iteration*	Synthesization ▪ *bridges abstract and* ▪ *concrete concepts to develop a single design*
What produces shifts to this perspective?	Opportunities to *embody*, *demonstrate*, *teach*, *test*, and *clarify*	Opportunities to *design*, *debug*, and *revise*	

	First-Person	Third-Person	Cycling Between Both
What modeling practices are fostered?	Analyzing Evaluating	Planning Explaining Searching	Synthesizing

In these episodes, we see students engage in two sets of practices that both utilize and are prompted by the adoption of first and third-person perspectives during embodied modeling activities (see Table 1). The generation of ideas, the explanation and justification of those ideas, and the gathering of new information is made possible by students embracing third-person perspectives while first-person perspectives mediate the analysis and evaluation of those ideas. Furthermore, it is when these two perspectives are cyclically leveraged together that Fretz et al.'s (2002) sixth modeling practice, *synthesization,* is present. During this synthesis, students' theoretical solutions can merge with practical findings hereby bridging the abstract with the concrete. We argue that the sense-making embedded in this synthesization both produce and is produced by students' shifts between perspectives.

Discussion

The use of modeling practices through the lens of perspective-taking is understudied. We provide this analysis as support for the leveraging of third-person perspective during model generation and first-person perspectives during evaluation. Furthermore, by facilitating shifts between perspectives we might offer students opportunities to take on the role of designer as they draw upon observer critiques during iteration and position them as the agents within their own simulated and experimental models. The abstract and hypothetical that is negotiated amongst students during third-person generative phases of design is made concrete through direct action and immediate feedback during the first-person moments of evaluation while the frequent transitions between the two perspectives foster a synthesis of ideas and practices. Students socially negotiate understandings of agent behavior within complex systems, author models of these understandings, and experientially evaluate them firsthand.

References

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: A sociocultural framework for embodied cognition. *International Journal of Computer-Supported Collaborative Learning*. https://doi.org/10.1007/s11412-020-09317-3

Danish, J. A., & Gresalfi, M. (2018). Cognitive and Sociocultural Perspectives on Learning. In *International Handbook of the Learning Sciences* (pp. 34–43). Routledge. https://doiorg.proxyiub.uits.iu.edu/-10.4324/9781315617572-4

Fretz, E. B., Wu, H. K., Zhang, B., Davis, E. A., Krajcik, J. S., & Soloway, E. (2002). An investigation of software scaffolds supporting modeling practices. *Research in Science Education*, *32*(4), 567-589.

Goodwin, C. (2017). *Co-operative action.* Cambridge University Press.

Louca, L. T., & Zacharia, Z. C. (2015). Examining learning through modeling in K-6 science education. *Journal of Science Education and Technology*, *24*(2-3), 192-215.

Tu, X., Danish, J., Georgen, C., Humburg, M., Davis, B., & Enyedy, N (2019) Examining how scientific modeling emerges through collective embodied play. In Lund, K., Niccolai., G., Lavoue, E., Hmelo-Silver, C., Gwen, G., & Baker, M., (Ed.), *A Wide Lens: Combing Embodied, Enactive, Extended and Embedded Learning in Collaborative Settings: The 13th International Conference on Computer Supported Collaborative Learning* (Vol. 2.). Lyon, France: The International Society of the Learning Sciences.

Scollon, R. (2001). *Mediated discourse: The nexus of practice.* London: Routledge.

Stec, K. (2012). Meaningful shifts: A review of viewpoint markers in co-speech gesture and sign language. *Gesture*, *12*(3), 327-360.

International Society of the Learning Sciences

Teacher Frameworks about Students' Capacity to Engage in Science Discussions

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Abstract: How do teachers conceptualize the capacity of their students to engage in rigorous science discussions? Through a comparative case study we examine two contrasting cases that provide insight into the interpretive schemas that teachers adopt, which shape instructional practice. We use narrative analysis to examine teacher narratives around salient moments in science discussions. Our findings show that the frameworks that teachers bring to discussion shape what they notice about student contributions and thinking, their reasoning about what they notice, and how to support student learning. We use these findings to inform iterative design of personalized teacher professional development on facilitating science discussions.

Introduction

In this paper, we examine the *frameworks* (or schemata of interpretation) that undergird teachers' pedagogical reasoning about facilitating science discussions (Goffman, 1974). Teachers play a critical role in shaping *opportunities to learn* through the ways in which they orchestrate classroom discussions. How teachers use talk in the classroom shapes what counts as knowledge, marks how it is constructed and who has the right to participate in that process (Clarke, 2015).

While there's a growing body of evidence on the benefits of carefully guided subject matter discussions on student learning and conceptual development (c.f. Resnick, Asterhan & Clarke), it is rare to find this kind of pedagogy in classrooms that serve black, indigenous, people of color (BIPOC) and students from low-income backgrounds (McNeill, Pimentel & Strauss 2013). Some studies have documented the relationship between teachers' beliefs about students' capacity and their speculative reasoning and decision making around how they would orchestrate science discussion as a consequence (e.g., McNeill et al, 2013).

In the present study, we focus on teachers' memory, their recollections about facilitating science discussions, and in doing so, we excavate these memory traces to examine the ways in which teachers *code* these moments of facilitating science discussion. It is through a systematic discourse analysis of how teachers code salient moments in discussion that we seek to better understand the schemas that inform what teachers notice about facilitating discussion, and how these noticings relate to their orchestration of them. This study is situated within a longitudinal design-based research project, thus we seek to generate actionable insights that can be used to ground co-design and ongoing professional development with teachers.

Conceptual framework

We are interested in what teachers *notice* (van Es & Sherin, 2008) about practice as an indicator of their professional vision (Goodwin, 1994). More specifically, we are interested in what teachers notice as objects to make-sense of, what we refer to as *pedagogical reasoning*. Pedagogical reasoning is defined as the sensemaking processes that teachers are constantly engaged in while teaching (Shulman, 1987). This includes planning (e.g., how to uncover student thinking and foster sensemaking about concepts), facilitating (e.g., helping students to reason about each others' thinking in discussion), assessing in real time (e.g., making sense of what students currently understand based on what they say, and there their thinking may still be nascent), and reflecting with rationale (e.g., what objects seem to be mediating understanding and what you can do to further students' conceptual development). We conceptualize pedagogical reasoning as reasoning that is mediated by institutions, histories, beliefs, knowledges and experiences.

In the present study, we examine the ways in which teachers think about practice, specifically facilitating science discussions. Central to our design is the notion that teacher practice is not simply an operation on canonical knowledge and pedagogical repertoires, and learning not simply a linear pathway between PD and practice. Rather, we conceptualize teaching and teacher learning as dynamically and recursively shaped by institutions, histories, beliefs, knowledges, and experiences (Clarke & Hollingsworth, 2002). Thus, in our work to understand teacher cognition and conceptualize how we support its development through PD, we seek to trace the interconnections between the ways teachers conceptualize and enact practice.

Following Goffman, we refer to coding as the meaning ascribed to what is noticed and reasoned about (see Goffman, 1974). That is, coding is the classification schema that categorizes a student statement as "emergent thinking", a student's reasoning as "argumentation", a word as "a concept", a hand raised as "a request to participate", and a student idea as "correct". Frameworks, however, are the interpretive schemas that organize our experiences. In this sense, where pedagogical reasoning points to specific ways of reasoning that are tied to the profession of teaching, and coding points to the ascribed meaning giving to noticing and reasoning, a framework is the connective tissue that binds that reasoning--what teachers notice, the pedagogical reasoning about what is noticed, how that noticing *coded*, and then instructional decisions that derive from that noticing. Berland & Hammer note that how teachers frame practice, specifically engaging in science argumentation, informs the frameworks that students themselves take up (Berland & Hammer, 2011).

In what follows, we utilize these concepts to investigate the following questions:

(1) What are teachers' frameworks about facilitating science discussion?

(2) How do teachers' frameworks inform their a) reasoning and sensemaking about instructional decisions around facilitating discussions?

Methods

This study is situated within a longitudinal design-based research project, *ClassInSight*. The partnership is focused on secondary science teacher professional development (PD) on facilitating class discussions. Through iterative design cycles, we are co-designing a personalized app for teachers to notice and reflect on their discussion facilitation practice, and utilize these noticings and reflections to engage in deliberative goal setting around subsequent lessons.

Secondary science teachers from two school districts in Southern California are participating in the longitudinal PD study (n=22). Baseline narrative interviews were conducted with teachers prior to participating in PD to elicit their beliefs and practices around facilitating science discussions for student learning.

In this paper we report on the analysis of baseline interviews with teachers to drive our ongoing PD design work. We seek to understand the lenses through which teachers notice and reflect on how they orchestrate student thinking and conceptual development through science discussions. We posit that teachers' pedagogical reasoning and decision making are operating on and mediated by their interpretive schemas. Through examining teachers' interpretive schemas about facilitating student learning through science discussions, we can trace the perspectives that give shape to pedagogical moves, and instructional practice.

We utilized narrative analysis to examine the interpretive schemas within the narratives told in these interviews (Riessman, 2008). Structural analysis segment interviews by narrative, then constitutive narrative clauses, which capture the internal logic of a story. Through systematic segmentation, we are able to examine thematic features of the narratives within and across participants. Two raters independently coded each story for its constituent narrative clauses then discussed and resolved disagreements.

In order to elucidate the findings, we focus this paper on a detailed contrasting case of two focal teachers, *Jeff* and *Ronald*. We selected these cases as they embodied similar philosophies about dialogue for learning, but oppositional frameworks about student knowledge and their role in facilitating discussions. Thus, these contracting cases help to delineate the connective tissue between teachers' noticing, pedagogical reasoning, and decision making.

Jeff is a 15 year veteran teacher of engineering and physics at Baxter High School. Baxter HS has a population of 26.9% percent of students who qualify for free and reduced lunch and a population of 0.7% English Language Learner (ELL) students. Ronald is an 8th grade middle school science teacher at Riverdale Middle School, having taught for 5 years. Riverdale MS serves a student population, with 85.3% of students qualifying for free and reduced lunch and a population of 55% ELL students.

Findings

We present three key themes that emerged from the narrative analysis that provide insight into teachers' frameworks: their *epistemic stance* about participation in discussion, *how they conceptualized the purpose of discussion*, and their *role as a facilitator of learning* in discussion.

Epistemic stance and role in facilitating discussion

One of the themes that emerged in the narratives of Jeff and Ronald were differences in the epistemic stance they adopted with respect to students' roles in discussion. By epistemic stance, we refer to orientation that teachers adopt around what counts as knowledge in science discussions, in this sense, what teachers code as valued contributions to knowledge building in the class.

For example, in referring to which discussions were high points, Jeff shared the following:

> "...every semester we do that discussion on time travel… that gets a lot of contribution from the students. So that one is definitely a high point in terms of students throwing out, not just ideas and theories about how time works, but things that are very close to if not identical to a lot of the ones that are accepted in the scientific community or at least um, being considered in the scientific community."

In this excerpt, we see that Jeff highlights student contribution as a key component of a successful discussion. He frames these contributions as a reflection of student knowledge and attributes value to that knowledge by describing students' contributions in terms of the kind that are "accepted" or "considered" in the scientific community.

Conversely, when Jeff recalled a discussion that he coded as less successful, he expressed: "... I wanna start with what they know but that's usually near zero...". In this excerpt, we can see that the interpretive schema (or frame) that Jeff applies to students' participation interprets students participation not knowing, where in the previous except expressing ideas like a scientist is interpreted as productive. His expectations are not that students are coming up with new ideas, but rather that they are prepared to do so later in their academic career. Jeff seemed to frame discussion as the space in which students are preparing for "pushing boundaries" later in their academic career, as the place for students to share *appropriate* knowledges and establish a foundation upon which they can later engage in argumentation and the sharing of new ideas. What seems important to note here is an absence of reference to his role and agency in the process of supporting knowledge building in discussion.

Ronald, on the other hand, adopts an epistemic stance centers students' agency and voice:

> "And I wanted to make sure that we were practicing some sort of science skill ... it's like giving them a voice to making, giving them the, um, agency to, to write the questions and be the like, be the ones to contribute... And in that process, they were collecting data, they were, um, you know, who picked yes, who picked no, who's in the middle."

Here we see that Ronald's epistemic stance codes students' resources as assets to discussion. When describing this low point in classroom discussion, Jeff frames himself as the driver of discussion and knowledge disseminator. In a narrative about a low point in discussions Ronald describes as:

> "And I think I was also at a place personally and like mentally where, um, I, I couldn't think of thoughtful feedback. Like I, they, and they would ask for help and, "Okay, tell me your question" and I sit there and I'm just like, "Oh, I'm just as stuck as you"...Um, they're not getting my help, uh, I'm not even providing help."

In contrast to Jeff, Ronald's places his role at the center of what he coded as a low point. He interprets a moment where he had challenges supporting their thinking in discussion as a point of failure. In addition centers idea development as what matters to him the most about what happens in discussion, e.g. "what mattered to me was like that development, you know, and like the development of one's ideas." He highlights the importance of the skills of argumentation for the negotiation of ideas, and his desire that students will learn these thinking practices through engaging in discussions.

Discussion and conclusion

This study investigated teachers' frameworks about science discussions and the relationship between the interpretive schemas they adopt to frame discussion in their classes and instructional decisions about how to facilitate them. By contrasting the case of Jeff and Ronald, we see that whilst teachers' might code forms of participation as productive in discussion, they can differ in interpretative schemas employed to make instructional decisions.

What connects what Jeff notices about salient high points and low points, how he makes sense of and reasons about these moments, what meaning he derives from them (coding), and then subsequent instructional moves he makes, center on the framework, that *students need to meet him where he is*. Thus he conceptualizes the discussion as a context where students should demonstrate that they know what he knows. Despite the experiences and knowledges that students may have brought with them into the classroom, Jeff does not code them as useful in the discussion. This is significant, in light of research that shows how carefully guided discussion can not only support students' knowledge and conceptual understanding, but that the process of joint construction of knowledge and negotiation of meaning is productive for the development of reasoning itself

(Clarke, Resnick & Rosé, 2016). Thus, this framework seems to inform Jeff's interpretations of experiences in discussion where students do not seem to rise to his standard, as moments of failure and not productive.

What connects what Ronald notices about salient high points and low points, how he makes sense of and reasons about these moments, what meaning he derives from them (coding), and then subsequent instructional moves he makes, center on the framework that he needs to *meet the students where they are.* His attention seems to be organized around making sense of what students need, what they know and what he can do to support them so they engage and learn. Ronald seems to be engaging in the ubiquitous work of understanding where students are and making instructional decisions dynamically and reflexively to attend to student learning. Further, Ronald's framework seems to center his own agency in supporting student learning, acknowledging that he has the capacity to make alterations in discussion to increase student learning and participation.

How Jeff and Ronald frame these discussion events directly impacts the opportunities for engagement that students are afforded in classroom discussion. In Ronald's classroom students are given space for exploration, whereas Jeff's focus on knowledge may potentially lead to decisions that decrease the opportunities for students to engage in discussion. This understanding allows us a glimpse into teacher cognition and reasoning.

Our analysis shows that when a teachers' framework attunes to engaging students in argumentation as an intellective and social practice, their instructional decision making focuses on scaffolding that process. Conversely, when their framework attunes to science as an acquisition of knowns, then their decision making seems to center instructional moves that focus on disseminating and validating these knowns.

Our work focuses on teachers' frameworks as a means to ground teachers' ongoing professional development around their sense-making about classroom discussion as a form of learning. Surfacing teachers' existing and emergent interpretive schemas about aspects of practices may help to support teachers to engage in critical reflective practice about what they notice, highlight and the forms of participation they value, and how their decision making is tied to that reasoning. In our work, we are leveraging these insights to map the design space for personalized professional development on facilitating science discussions that engage students in sense-making about science.

References

Berland, L. K., & Hammer, D. (2012). Framing for scientific argumentation. *Journal of research in science teaching*, *49*(1), 68-94.

Clarke, S.N. (2015) The Right to Speak. In L.B. Resnick, C.A. Asterhan & S.N. Clarke (Eds.) *Socializing Intelligence through Academic Talk and Dialogue*. Washington, D.C.: American Educational Research Association.

Clarke, S.N., Resnick, L.B., Rosé, C.P. (2016). Dialogic Instruction: A New Frontier. In L. Corno and E. Anderman (Eds.), Third handbook of educational psychology. American Psychological Association, pp. 378-389.

Clarke, D. & Hollingsworth, H. (2002). Elaborating a model of teacher professional grow*th. Teaching and Teacher Education*, 18(8), 947-967. 10.

Goffman, E. (1974). *Frame analysis: An essay on the organization of experience.* Harvard University Press.

Goodwin, C. (1994). Professional vision. *American Anthropologist*, 96(3), 606-633.

McNeill, K. L., Pimentel, D. S., & Strauss, E. G. (2013). The impact of high school science teachers' beliefs, curricular enactments and experience on student learning during an inquiry-based urban ecology curriculum. *International Journal of Science Education*, *35*(15), 2608-2644.

Riessman, C. K. (2008). *Narrative methods for the human sciences*. Los Angeles: Sage Publications

Shulman, L. (1987). Knowledge and teaching: Foundations of the new reform. Harvard Educational Review, 57(1), 1-22

van Es, E. & Sherin, M. (2008). Mathematics teachers' "learning to notice" in the context of a video club. *Teaching and Teacher Educatio*n, 24(2), 244-276.

Identifying the Practices of Girls' Maker Hobbies: The Case of Doll Makeovers

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Abstract: Making is a popular endeavor and a rich learning opportunity for children. Yet, we know very little about how children self-initiate and pursue making as hobbies, and the value of such engagements as learning opportunities. To support STEM learning in relevant, familiar contexts for all interested children, we need to know the diverse experiences that support maker hobbies, including those not immediately apparent as STEM-rich (Bevan, 2014). I describe three young girls' doll makeover projects where they fix old dolls and make clothes and accessories for them as a maker hobby. Conceptualizing maker projects as representations, I examine the girls' practices as they give makeovers to old dolls throughout a summer break. Using a qualitative content analysis method, I identify Maker practices as a combination of STEM, literacy, social practices, and making as a hobby situated in the fabric of young girls' interests and contexts.

Introduction

Maker education research, just like the nature of making that youth engage in, is extensive in scope. The bulk of the research in making and learning concerns a pedagogical approach to developing students' interests, capacities, and productive learning identities by building and exploring ideas. Although this educational approach breathes new life into STEM education by emphasizing learning by doing as opposed to by reading only, it is distinct from making as a hobby that children pursue solely out of interest. Diverse ways of making and the related skills and practices are critical to our understanding of STEM as practiced by children and the merit inherent in such activities.

Despite the continuous and well-intentioned efforts, we continue to associate a restricted range of knowledge and practices with STEM learning. Our understanding and acknowledgment of STEM learning is also related to gender and identities (Gutiérrez, 2013), and tools, materials, and technologies (Searle & Kafai, 2015) with histories in and of themselves. Disconnects between these two sets of attributes can discourage youth from engaging in STEM (Calabrese Barton et al., 2013). Based on this rich knowledge of making, gender, and STEM learning, I describe three young girls' experiences passionately pursuing a doll makeover hobby over a summer break. I illuminate their interest-based making as a rich learning experience and answer the following research questions.

1. What constitutes girls' interest-based maker practices?
2. How do these practices relate to other interests and skills that the girls have?

Making as a way of STEM learning has been welcomed by the education community to engage learners with a wide range of STEM learning interests. Application of STEM practices, processes and phenomena are possible in a range of contexts beyond robotics and 3D printing. For example, Calabrese Barton & Tan (2018) recognized that cooking and embroidery projects could have some STEM orientations in unique ways. Halverson (2013) examined digital art as representations of the sense-making process. Studying making as a hobby affords new opportunities. First, it helps us study making in natural settings and document the many ways in which children use technologies that are available to them. Second, technologies that have become popular because of widespread interest in educative making have been used to educate youth, but in projects and ways we deem suitable. However, related activities such as crafting with available resources have received little attention. Owing to this gap, we don't know about the other uses of these technologies, situations in which they become meaningful, and the skills children employ to use them. Children's own interests in making is a rich domain of practice and merits scholarly attention.

Maker projects as representations and constructions

Research on making and maker practices draws from a range of settings, material and technological resources, and educational contexts. To bridge children's making across these domains, I first examine the conceptualization of maker projects. Maker education research values maker projects as constructions (Papert, 1980) - objects-to-think-with that lie neither solely in the head nor in the world but rather at the intersection of the two and relies on the general constructivist idea that children actively build ideas that represent what they know of the world around them. Through the creation of representations, artists are known to transform the materials and express ideas (Eisner, 2002, p. 80). Designers abstract irrelevant details in the process of creating representation as a valuable experience (Norman, 1993). Overall, experts across these domains agree that the process of creating representations is an iterative one that compels creators to address assumptions, test new knowledge, identifying problems, and look for solutions. I conceptualize maker projects as representations that require the use of tools and materials, as engagement in habits of thinking, practices, cultures, and contexts, and as documentation of our knowledge of the natural and material world.

Making, STEM learning, and gender

That a restricted approach to making and makerspaces might reinforce the existing gender disparities and stereotypes in STEM fields concerns many. Initiatives to combat such a disadvantage include raising awareness of the lack of representation of women in maker movement press, organizing all-girls Maker clubs, and offering workshops designed to further girls' technological fluency in working with e-textiles. Some scholars (for example, Sengupta-Irving & Vossoughi, 2019; Calabrese Barton & Tan, 2018) have criticized the deficit perceptions of STEM participation that often shape girls' experiences in STEM including the suggestion that girls *can* and *should* engage in STEM the same way as boys do, that special spaces be created for girls because they *must* pursue STEM careers, and that girls of color *need* to be STEM practitioners to gain access to a better life. These suggestions highlight the belief that choosing certain kinds of STEM careers reflects a sound judgment on girls' part while ignoring girls' possibility to be interested in other kinds of STEM or not be interested at all. In studying doll makeovers as a maker hobby, I consider girls' making a domain unto itself worthy of scholarly pursuit. In the following sections, I describe the methodology and findings in response to the research question.

Methodology

I examined children's interest-driven making as a collection of multidimensional practices across STEM, Maker Education, and STEM literacy. I employed Maker practices as identified by researchers (Bevan et al. 2014; Wardrip & Brahms, 2015), Computational Thinking practices (Wing, 2006); and STEM literacy practices (Gravel, Tucker-Raymond, et al. 2018). In doing so, I explored making beyond the constructions, the projects to the process of their creation. This is important because STEM includes a wide variety of practices and literacies, but are often ignored in understanding and contextualizing learning. I collected data for this study as a participant-observer and mentor in a series of loosely structured making activities involving my daughter and two of her friends. At the time of data collection, the girls were eleven, nine and eight years old respectively. I considered transcripts of the girls' conversations in the recorded videos, logs of girls' actions on projects supplemented with photographs, transcripts of interviews with them, and extensive field notes as data. I conducted content analysis (Schreier, 2012) with two attributes of the girls' work in mind - a) making processes and b) maker practices with the meaning unit as the unit of analysis. I began with an inductive approach and open coded the data using definitions of the practices. I then used thematic content analysis (Carley, 1990) to compare these instances to understand the nuances of these practices. Later, I applied this understanding in a second round of coding involving fewer practices with related practices collapsed in suitable ways. Finally, I organized our findings into three categories - STEM thinking and learning skills, literacy skills and social skills. Once I had identified the findings, I shared and discussed the findings with the girls as a way of member checking (Lincoln and Guba, 1985).

Findings

Doll makeovers as a hobby comprised of several pre-existing interests that the girls already had. These include playing with dolls, digital art, printing on transfers, slime making, play dough constructions, and 3D art using 3D pens. Doll makeovers include repairing old dolls (untangling doll hair, cleaning the dolls by removing stains carefully, etc.) to give them new looks by changing their hairstyles and clothing, making new clothing from scratch, changing their skin tone, and replacing them hair, and facial makeup.

STEM maker practices

The girls purchased doll clothing patterns on Etsy stores run by older women trained seamstresses and experts in pattern making and aware of the many dolls. With no experience in using patterns to make clothing for dolls, the girls faced steep challenges. First, they had to learn to "read" and use a pattern, and second, they had to learn to modify the patterns for dolls of different shapes sizes. For example, patterns for clothes for Barbies did not fit other dolls (Ever After High, Disney princess dolls, and other unknown types) well. Realizing the need for modified patterns, the girls adopted a few trial and error approach. The girls eventually tried out all three ideas and finally found a way to create their own doll clothes patterns using masking tape. Overall, they could either consider the dolls' proportions or the pattern measurements to make clothes that were to scale. Their approach to look for "a pattern (of solving the problem) to make patterns" required them to understand the problem as a combination of not knowing the rules and a lack of skills. To solve the problem, they used the practice of abstraction that later helped them understand patterns better. Further, in their pursuit of making doll clothes alone, the girls made and traversed multiple representations created by practitioners and transitional ones that they created for their own use. As the girls explored the digital drawing tool, they talked about a digital drawing tool's unique affordances in contrast to paper and pencil drawings. The girls explained technical concepts such as that of layers to each others, weighed their options when using the digital drawing tool while not compromising the desired visual effect , and acknowledged that "it takes time" to explore a "dense" tool thoroughly. Each of the girls explored the drawing tool to meet her individual goal.

Literacy practices

Across their projects, the girls switched back and forth between identifying goals, seeking information relevant to those goals, experimenting with applying the information to physical objects and tools, and seeking further information when problems arose in their work. The girls' work on doll makeovers was iterative; despite the range of information and inspiration available on YouTube, the girls had to make room for their inexperience and the lack of specialty supplies. For this reason, their work was heavily shaped by emergence. Throughout each of their many projects, they actively sought and evaluated information from various texts (e.g., websites, product descriptions, images, instructions); their ability to locate relevant information was crucial to each project's success and how they planned to further their interest. Making draws on multiple domains and a crucial component of literacy practices involves identifying relevant knowledge domains and communities (Gravel et al. 2018).

Social skills

Each girl positioned herself as an expert or novice concerning each of their hobbies and assumed an expert's role, a fast-progressing learner, and a novice. When they needed help locating and procuring fabric and thread and needles for the clothes, they sought assistance from their grandmother, an expert seamstress who later taught them to take apart doll clothes to create clothing patterns carefully. The girls explained processes and problems and provided and made sense of information for each other. In doing so, they collaboratively constructed their activities in a way that allowed them all to assert their opinions and ideas. Further, the roles they assumed while working on each project shaped how their social interactions with each other and adults unfolded. Having described the practices that the girls engaged in as they pursued interest-based making through doll makeovers, I now describe how these practices were embedded in their everyday lives and related to their other interests and skills.

Maker hobbies as lines of practice

The above observations indicate that interest-based making is a line of practice – "a distinctive way in which a person's preferences are attuned, over the long haul, to specific conditions of practice"(Azevedo, 2011). The girls' persistence in making as one line of practice was also attuned to the context and practice conditions (support for children's independent, playful engagement, supportive adults, access to materials and tools, and their mutual support), and their more extensive repertoire of practices and skills. Each girl had developed skills in the pursuit of an existing interest; working on doll makeover was the context in which these skills gained relevance.

Making as a collection of complementary identities and practices

The girls were novices in some areas and experts in others, even within their work on one project. Each girl was a novice in some tasks (pattern making and sewing), tools, and technologies and well versed in others; their identities of expertise were complementary and the tasks they performed were complementary too. Based on the above analysis, we see that the practice of interest-based making, such as doll makeovers requires youth to implement STEM thinking skills such as abstraction, problem decomposition, and traversing multiple representational forms, and posing and solving problems in a process, as well as literacy practices and social skills.

Discussion

A frequently stated goal of maker education is to help youth develop STEM interests and identities and potentially venture into STEM careers. That informal childhood experiences in science often spark initial interests and identities as scientists is widely acknowledged. I have demonstrated that children can engage deeply and meaningfully in STEM literacies through self-initiated maker hobbies that are not traditionally thought of as STEM.

One implication of these findings for educators, parents and mentors in informal settings is to find ways to find out and understand the richness of children's experiences at home and with peers so that these can form the basis for science education and connecting students to relevant communities of practice. Additionally, the girls' practice of doll makeovers indicates that identities, too, are relevant to such an embodied experience. These findings iterate what we already know of identity as malleable, tied to circumstances and social contexts, as well as individually constructed. Studying girls' hobbies brings an opportunity to study their STEM engagement as multidimensional and involving multiple intersecting social identities beyond the usual stereotypes surrounding the conceptualizations of both STEM activities and identities.

References

Azevedo, F. S. (2011). Lines of practice: A practice-centered theory of interest relationships. *Cognition and Instruction*, *29*(2), 147-184.

Bevan, B., Gutwill, J. P., Petrich, M., & Wilkinson, K. (2014). Learning through STEM-rich tinkering: Findings from a jointly negotiated research project taken up in practice. *Science Education*, *99*(1), 98-120.

Calabrese Barton, A., Kang, H., Tan, E., O'Neill, T. B., Bautista-Guerra, J., & Brecklin, C. (2013). Crafting a future in science: Tracing middle school girls' identity work over time and space. *American Educational Research Journal*, 50(1), 37-75.

Carley K. 1990. Content analysis. In The Encyclopedia of Language and Linguistics, Asher RE (ed.). Pergamon: Edinburgh. 2: 725–730.

Eisner, E. (2002). The arts and the creation of mind. New Haven, CT: Yale University Press.

Gee, J. P. (2000). Identity as an analytic lens for research in education. *Review of Research in Education*, 25, 99–125.

Gravel, B. E., Tucker-Raymond, E., Kohberger, K., & Browne, K. (2018). Navigating worlds of information: STEM literacy practices of experienced makers. *International Journal of Technology and Design Education*, *28*(4), 921-938.

Gutiérrez, R. (2013). The sociopolitical turn in mathematics education. Journal for Research in Mathematics Education, 44(1), 37-68.

Halverson, E. R. (2013). Digital art making as a representational process. *Journal of the Learning Sciences*, *22*(1), 121-162.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard educational review*, *84*(4), 495-504.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Lincoln, Y., & Guba, E. (1985) Naturalistic inquiry. Newbury Park, CA: Sage Publications.

Norman, D. (1993). Things that make us smart. New York, NY: Doubleday.

Papert, S. (1980). Mindstorms: Computers, children, and powerful ideas. *NY: Basic Books*, 255.

Schreier, M. (2012). *Qualitative content analysis in practice*. Sage publications.

Searle, K. A., & Kafai, Y. B. (2015, July). Boys' Needlework: Understanding Gendered and Indigenous Perspectives on Computing and Crafting with Electronic Textiles. In *ICER* (pp. 31-39).

Sengupta-Irving, T., & Vossoughi, S. (2019). Not in their name: re-interpreting discourses of STEM learning through the subjective experiences of minoritized girls. *Race Ethnicity and Education*, *22*(4), 479-501.

Tucker-Raymond, E., Gravel, B. E., Kohberger, K., & Browne, K. (2017). Source code and a screwdriver: STEM literacy practices in fabricating activities among experienced adult makers. *Journal of Adolescent & Adult Literacy*, 60(6), 617-627.

Vossoughi, S., Escudé, M., Kong, F., & Hooper, P. (2013, October). *Tinkering, learning & equity in the after-school setting*. Paper presented at the FabLearn conference, Stanford University, Palo Alto, CA. Retrieved from http://www.sesp.northwestern.edu/docs/publications/49224626354098196e0b03.pdf

Wardrip, P. S., & Brahms, L. (2015, June). Learning practices of making: developing a framework for design. In *Proceedings of the 14th international conference on interaction design and children* (pp. 375-378).

Wing, J. M. (2006). Computational thinking. *Communications of the ACM*, *49*(3), 33-35.

Improvisational Dance as Enactive Cognition

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Abstract: We show the ways an improvisational dance workshop provided the opportunity for participants to be autonomous actors and engage in embodied sense-making through dance – two key parts of the conceptualization of *enactive* cognition. As part of a Design Based Research study (DBR Collective, 2003) we use Interaction Analysis (Jordan & Henderson, 1995), Diagrammatic Transcripts (Lindberg & Marin, 2020) and in-depth qualitative analysis to present examples of autonomy and agency in dance learning in a contemporary art museum. We describe the interactions of two pairs engaging in a designed dance activity, and the ways their improvisational movements highlight the ways in which dance is a tool for sensemaking.

Introduction

We present data in which an improvisational dance workshop provided the opportunity for adults to be autonomous actors, and engage in embodied sensemaking through improvisational dance. Improvisational dance as a learning activity has been studied by many, and has no simple definition (De Spain, 2014). For the purposes of this paper we define the term improvisational dance as an activity in which people participate as active agents and observers (Dils, 2007) and generate spontaneous movement in creative play and exploration (Lord, 2001; Blom & Chaplin, 1988). Building on research on enactive cognition (Menary, 2010) and analyses of collaborative dance making as a cognitive process (Giugere, 2011), we ask two questions. First, how do we see autonomous activity and sense-making (components of enactive cognition) in improvisational dance? And second, what methods allow us as researchers to represent dance - aesthetic, embodied movements - as cognitive acts when making sense of art in a museum?

4E cognition in relation to dance

4E cognition aims to explore the role of the whole body in interaction with a context - how bodies embody, embed, extend, and enact with and in their environments. Enactivists in particular conceptualize learning as "whole-body engagement" (Gallagher & Lindgren, 2015, p. 391) through autonomy and embodied sensemaking. Despite this, the ways in which the "whole-body" is conceptualized is typically not attended to in education with the nuance that dancers bring. Cognitive processes, according to 4E scholars, are not separate from the body and environment but are influenced through interaction with the physical and social world (Menary, 2010). This is especially relevant for this analysis of improvised dance, as an embodied conceptualization of learning has long been held by dancers (Snowber, 2016). While tensions between dance theory, 4E cognition and embodied cognition are clear throughout the literature, at the center of each field are similar assumptions about cognition and interaction - that movement influences the act of making sense of interactions with the world. This paper positions dance as an *enactive* process looking at two key aspects: autonomy and sensemaking.

Autonomy in dance

Described by enactivists, "[a]n autonomous system is defined as a system composed of several processes that actively generate and sustain an identity under precarious conditions" (De Jaegher & Di Paolo, 2007, p. 487). We extend the idea of an autonomous system by drawing upon literature exploring autonomy in language learning (Toohey & Norton, 2003; Little, 1995) to expand the ways in which autonomy can be seen in learning interactions, specifically through dance. In these conceptualizations of autonomy in learning, the individual takes on active roles of engagement with the material – applying their learning from formal schooling contexts to their lived experiences. The learners in this paper demonstrate autonomy through improvisational dance choices in location, spacing, speed, and movement – making their thinking and sensemaking physically visible, and therefore actionable, for their peers and analysis.

Participatory sensemaking in dance

Autonomous beings, as described above, interact with themselves and the world by actively making sense of their surroundings. *Participatory sense-making* (De Jaegher & Di Paolo, 2007) regards social cognition and interactions as central to the concept of enactive cognition. Hanne de Jaegher (2013) describes participatory sense-making as "the coordination of intentional activity in interaction, whereby individual sense-making processes are affected and new domains of social sense-making can be generated that were not available to each individual on her own" (Cited in Hermans, 2019, p. 23). Dance provides a unique context in which to study enactive participatory sensemaking, as we have social, interpersonal, intrapersonal, and interactive responses magnified through the visibility of danced movements and audibility of verbal utterances.

Cognition as a collaborative process in dance

We draw on work that emphasizes the collaborative nature of cognitive processes like choreographing and improvising movements (Rogoff, 1998). This is an important distinction, as much of the research on dance and cognition (e.g., Giguere, 2011) and cognitive science has studied individuals engaging in the creative process (Moran & John-Steiner, 2003). Recent research on creativity in the learning sciences (Sawyer, 2005) attends to the more collaborative nature of learning (Enyedy & Stevens, 2014), which this work builds upon - using collaborative dance and enactive cognition as a site for thinking, learning, and creating.

Methods

This Design Based Research Project (DBR Collective, 2003) positions postmodern and improvisational dance as enactive resources for learning in the context of a contemporary art museum. In partnership with a staff member at the museum, we designed a 90-minute dance workshop that was implemented for 15 University students learning to become museum docents. Participants were between the ages of 19 and 35 and each was a paid employee at the museum, participating in a docent training program. We collected video data from the intervention using four Go-Pro cameras that were placed in different locations in the gallery. This paper reports on our analysis that we hope to use to inform future iterations of the workshop.

The workshop design

Closely inspired by Liz Lerman's postmodern conceptualization of dance (Borstel, 2007) that every action can be done with intention, each movement can be a dance, and dances take up space and shape, we designed a series of dance improvisation games to promote engagement with and observation of artwork in an art gallery. After a mindfulness warm-up, an improvisational dance-based "mirroring" practice moved into a "See and Move" designed dance game, and finally participants engaged with a "Docent Dance" exercise with a partner. All four elements of the workshop invited participants to improvise and share postmodern dance movements inspired by the visual art in the gallery and were followed by discussion and written reflection. These activities were designed as low-stakes entry points to begin improvising movement spontaneously, being physically alert, and relating to a partner while in motion. In the remainder of this paper we report analysis on the "Docent Dance" design.

Data analysis

Using interaction analysis (Jordan & Henderson, 1995), diagrammatic transcripts (Lindberg & Marin, 2020), and the lens of movement as enactive cognition, we analyzed the "Docent Dance" design. The first author viewed the video from the 90 minute workshop and content logged in 30 second increments. Participants' physical location in the gallery, what designed activity they were participating in, who they were with, the scale of their movements, and verbal utterances were all noted. Attention was paid to participants who were in full view of the cameras when participating in each of the designed activities. We then traced all 15 participants' physical locations in the museum gallery using diagrammatic transcripts (Lindberg & Marin, 2020) to understand their facings and location over the 90 minutes. Through an inductive analysis of the data, moments of interest were identified in which participants improvised dance movements and described their sensemaking verbally. These instances were analyzed using Interaction Analysis and then cross-referenced with interview transcripts, and students' written reflections during the workshop. In this paper, we focus on the ways in which both autonomy and participatory sense-making are seen in one activity, for two pairs playing the "Docent Dance" game.

Major findings

This section presents an analysis of two pairs of participants from the data corpus making sense of the same piece of art. We also show how we used both interaction analysis and diagrammatic transcripts together to represent dance as a form of enactive cognition. In each instance, we see dance as a context for cognition, as learners demonstrate autonomy and participatory sensemaking. We also demonstrate the ways in which diagrammatic transcripts are useful as a tool of analysis with which to add depth and rigor to an analysis of improvisational dance in representing bodily positions.

Autonomy and sensemaking In the Docent dance: Case 1

In Figure 1, we see Partner 1 acting as the docent, engaged in both autonomous activity and sense-making through improvisational dance. She first demonstrates autonomy by selecting the artwork she wants to guide her partner to. Out of the more than 60 pieces on display in the gallery, she chose this piece. She then transformed the rules of the game by adding a traveling element - she took three long, low-level running steps to her left, before she struck a final pose. This change in location is represented in the diagrammatic transcript 1.1 to 1.2. While the transcripts look similar, the movement is significant for the experience and sensemaking of the pair. They are still in front of the painting, but they have traveled, which we analyze as an autonomous choice made while engaged in improvisational dance in response to the artwork.

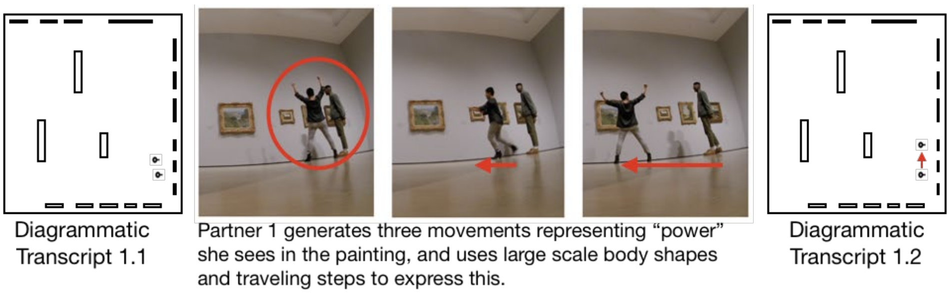

Figure 1. One pair of participants, Partner 1 and 2, use improvisational dance during sensemaking.

After verbally describing what Partner 1 interpreted from the piece (per the *Docent Dance's* design), she improvised a dance sequence demonstrating her sensemaking. She represented the "power" she saw in the painting with strong, large-scale movements with her arms raised over head and her legs wide, feet planted into the ground. We regard this as sensemaking because she actively transformed what she saw in the painting into her own movement as an active, autonomous agent in the environment, rather than mimicking the painting or gesturing towards an element in the artwork. Her sensemaking is recognizable here in part through her verbal descriptions of the "power" and strength in the painting into a movement phrase which she shared with her partner. Autonomy and sensemaking were both recognizable in this interaction because of the designed nature of the workshop.

Autonomy and sensemaking In the Docent dance: Case 2

For the second case, we present a second pair of participants in front of the same artwork. Their starting position seen in the diagrammatic transcript 2.1 is similar to the first pair, however the movement responses and sensemaking were quite different. In this case, Partner 1 stood in a split stance with her left foot forward, right foot back, arms positioned at an upward angle towards the painting – right hand cupped as if embodying the shape of a shell, as the left hand caressed the right hand, exploring the crevices of the concave shape (Figure 2B). She shared with her partner that she was responding to the seashells carved into the frame of the painting, which she had not noticed before. This careful embodied attention to a newly observed portion of the artwork – a pattern of carved shells on the frame of this painting – was brought into the conversation after engaging in dance-based observation protocol. The movement response required close observation, autonomous decision making, and enactive sensemaking.

Figure 2. A second pair of participants use careful attention to detail when observing an artwork.

Analytic precision with interaction analysis and diagrammatic transcripts

By comparing the diagrammatic transcripts of all participants in the workshop, we were able to see where there was overlap, and which pairs autonomously chose to visit which paintings. This allows us to compare the different autonomous choices and sensemaking strategies used in response to the same artwork. Both cases attended to the same painting, and the diagrammatic transcripts look very similar. However, participants observed, commented on, and improvised very different dance movements. Thus, interaction analysis in conjunction with diagrammatic transcripts helped surface the expansive ways we can understand dance as enactive cognition.

Discussion and conclusion

This article aims to build on the conceptualization of dance as enaction, attending to the ways in which dance supports thinking, learning, and interaction. Positioning improvisational dance as a tool for demonstrating autonomy through movement, and sensemaking in response to external stimuli (visual art) makes improvisational dance more accessible to a broad audience of learners. We have endeavored to describe how dancing provides an opportunity for participants to actively engage with themselves, their surroundings, and provide examples of how dancing *is* thinking – not merely a representation of cognitive thought. This research aims to demonstrate both the ways enactive cognition can be used as a lens to view dance as a cognitive act, and the ways in which both diagrammatic transcripts and interaction analysis can support a rigorous approach to an analysis of improvised dance movement as a cognitive act. Newly designed methods can help to support data collection and analysis methods for consequential improvisational dance movements moving forward.

References

Blom, L.A. & Chaplin, L.T. (1988) *The Moment of Movement: dance improvisation* (Pittsburgh, PA, University of Pittsburgh Press).

Borstel, J. (2007). Liz Lerman Dance Exchange: An aesthetic of inquiry, an ethos of dialogue. *Dialogue inartistic practice: Case studies from animating democracy*, 57-91.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. Educational Researcher, 5-8.

De Jaegher, H., & Di Paolo, E. (2007). Participatory sense-making. *Phenomenology and the cognitive sciences*, *6*(4), 485-507.

De Jaegher, H. 2013. "Embodiment and Sense-Making in Autism." Frontiers in Integrative Neuroscience 7:15. doi:10.3389/ fnint.2013.00015.

De Spain, K. (2014). *Landscape of the now: A topography of movement improvisation*. Oxford University Press.

Dils, A. (2007). Moving into dance: Dance appreciation as dance literacy. In *International handbook of research in arts education* (pp. 569-585). Springer, Dordrecht.

Enyedy, N., & Stevens, R. (2014). Analyzing collaboration. In *The Cambridge Handbook of the Learning Sciences, Second Edition* (pp. 191-212). Cambridge University Press.

Gallagher, S., & Lindgren, R. (2015). Enactive metaphors: Learning through full-body engagement. *Educational Psychology Review*, *27*(3), 391-404.

Giguere, M. (2011). Dancing thoughts: an examination of children's cognition and creative process in dance. *Research in Dance Education*, *12*(1), 5-28.

Hermans, C. (2019). Let's Dance: Participatory Sense-Making in an Eight-Year-Old Boy with Autism. *Journal of Dance Education*, *19*(1), 23-33.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. The journal of the learning sciences, 4(1), 39-103.

Lindberg, L., & Marin, A. (2020). Designing Dance for Museums: Using Diagrammatic Transcripts to Analyze Embodied Interactions in an Informal Learning Environment.

Little, D. (1995). Learning as dialogue: The dependence of learner autonomy on teacher autonomy. System, 23(2), 175-181.

Lord, M. (2001). Fostering the Growth of Beginners' Improvisational Skills: A study of dance teaching practices in the high school setting. *Research in Dance Education, 2*, 19 - 40.

Menary, R. (2010). Introduction to the special issue on 4E cognition. Phenomenology and the Cognitive Sciences, 9(4), 459-463.

Moran, S., John-Steiner, V., & Sawyer, R. (2003). Creativity in the making. Creativity and development, 61-90.

Rogoff, B. (1998). Cognition as a collaborative process. In W. Damon (Series Ed.) and D. Kuhn & R.S. Siegler (Vol. Eds.), Handbook of child psychology, Vol 2: Cognition, perception, and language. New York: Wiley, 1998.

Sawyer, R.K. (2005). The new science of learning. The cambridge handbook of the learning sciences (pp.1-16). Cambridge, England: Cambridge University Press.

Snowber, C. (2016). Embodied inquiry: Writing, living and being through the body. Springer.

Toohey, K., & Norton, B. (2003). Learner autonomy as agency in sociocultural settings. In Learner autonomy across cultures (pp. 58-72). Palgrave Macmillan, London.

Integrating Data Literacy into Secondary School Science: An Exploratory Study of a Pilot Professional Development

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Abstract: In our data-rich world, data literacy is becoming an increasingly important goal in education as data sets become bigger, and more complex. However, data literacy falls outside the traditional topic domain of secondary science curricula and so may be beyond the scope of the pedagogical content knowledge (PCK) of teachers who have received training in only one subject area. This paper presents an exploratory study of how secondary school science teachers learn and use the content and skills of integrating data literacy into their curriculum, within the context of a PD program for bioinformatics. The findings suggest that there are a separate set of PCK components that teachers need to master in order to successfully teach data literacy, and that successful PD must support teachers in developing them.

Keywords: data literacy, pedagogical content knowledge, professional development

Introduction

In our data-rich world, there are strong calls for greater focus on data literacy within education (Gebre, 2018; Gould et al., 2016; Rubin, 2020). Though it is interdisciplinary in nature, data literacy suffers from being nebulously defined and having no clear home within the traditional secondary school subject-based curriculum (Gebre, 2018; Lee & Wilkerson, 2018). As integration of subjects has been shown to present a challenge to teachers who have received training in only one subject area (Aslam et al., 2018), teachers may need additional support to develop knowledge and skills for teaching data literacy, also known as pedagogical content knowledge (PCK) (Neumann et al., 2019). Data literacy as a component of teacher education is a relatively new concept. As the way we interact with data through increased technology exposure, and greater computing power changes, the way we seek to teach students to interact with data also needs to change to promote a broader relationship with data (Lee & Wilkerson, 2018; Wise, 2020) and a greater focus on the context in which data is collected and used (Rubin, 2020). In this study, we sought to better understand how PD can support teachers in developing PCK for data literacy. Through analysis of interviews, surveys, and classroom observations we asked, how does a PD program for bioinformatics support teachers in learning and implementing the content and skills of integrating data literacy into their science classroom and existing curriculum?

Background

Researchers and practitioners are thinking about what it means to teach data literacy and what the pedagogical implications are for integrating data into the classroom (Gould et al., 2016). Wilkerson and Polman (2020) outline two core pedagogical commitments for teaching with data. (1) that teachers should be flexible with learning and promoting new tools and methods for working with data, and (2) that data based teaching should be grounded in full cycles of inquiry using real, consequential data. Lee and Wilkerson (2018) also support the notion that work with data should be conducted within the context of meaningful scientific investigations, and add that the interdisciplinary nature of data should be highlighted with connections between math and science classes, and that the complex and dynamic nature of data should be explicitly discussed and multivariate relationships explored. Since training for secondary school teachers is often specialized by subject, these pedagogical skills may be new to many teachers (Aslam et al., 2018) and require new PCK. A review by Neumann and colleagues (2019) offered a consensus definition of PCK as "teachers' personal knowledge that drives their planning for, implementation of, and reflection on instruction" (p. 856). In merging knowledge of pedagogy and knowledge of content, PCK is topic specific, which can hinder a teacher in integrating new content material that may fall outside their learned topic domain (Aslam et al., 2018). Data literacy currently exists in that space outside of traditional secondary school topic domains (Gebre, 2018) and as such, most science teachers are not supported in developing PCK for data literacy. Additionally, data literacy as a concept is still being defined which further complicates efforts to support teachers in integrating it into their classrooms

Data literacy is an emerging concept without a clear definition or set of core competencies that are widely accepted across different fields (Wolff et al., 2016). A recent review of literature on data literacy attempted to synthesize a working definition of the concept as "the ability to ask and answer real-world questions from large and small data sets through an inquiry process, with consideration of ethical use of data" (Wolff et al., 2016, p. 23). However, this definition leaves space for a number of different competencies, especially as data sets become more complex, and as students become participants in data creation (Gebre, 2018; Wise, 2020). In their report on data use in secondary school, Lee and Wilkerson (2018) begin to create a framework for some of these competencies which could help in defining PCK for data use. They outline four understandings that are required to develop data literacy: a) *measurement and sampling*, b) the *characteristics of data*, c) different types of *data representation*, and d) *making inferences from data*. Rubin (2020) supports these themes, and adds a fifth understanding, which is e) *context*, the who, when, where, what, why and how of data collection and use.

Defining competencies that lead to development of data literacy is a helpful step leading to integrating data literacy into science classrooms, but teachers also need to be supported in learning these competencies and developing PCK for data. Though research has shown that PD can enact change in teachers' practice (e.g., Darling-Hammond et al., 2017), it is important to design PD in a way that is mindful of the unique challenges posed by promoting data use in science classrooms. Lee & Wilkerson (2018) lay out a number of recommendations for improving teachers' knowledge and practice when it comes to working with data in the classroom. These include: providing extended time for teachers to use the technology through a full cycle of inquiry; highlighting that though technology and data-based inquiry can be used to teach content, additional data literacy skills also need to be taught in order for content learning to be achieved; and provide case-study examples of students working with data and technology. Where we know that integrating data literacy in science education content has presented challenges, teachers will need support for developing PCK in PD opportunities. For this reason, considering high quality PD characteristics (Darling-Hammond et al., 2017) is important.

Methods

This is an early stage, exploratory study that draws on qualitative data from a small pilot group of teachers. The goal of the full project is to support teachers in implementing a problem-based learning (PBL) curricular unit that challenges students to come up with data-based solutions for addressing asthma rates in their urban district. The curriculum requires reasoning with less traditional data sources such as that collected by digital sensors, and that available in large public data sets (Lee & Wilkerson, 2018).

Designing for data literacy

The PD was designed and developed in the winter and spring of 2019 and implemented over three weeks in July 2019. Teachers attended in-person for 6 hours of learning time each day, for a total of 90 hours. Of those, about 7 hours were devoted to data literacy. Data literacy instruction utilized five primary activities: a) defining data literacy, b) learning new tools for working with data, c) working with data as a learner, d) reflecting on learning about data, and e) reflecting on teaching with data. These activities were based on design principles for high quality PD and emerging theories on developing data literacy as outlined in the above section. In defining data literacy, participants explicitly highlighted the need for data literacy skills while grounding learning in the context of their classroom. The PD engaged participants as active learners while learning a new app for data analysis. Participants worked in pairs to conduct a full cycle of data collection, analysis, and communication of results, using student-facing materials from the example PBL unit. The PD provided time for reflection both on the process and experience of learning with data, and on how to apply what they learned to strategies for teaching with data in their classroom. All data literacy instruction was grounded in a community level scientific problem (high asthma rates in urban areas) and structured around a full inquiry-cycle to address that problem. Throughout the PD, the facilitators modeled effective instructional practices and encouraged collaboration.

Participants

The pilot study consisted of six teachers from a large urban school district in the northeastern US where over 85% of students are racial minorities and 100% of students are considered economically disadvantaged. Three of the teachers taught biology and three taught environmental science. Three of the participants identified as female and the other three as male. Half of the participants identified as Black and the other half as White. They had an average of 9.8 years of experience ranging from 2 to 18 years.

Data sources and analysis

The sources for this study consisted of surveys conducted pre and post PD, external evaluator memos from focus groups during the PD, classroom observations during implementation, and interviews conducted post implementation. A content knowledge survey which included a set of questions about teachers' understanding of data literacy and their pedagogical practices was given at the beginning and end of the PD. On the last day of the PD, participants were also asked to complete an Evaluation Survey of the PD experience with a few questions specifically aimed at the data literacy content. The external evaluator on the project conducted focus group interviews with the participating teachers three times during the PD (Day 1, 5 and 10) and wrote up notes summarizing themes with supporting quotes that were shared with the research team. Classroom observations were conducted throughout the school year by different members of the research team. At the end of the school year, semi-structured post-implementation interviews were conducted with five of the six teachers which included questions that asked teachers to reflect on their teaching and their students' learning.

The data was qualitatively mined for articulations of data literacy themes in order to study the pilot run of the PD and teachers' impressions of it and success with implementation. There were some prompts in the surveys and interviews that specifically asked about impressions of the data literacy content, and these were used to frame pre and post self-reported beliefs from the six teachers. These beliefs and experiences were then compared to observation notes from classroom implementation to determine the fidelity with which the data literacy components of the curriculum were enacted.

Findings

Three primary themes were drawn from the data analysis: a) teachers came into the PD with hesitations about working with data; b) the PD helped some but not all teachers feel prepared to teach with data; and c) teachers encountered a number of challenges in implementing integrated data literacy content.

Initially, teachers demonstrated hesitancy in working with data. The pre-surveys showed that five of the six teachers held a traditional view of what working with data means in a classroom, highlighting skills such as analyzing data and creating graphs, with only one participant linking skills to larger ideas such as solving problems. This focus on discrete steps for working with data is evidenced in this typical response from the pre-survey: "[Data literacy is] the method individuals use to collect, interpret and analyze data. This can include building data tables, using variables and/or drawing graphs." Though all six teachers indicated that they had worked with data in their classrooms previously, they came in with a range of experiences for how often data was used in their classrooms, and the level of rigor it was taught with. Throughout the first week of the PD, teachers expressed nervousness about the data literacy components of the curriculum, with one teacher on the first day saying, "The most difficult aspect will be helping students analyze data and interpreting graphs. This is something that they have rarely, if ever, done in their life." Additional notes from the focus group interview on day one support this quote, stating that "they [the teachers] mentioned students struggling to understand the X and Y axis of graphs. They rely on math teachers to teach graphing; they feel insecure in doing this themselves." This shows that they were expressing uncertainty about certain aspects of data collection and analysis.

By the end of the PD, in the post-surveys, teachers showed more confidence than they had at the beginning and midway through the workshop. When asked about the efficacy of the data literacy component of the PD, all six teachers responded positively, suggesting that the goals of the PD were met and that teachers felt they had learned something useful for implementing data literacy instruction. When asked what additional support they would need in order to implement the PBL curriculum in their classroom, most teachers said they felt prepared to teach, however some of them mentioned that they were still feeling insecure, such as the teacher that wrote in response to a prompt about foreseen challenges for implementation, "the most difficult challenge will be data analysis, and chart making. I just foresee the students having difficulties... and with my own insecurities about the topic." There were hints that more teachers felt this way than chose to admit it. In response to the question *What would you have liked to spend more time on?*, universally, teachers requested more time with data collection and analysis and "More practice analyzing and creating graphs." So, despite praising the PD for adequately preparing them to teach data literacy, most teachers desired more time to internalize the concepts.

The fidelity of the data literacy components during implementation was low. Though teachers were encouraged to modify the example curriculum to fit the needs of their students and classroom, every teacher cut out at least some of the data literacy components, with some teachers skipping entire lessons and sets of objectives. During the lessons that were observed, many of the teachers struggled with aspects of working with the data. As in the following example where the researcher noted that their "Overall impression of Tamara' data analysis class is that only a surface level of data analysis (getting average) is being taught. Tamara looks a little discouraged since she has been struggling with facilitating these lessons with students." As the teachers struggled to implement the data literacy components of the unit and cut back on the activities and lessons being presented to the students, the bigger picture of the meaning and relevance of data to real-world problems got lost. Teachers fell back on approaches to data literacy that they were comfortable with, which deprioritized focusing on the meaning and relevance of the data sets for exploring real world problems. Together, these findings showed that teachers felt underprepared to teach data literacy in their science classrooms, and though a three week intensive PD helped them to feel more prepared, that increase in confidence did not translate into effective teaching of data literacy.

Discussion and implications

In this preliminary study, the goal was to highlight themes that would help guide the researchers in modifications to the intervention and further support for teachers in developing PCK for data literacy integration. The analysis of data sources tells a story that aligns with common pitfalls of PD (Darling-Hammond, 2017) and the limited literature on teachers engaging with data literacy concepts in their classrooms (Lee & Wilkerson, 2018). By studying how teachers learned and implemented data literacy integration, this research has highlighted the ways in which the PD failed to adequately support teachers in integrating data literacy into their science classrooms, and in the process uncovered the need to focus more on PCK development. Teachers entered the PD a little wary of the data literacy and technology components. They reported learning a lot during the PD and feeling prepared to teach, while simultaneously wishing for more time to grapple with data literacy concepts. However, once they were in the classroom, the confidence faltered, and they mostly fell back on more traditional and conservative understandings of data literacy that divorced the data engagement from the content and framing problem.

The designers and facilitators of the PD overestimated the extent to which teachers would be prepared to implement the data literacy component of the PBL curriculum. The PD was designed based on assumptions that participating teachers would have knowledge and skills about the complexity of data and tools for data analysis that would translate quickly onto the new technology and data sets. However, the challenges that teachers faced in implementing align with the two core competencies for teaching with data laid out by Wilkerson and Polman (2020) and suggest that there may be a separate set of PCK components that teachers need to master in order to successfully teach data literacy, beyond those commonly considered part of science teachers' PCK. In order to better support teachers in integrating data literacy into their science classrooms, PD needs to focus on not only the content of data literacy and its' connections to science content, but also on the separate PCK that teachers need to implement with complex data and new technologies. The findings from this preliminary study add to the growing literature (e.g., Wilkerson & Polman, 2020; Wise, 2020) that highlight the need to support teachers in rethinking the way they engage with data in their science classrooms.

References

Aslam, F., Adefila, A., & Bagiya, Y. (2018). STEM outreach activities: an approach to teachers' professional development. *Journal of Education for Teaching, 44*(1), 58–70.

Darling-Hammond, L., Hyler, M. E. and Gardner, M. (2017), *Effective Teacher Professional Development*. Learning Policy Institute.

Gebre, E. H. (2018). Young adults' understanding and use of data: Insights for fostering secondary school students' data literacy. *Canadian Journal of Science, Mathematics and Technology Education*, *18*(4), 330–341.

Gould, R., Machado, S., Ong, C., Johnson, T., Molyneux, J., Nolen, S., Tangmunarunkit, H., Trusela, L. & Zanontian, L. (2016, July). *Why Teach Data Science?* Proceedings of the Roundtable Conference of the International Association of Statistics Education (IASE), Berlin, Germany.

Lee, V. R., & Wilkerson, M. (2018). Data use by middle and secondary students in the digital age: A status report and future prospects. Commissioned Paper for the National Academies of Engineering, and Medicine, Board on Science Education, *Committee on Science Investigations and Engineering*, 1–43.

Neumann, K., Kind, V., & Harms, U. (2019). Probing the amalgam: the relationship between science teachers' content, pedagogical and pedagogical content knowledge. *International Journal of Science Education*, *41*(7), 847-861.

Rubin, A. (2020). Learning to reason with data: How did we get here and what do we know? *Journal of the Learning Sciences, 29*(1), 154-164.

Wilkerson, M. H. & Polman, J. L. (2020). Situating data science: Exploring how relationships to data shape learning. *Journal of the Learning Sciences, 29*(1), 1–10.

Wise, A. F. (2020). Educating the next generation of data scientists for the next generation of data. *Journal of the Learning Sciences, 29*(1), 165–181.

Wolff, A., Gooch, D., Montaner, J. J. C., Rashid, U., & Kortuem, G. (2016). Creating an understanding of data literacy for a data-driven society. *The Journal of Community Informatics, 12*(3), 9–26.

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International Society of the Learning Sciences

Designing a Global Community of Critical Action Educators

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Abstract: This paper presents the Critical Action Learning Exchange (CALE), an international professional learning community of educators for development and exchange of Critical Action curriculum, resource sharing, and empowerment of students in responding to issues including climate change, social and environmental justice, pandemics, or economic inequality. Our research focuses on teacher knowledge and learning, and examines the role of a pedagogical framework grounded on Knowledge Building (Scardamalia, 2002) and Critical Pedagogy (Freire, 1970) in supporting collaborative design of curriculum. This paper maps our analysis of our first design cycle to Reeves' (2007) four phases of design-based research.

Introduction

This paper presents the Critical Action Learning Exchange (CALE), an international professional learning community of educators for development and exchange of Critical Action curriculum, resource sharing, and empowerment of students in responding to issues including climate change, social and environmental justice, pandemics, or economic inequality. Our research focuses on teacher knowledge and learning through collaborative design, enactment and reflection about Critical Action curriculum with a theoretical perspective grounded in Knowledge Building (Scardamalia, 2002) and Critical Pedagogy (Freire, 1970). This paper adopts a design-based methodology, explicitly mapping our analysis of the CALE design and first year's activities to Reeves' (2007) four phases of design-based research. We focused on three research questions: (1) How can a professional learning community support teachers in designing curriculum that empowers students in relation to pressing social challenges like climate change, pandemics, racism, poverty and inequality? (2) What forms of materials, activities and technology environments are needed to scaffold such a community? And (3) What is an accessible framework to guide teachers' designs of Critical Action curriculum?

The first design cycle culminated in a 5-week online workshop that established CALE's inaugural cohort, with 60 participants from Brazil, Canada, Colombia, and the United States. During the workshop, teachers engaged in collaborative design of curriculum, reflected about classroom practice and student learning, and discussed pedagogical approaches to Critical Action, defined as the engagement in individual and collective action to produce socio-political change in aspects of society that generate unjust, oppressive, harmful, or unhealthy conditions (Jemal & Bussey, 2018). This paper describes our first design cycle of community activities, scaffolds, and technology environment. It reports on the ideas brought in by initial participants and their progress over the workshop, focusing on teachers' developing ideas, as manifested in their curriculum designs, and discussions related to those designs. We close with a discussion of how these analyses contribute to refinements of our theoretical framework, technology environment, and teacher scaffolds.

The need for critical action

This project grows from an understanding of the current global landscape as a point of confluence of several crises, as reflected by the UN Secretary-General António Guterres in his opening speech of the 75th UN General Assembly:

> *"We face simultaneously an epochal health crisis, the biggest economic calamity and job losses since the Great Depression, and dangerous new threats to human rights. COVID-19 has laid bare the world's fragilities. Rising inequalities. Climate catastrophe. Widening societal divisions. [...] Our world is struggling, stressed and seeking real leadership and action." (Guterres, 2020)*

Each of these multiple crises—environmental, sanitary, geopolitical, economic, civilizational—have a direct effect on students. In recent years, new terms such as *eco-anxiety* (Ojala, 2018) and *climate anxiety* (Wamsler & Brink, 2018) have emerged to describe a range of psycho-emotional responses to the perceived threat of climate change, including worry, anger, and hopelessness. Similarly, these kinds of psycho-emotional responses have been reported in groups and communities worldwide that are particularly affected by other situations perceived as oppressive and overpowering, such as systemic racism and other forms of discrimination, war, poverty, etc. (Ridley et al. 2020; Thabet, Thabet, & Vostanis, 2016; Williams, 2018).

Typical school curriculum addresses such complex socio-environmental problems by helping students understand the mechanics of those issues. But such approaches may have the unintended consequence of reinforcing a passive perspective in which students feel alienated from consequential decision-making and action. Research suggests that anxiety might be alleviated by engagement in some form of committed action (Hoggett & Randall, 2018), indicating that approaches that emphasize students' collective agency and connection with others may help educators counter the potentially damaging narrative of overpowering, insurmountable calamities. Moreover, problems such as climate change and threats to democracies around the world decisively affect the future of the current generation of students. Thus, if a goal of Education is to equip children with the means to thrive in the future, we must emphasize pedagogical approaches that reinforce students' agency and empower students through critical action. CALE aims to respond to this challenge by providing both a pedagogical framework for Critical Action education and a structure for teachers' peer support, in the form of a community of educators engaged in collaborative design, enactment, exchange, and advancement of curriculum that empowers students as agents for positive change.

Methods

Design-Based Research (DBR) is an approach used to improve design practice as well as to enhance scientific understanding of how design affects learning (Barab & Squire, 2004). DBR is well suited as a methodology for this study because it will help produce new understandings, theories, artifacts, and strategies that account for and potentially impact knowledge building in a teacher professional community. Figure 1 shows the first iteration (year) of our research design, structured according to Reeves' (2007) 4-phase framework for DBR. Through this cyclical process, a specific design is informed (phase 1), produced (phase 2), implemented and tested (phase 3), and evaluated and refined (phase 4). In this sense, the designed artifact or intervention becomes, in itself, an important outcome of the research, and an object for further inquiry.

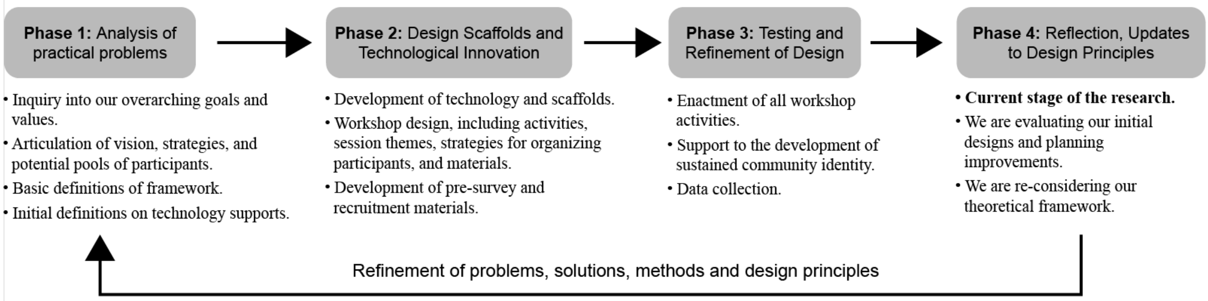

Figure 1: Four phases of our research design. Adapted from Reeves (2007).

Findings

As described in Methods, we present our findings here in terms of Reeves' (2007) four phases of DBR. We focus on the first three phases, as research outcomes, and address the fourth phase in our Discussion.

Phase 1 – Analysis of practical problems

Articulating a theoretical perspective. In Knowledge Building (KB; Scardamalia, 2002) and Critical Pedagogy (CP; Freire, 1970) we identified a set of mutually reinforcing similarities and some important complementary features that offer a solid theoretical foundation for Critical Action education. KB contributes to our approach by proposing a series of practices and principles that foster epistemic agency and collective responsibility to promote continuous improvement of ideas through dialogue and joint investigation (Scardamalia, 2002). CP complements our framework with a philosophy of praxis that stresses the importance of an educative process that interweaves theory, action, and reflection as a means to advance the broader society towards social change and justice (Freire, 1970). CP's commitment to transformative action (Jemal & Bussey, 2018) is articulated around the "problem-posing model" of education proposed by Freire (1970), which intends to reframe inescapable "realities" as actionable "problems".

Conceptualizing goals. A primary goal defined in this phase was to support collaborative design and exchange of Critical Action curriculum. We also sought to support sustained discussions across the community, both within groups of teachers working on the same subject or grade level and among groups to promote cross-cultural collaborations for symmetric knowledge advancement. To support peer feedback and recursive design cycles, we identified the need for a technology environment to make thinking visible, promote discussions, and support international participants engaged in exploring local issues and contexts.

Outlining design elements. Building on our theoretical framework, we began to delineate the forms of technology, materials, and activities that were needed in the design, as well as the survey instruments and communications modes. A website would be needed to support design activities and curation of resources, as well as social networks. Some form of shared document editing, and design templates would be needed for creating curriculum projects. The curriculum could span multiple iterations of design and enactment, such that designs should be versioned, to support derivative use by others. A workshop model was advanced, including theme groups and synchronous and asynchronous modes of interaction.

Phase 2 - Initial designs

Critical Action Pedagogical Framework. We produced the initial version of a pedagogical framework for Critical Action curriculum design, comprising five dimensions: (1) *Knowledge:* How does your design provide opportunities for students to build their understanding of the issue and advance on some ideas?*; (2) Criticality:* How does your design provide opportunities for students to develop a critical perspective of the problem they are exploring and the social structures that might constrain or leverage their actions? (3) *Action:* How does your design help students to move from understanding to acting on the issue? (4) *Individual*: How does your design help students to reflect on their potential unique contributions to this issue, and develop a sense of direction in schooling and career? (5) *Community*: How does your design help students to organize and coordinate their skills, perspectives, and experiences within a community of peers?

Workshop design. We developed a 5-week workshop model, built around the five dimensions of the pedagogical framework, and supported by a website with discussion areas, shared resources, and design templates. Week 1 (Introductions and orientation) introduced the framework and focused on its first dimension (Knowledge). Participants curated resources and strategies, and developed ideas for lesson designs. Week 2 (Curriculum, Pedagogy and Peer Community) engaged teachers in discussions about Critical Pedagogy and design strategies. Week 3 (Designing with a critical eye) focused on Criticality; Weeks 4 (The critical designer's toolbox) and 5 (Teaching practices, reflections and professional communities) progressed through the framework and focused on helping teachers advance their designs and engage in peer review.

Phase 3 - Outcomes and evaluation of initial designs

Participants. Overall, 60 participants signed up to take part in the CALE summer workshop, coming from Minas Gerais (Brazil), Alberta, Quebec, and Ontario (Canada), Bogota and Cali (Colombia), and California (USA). From the total participants in the workshop, 52 consented in participating in the research, and 47 filled out the pre-survey and shared both their past experiences and expectations of the workshop. Our research participants included 3 school administrators, 8 higher-ed instructors, 2 instructional designers and 39 K-12 teachers teaching a wide range of subjects. 25-45 teachers participated in the weekly Zoom meetings.

Workshop outcomes. 8 discussion topics were built upon with 170 different notes in the asynchronous online community discussions. Overall, 10 lesson designs were created by 11 design teams during the 5-week period. Participants worked in 4 different theme groups negotiated during the first synchronous meeting session: Science, Social Justice, Elementary and Higher Education. All four themes saw at least a medium to high level of activity in three coded dimensions: Peer exchange, Sharing of tools and resources, and use of Critical Action elements. During the final synchronous session, all teams shared their designs with the community, and all 28 participants in that meeting expressed interest in continuing within the CALE community.

Community dynamics. We relied on Knowledge Building principles throughout the workshop to support the collective advancement of community knowledge. Every design team received some peer feedback from a different team. On the final day of the workshop, a high school teacher in practice who had designed a "Science at Home" lesson plan stated: "I would not have been able to think of this goal without the CALE group. Having such passionate people come together [...] makes you change your mind and be curious again."

Discussion

After concluding the workshop, we entered Phase 4 of our DBR—Reflections and Updates to Design Principles. This phase generated three main outcomes: (1) a series of modifications to our pedagogical framework; (2) identification of new features to be added to our technology; and (3) the definition of a model for expanding CALE community to a wider international audience

Improvements to the pedagogical framework

To provide improved support for Critical Action learning designs, we modified the framework to include six components—adding an element of "Global" and organizing according to two axes. The first "vertical" axis includes components that move the community increasingly "deeper" towards action. The second "horizontal" axis increasingly broadens the scope of Critical Action from the individual, to the community, to the whole globe:

Vertical axis (depth): (*1) Knowledge.* Critical Action demands a comprehensive understanding of the issue being addressed. This goes beyond helping students acquire knowledge within a domain, to help them develop abilities to acquire, assess, and build new knowledge. (*2) Criticality.* The process of social transformation implies a value judgment on the issue in hand, and a critical analysis of forces and structures in play that might constrain or empower transformative action. (*3) Action.* A Critical Action curriculum recognizes students' potential as transformative agents, contributing to shift their perspective towards socio-environmental issues from "that's just the way things are" to "that's a problem that I can act upon."

Horizontal axis (scope): *(4) Individual.* Students must have opportunities to explore their intersections with the issue, helping each student create personal meaning and purpose in learning and develop a sense of direction. (*5) Community.* Students must be able to coordinate their individual work and collaborate as a community. (*6) Globe.* Socio-environmental problems transcend borders. Students must comprehend the diverse regional contexts, and how their actions interconnect with other local or global initiatives.

New technology features and future events

We identified two important features that will be implemented in future versions of our technology environment: "Projects" and "Exchange". The Projects area will allow participants to create short descriptions of their intended designs to attract possible collaborators and serve as a project management environment to facilitate the definition and tracking of goals, tasks, deadlines, etc. The Exchange area will allow participants to submit completed designs of lesson plans, resources, and enactments. These materials will then be available to other participants to create copies that can be edited, modified, or adapted to different contexts. Finally, the result of our workshop will inform the design of a series of events to establish CALE cohorts in different countries with the intention to move towards the establishment of a fully open global community. For this purpose, workshops will be conducted in India, Brazil, and Tanzania during the first semester of 2021, and a MOOC will be offered in Summer 2021.

References

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The journal of the learning sciences, 13*(1), 1-14.

Jemal, A., & Bussey, S. (2018). Transformative action: A theoretical framework for breaking new ground. *EJournal of Public Affairs.*

Freire, P. (1970). *Pedagogy of the oppressed*. Continuum.

Guterres, A. (2020). *Address to the Opening of the General Debate of the 75th Session of the General Assembly.* Retrieved November 13, 2020, from https://www.un.org/sg/en/node/252655

Hoggett, P., & Randall, R. (2018). Engaging with climate change: Comparing the cultures of science and activism. *Environmental Values, 27*(3), 223-243.

Ojala, M. (2018). Eco-anxiety. *RSA Journal, 164*(4 (5576)), 10-15. doi:10.2307/26798430

Reeves, T. C. (2007). Design research from a technology perspective. *Educational Design Research*, Routledge, New York, 52-66.

Ridley, M., Rao, G., Schilbach, F., & Patel, V. (2020). Poverty, depression, and anxiety: Causal evidence and mechanisms. *Science, 370*(6522).

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. *Liberal education in a knowledge society, 97*, 67-98.

Thabet, A. M., Thabet, S. S., & Vostanis, P. (2016). The relationship between war trauma, PTSD, depression, and anxiety among Palestinian children in the Gaza Strip. *Health Science Journal, 10*(5), 1.

Williams, D. R. (2018). Stress and the mental health of populations of color: Advancing our understanding of race-related stressors. *Journal of health and social behavior, 59*(4), 466-485.

Wamsler, C., & Brink, E. (2018). Mindsets for sustainability: Exploring the link between mindfulness and sustainable climate adaptation. *Ecological economics, 151*, 55-61.

Expansive Framing of Engagement Survey for Online Learners: A Situative Alternative to the Community of Inquiry Survey

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Abstract: *Expansive framing* is a situative instructional perspective that (a) pushes students to make connections with people, places, topics, and times beyond the course, (b) positions students as authors (rather than consumers) of disciplinary knowledge, and (c) holds students accountable to disciplinary discourse. A new survey of perceived expansive framing was completed by 6,452 fully online students as experimental items within the larger National Survey of Student Engagement (NSSE). Exploratory factor analysis uncovered five of the six intended factors in our 16-item survey and the internal consistency of the six scales ranged from 0.77 to 0.86. Significantly, one of our scales (*Outside Places*) was more highly correlated with the NSSE *Perceived Learning* scale (0.56) than any of the NSSE scales. Pending confirmatory factor analysis, we hope the survey will be more predictive of actual learning outcomes than the popular socio-constructivist *Community of Inquiry* survey or the atheoretical NSSE survey.

This study concerns a new survey of student engagement that is based on situative theories of learning (Greeno, 1998). We contend that the design principles for "expansive framing" of learning that emerged in the work of Randi Engle (1965-2012) are among the most useful to emerge from situative theory. These principles suggest learners "problematize" learning from their own perspective by framing their engagement using people, places, topics and times from outside of the course. This positions learners as authors (rather than consumers) of knowledge participating in a larger intellectual conversation while holding them accountable to disciplinary discourses. Expansive framing is proposed to result in *generative* school learning that transfers widely and broadly. This paper first summarizes the roots of these design principles and our own efforts to use them to create engaging online courses. We then describe the socio-constructivist *Community of Inquiry* (CoI) framework and survey that is widely used in online education. After reviewing our concerns and evidence that CoI scores are unrelated to learning outcomes, we describe our new Expansive Framing of Engagement (EFE) survey and our initial efforts to validate it with responses from 6,452 fully online college students alongside the National Survey of Student Engagement (NSSE).

Productive disciplinary engagement

Expansive framing is rooted in Engle and Conant's (2002) introduction of *productive disciplinary engagement* (PDE) to explain a particularly compelling extended discussion that was recorded in a 5th-grade environmental science classroom. Engle and Conant's analyses were distinctive because they used situative theories of cognition (i.e., Greeno, 1998). Most prior characterizations of student engagement (i.e., in the processes of learning) focused on cognitive associations and thinking processes. In contrast, PDE characterized engagement fundamentally in terms of *discourse*. While this engagement is most obvious in classroom discussions, it can also take place as students interact independently with educational resources. From a PDE perspective, engagement means that students are making substantive contributions to discussions, coordinating their contributions with those of others, attending to others, demonstrating passion or emotion, staying engaged for long periods of time, and spontaneously re-engaging. Regardless of its form, PDE refers to engagement that concerns the *discipline* at hand.

Engle and Conant concluded that there were four "guiding principles" that had caused the PDE they documented. The first principle was *problematizing content*. This principle suggests that educators "should encourage students' questions, proposals, challenges, and other intellectual contributions, rather than expecting that students should simply assimilate facts, procedures, and other 'answers'" (p. 404). The second principle for fostering PDE is *giving students authority*. This is about "students having an active role, or *agency*, in defining, addressing, and resolving such problems" (p. 404). The third PDE principle is *holding students accountable to others and to disciplinary norms*. This means that "the teacher and other members of the learning community foster students' responsibility for ensuring that their intellectual work is responsive to content and practices established by intellectual stakeholders inside and outside of their immediate learning environment, as well as to disciplinary norms" (p. 405). The fourth PDE principle, *providing relevant resources*, reminds educators that students need time and resources to accomplish the goals of the first three principles, and warns that the quest for "authenticity" may lead to disciplinary resources that are too advanced to be used productively by intended students. Arguably, the PDE principles are among the most useful and used instructional frameworks to emerge from situative theories. Engle's (2012) retrospective review identified fourteen other widely cited efforts to reform mathematics or science instruction (many of which occurred before 2002) that had been described by others (i.e., not Engle) as being consistent with the PDE framework.

Expansive framing

The design principles for expansive framing emerged across several studies that moved PDE into the study of *transfer* and the search for generative school learning. This includes Engle's (2006) further analysis of the data from Engle & Conant (2002), the quasi-experimental tutoring studies in Engle and Faux (2006) and Engle et al. (2011), and the extended program of secondary biology research reported in Zheng et al. (2011/in revision). All of these studies pushed learners to frame their learning expansively by (a) finding connections with *settings* (*times*, *places*, and *participants*) and *topics* beyond the learning environment, and (b) positioning learners as authors (rather than consumers) of disciplinary knowledge who are participating in a broader intellectual conversation that extends over time.

The insights across this program of research were summarized in Engle et al. (2012), which presented five explanations of why expansive framing should promote transfer. These included *creating more "intercontextuality" between settings during learning*. Practically speaking, this means that it is crucial for teachers to help students make connections between the learning context and potential transfer contexts. The second closely related explanation is that students will be *more likely to recognize the relevance* of the learned content in the transfer context. The third is that students should *transfer in more of their prior knowledge* because they see the relevance of the prior knowledge and because that knowledge might be uniquely useful for framing and therefore socially desirable. The fourth explanation is that positioning students as authors is likely to *foster accountability to content* which engenders confidence in using that knowledge in potential transfer contexts. The closely related fifth explanation is that positioning students as authors should lead them to *position themselves as authors in transfer settings* independent of the transfer content. In other words, multiple experiences authoring knowledge should result general disposition toward authorship in all settings. The paper provided detailed examples from multiple prior studies for each of these five explanations and went on to consider the potential interactions between the explanations.

While not as widely taken up as PDE, a review by Hickey et al. (2021) identified several promising efforts by others to use expansive framing to support generative learning. This includes our own efforts to use expansive framing to foster PDE in a wide range of online courses, including secondary, undergraduate, graduate, professional, and conventional, open, self-paced courses (e g., Hickey et al., 2017, 2020). Beyond this work, PDE and expansive framing have yet to be taken up widely in online education and computer-supported contexts (but see e.g., Sinha et al. 2015; Fasso & Knight, 2015; Damşa, 2014; Mendelson, 2010). This is surprising because framing seems particularly important in online courses, where curricula must be developed in advance and instructors cannot frame content "on-the-fly" in classroom discussions. This is presumably due in part to the dominance of didactic/expository approaches (as in most MOOCs) and socio-constructivist approaches (embodied in CoI discussed below) and the tensions between them. This situation is likely further due to the emergence of "connectivist" theories of digital learning (Siemens, 2005) that capture some (but we believe) not all of the aims of expansive framing.

The Community of Inquiry framework and survey

Our secondary purpose is creating an alternative to the popular *Community of Inquiry* (CoI) framework and survey that are widely used in online learning research. Consistent with modern socio-constructivist learning theory, Garrison, Anderson, and Archer (1999) characterize the ideal educational experience as "a collaborative communication process for the purpose of constructing worthwhile and meaningful knowledge" (p. 92). CoI is organized around three aspects of "presence." These include *social presence*, *cognitive presence*, and *teaching presence*. The factor structure of the COI survey has been validated (Garrison et al., 2004); and it has been used in over 1,500 empirical studies of online learning (Kineshanko, 2016).

Our concern is in part that the CoI survey seems likely to encourage relatively bounded framing of course contexts. This is because most of the 34 CoI items define presence *within the context of activities and courses themselves*. Just two of the cognitive presence items appear to capture perceptions of anything remotely related to expansive framing. From our perspective, this explains the lack of evidence that CoI scores are related to actual learning outcomes (not just *perceived* learning outcomes). Rourke and Kanuka (2009) reviewed 48 empirical studies of CoI published between 2000 and 2008, and they concluded that only 5 studies measured perceived learning and that none measured actual learning. More recently, Maddrell et al. (2017) found no relationship between the three CoI presences and instructor-assessed learning outcomes.

A practical concern is that the CoI framework encourages practices like individual student-teacher interactions and complex group projects that may be unnecessary, unmanageable, and/or exhausting. Our own approach to online expansively framing (Hickey et al., 2017; 2020) minimizes private instructor grading and student interaction, maximizes public instructor and peer-to peer interactions, and minimizes group projects. More generally, we believe that the interactions encouraged by the CoI framework are partly responsible for the workload and instructor burnout associated with high-quality online courses (e.g., Fox & MacKeogh, 2003; Shea et al., 2010).

With a small internal grant, our original goal was creating an Expansive Framing of Engagement survey and administering it alongside the CoI survey in several large undergraduate online STEM classes that included a high-quality learning outcome assessment. We expected that some of the EFE scales would be highly correlated with those learning outcomes and that all of our scales would be more highly correlated than any of the CoI presences. However, we were unexpectedly presented with an opportunity to administer our new EFE survey items as experimental items to at least 6,000 fully online college students who were also completing the 170 items on the long-running National Survey of Student Engagement (NSSE) administered by the Indiana University Center for Postsecondary Research.

Method

Drawing on Zheng, Engle, and Meyer (2011/in revision), 16 items were drafted to create six scales: *Time:Past*, *Time:Future*, *Other Places*, *Other Topics*, *Roles:Authoring*, and *Roles:Accountability*. Thus, one of the Other Places items asked, "During the current school year, about how often have you ... made connections in a course with settings outside of that course?" ("very often," "often," "sometimes," "never"). Draft items were revised in three cognitive interviews and reviews by NSSE experts; items were deleted to meet a 16-item limit on experimental items, resulting in two to three items per scale.

The 16 EFE survey items were completed by 6,452 fully online college students alongside 170 other NSSE items in 2019. An exploratory factor analysis (EFA) was carried out with odd-numbered participants. The correlations between six EFE scales and other NSSE measures of perceived engagement were explored, with a focus on the *Perceived Learning Gains* NSSE scale.

Results

The EFA showed that the hypothesized factors were indeed present in the data, with the exception of Time:Future and Other Places collapsing into a single factor. This exception made sense in retrospect, because any activity outside of a course necessarily takes place at a different time. Nonetheless, the original six-factor model yielded an acceptable fit with $CLI = 0.944$, $TLI = 0.925$, and $RMSE = 0.064$. Each of the six scales demonstrated reasonable internal consistency (alphas 0.77 to 0.87) and the scale intercorrelations ranged from $r = 0.81$ (Time:Future and Other Places) to $r = 0.42$ (Time:Future and Roles:Authoring). Most importantly, the Roles:Authoring and Roles:Accountability scales (which theoretically reflected the result of the of the other four perceived aspects of engagement) demonstrated acceptably low correlations with the other four scales (< 0.56), though we acknowledge that correlations were attenuated by the lower reliabilities of the two Roles scales. Notably, scores on the EFE Other Places scale were more highly correlated ($r = 0.56$) with the NSSE Perceived Learning Gains scale than any of the ten NSSE perceived engagement scales (though NSSE *Supportive Environment* was $r = 0.55$).

Conclusions and next steps

These results are promising. Our intended factor structure was mostly confirmed, and the scales were sufficiently reliable. Our next step is conducting a confirmatory factor analysis with the existing 16 items. We will then add one item to each of the two 2-item scales, resulting in a 19-item scale. We will also revise the existing items to (a) increase divergence between Other Places and Time:Future and between Other Places and Other Topics and (b) increase the reliability of the crucial Roles:Authoring and Roles:Accountability scales. Consistent with our original goals, we will then administer the revised EFE, the CoI survey, and one or more of the NSSE engagement scales to students in one or more large general education STEM course that includes outcome measures that estimate likely transfer to subsequent educational, professional, and personal settings.

References

Cognition and Technology Group at Vanderbilt. (1990). Anchored instruction and its relationship to situated cognition. *Educational Researcher*, *19*(6), 2–10.

Damşa, C. I. (2014). The multi-layered nature of small-group learning: Productive interactions in object-oriented collaboration. *International Journal of Computer-Supported Collaborative Learning*, *9*(3), 247–281.

Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, *20*(4), 399–483.

Engle, R. A. (2006). Framing interactions to foster generative learning: A situative explanation of transfer in a community of learners classroom. *Journal of the Learning Sciences*, *15*(4), 451–498.

Engle, R. A. (2012). The productive disciplinary engagement framework: Origins, key concepts, and developments. In D. Y. Dai (Ed.), *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning* (pp. 161–200). Routledge.

Engle, R. A., & Faux, R. B. (2006). Towards productive disciplinary engagement of prospective teachers in educational psychology: Comparing two methods of case-based instruction. *Teaching Educational Psychology*, *1*(2), 1–22.

Engle, R. A., Nguyen, P. D., & Mendelson, A. (2011). The influence of framing on transfer: Initial evidence from a tutoring experiment. *Instructional Science*, *39*(5), 603–628.

Engle, R. A., Lam, D. P., Meyer, X. S., & Nix, S. E. (2012). How does expansive framing promote transfer? Several proposed explanations and a research agenda for investigating them. *Educational Psychologist*, *47*(3), 215–231.

Fasso, W., & Knight, B. A. (2015). Knowledge transfer in community-embedded learning: A case study. *Journal of Education Research*, *9*(3), 267–281.

Fox, S., & MacKeogh, K. (2003). Can elearning promote higher-order learning without tutor overload? *Open Learning: The Journal of Open, Distance and e-Learning*, *18*(2), 121–134.

Garrison, D. R., Anderson, T., & Archer, W. (1999). Critical inquiry in a text-based environment: Computer conferencing in higher education. *The Internet and Higher Education*, *2*(2-3), 87–105.

Garrison, D. R., Cleveland-Innes, M., & Fung, T. (2004). Student role adjustment in online communities of inquiry: Model and instrument validation. *Journal of Asynchronous Learning Networks*, *8*(2), 61–74.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American Psychologist*, *53*(1), 5–26.

Hickey, D. T., Chartrand, G. T., & Andrews, C. D. (2020). Expansive framing as a pragmatic theory for instructional design. *Educational Technology Research and Development*, *68*(2), 751–782.

Hickey, D. T., Chartrand, & Harris, T. (2021, April). *A comprehensive review of productive disciplinary engagement and expansive framing*. Paper presented at the American Educational Research Association conference

Hickey, D. T., & Uttamchandani, S. L. (2017). Beyond hype, hyperbole, myths, and paradoxes: Scaling up participatory learning in a big open online course. In E. Losh (Ed.), *MOOCs and their afterlives: Experiments in scale and access in higher education* (pp. 13–36). University of Chicago Press.

Kineshanko, M. K. (2016). *A thematic synthesis of community of inquiry research 2000 to 2014* [Doctoral dissertation, Athabasca University]. Athabasca University DTheses.

Maddrell, J. A., Morrison, G. R., & Watson, G. S. (2017). Presence and learning in a community of inquiry. *Distance Education*, *38*(2), 245–258.

Mendelson, A. (2010). Using online forums to scaffold oral participation in foreign language instruction. *L2 Journal*, *2*(1), 23–44.

Rourke, L., & Kanuka, H. (2009). Learning in communities of inquiry: A review of the literature. *Journal of Distance Education, 23*(1), 19–48.

Shea, P., Hayes, S., & Vickers, J. (2010). Online instructional effort measured through the lens of teaching presence in the community of inquiry framework: A re-examination of measures and approach. *International Review of Research in Open and Distributed Learning*, *11*(3), 127–154.

Siemens, G. (2005). Connectivism: Learning as network-creation. *ASTD Learning News*, *10*(1), 1–28.

Sinha, S., Rogat, T. K., Adams-Wiggins, K. R., & Hmelo-Silver, C. E. (2015). Collaborative group engagement in a computer-supported inquiry learning environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(3), 273–307.

Zheng, K., Engle, R. A., & Meyer, X. S. (2011/in revision). Student responsiveness to the teacher's expansive framing. Paper presented at the annual meeting of the National Association for Research on Science Teaching and in revision for Journal of the Learning Sciences.

Symposia

Dignity Affirming Learning Contexts

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Abstract: We examine how individuals from non-dominant communities and very young children engage with others in ways that affirm their educational dignity—"the multifaceted sense of a person's value generated via meaningful participation in substantive intra- and inter-personal learning experiences that recognize and cultivate one's mind, humanity, and potential" (Espinoza et al., 2020, p. 19). We analyze dignity through the lens of agency and affect to explore interactions between an autistic child playing with a family friend, Indigenous families on forest walks, young people's use of media for affective and sociopolitical action., and a young child recruiting adults to engage in an occasioned knowledge exploration practice. Through pairs of junior Learning Scientist with experts from child development, cultural psychology, anthropology, and linguistic anthropology, we articulate how sharing agency and centering affect can support new possibilities for dignity affirming learning contexts.

Symposium overview

Learners conceptualized as "normal" receive vastly different treatment than those seen as abnormal, outside the norm, or even defined as what they are not-yet (e.g., not-yet adults, Annamma et al., 2013; Goodwin, 1990). The developmental trajectories of White, middle-class neurotypical older children are used as a marker for normality. These trajectories become set-points leading to the categorization of many youth and families from non-dominant communities and neurodivergent learners as deficient or less than "normal" (Annamma et al., 2013; Rogoff, 2003). Young children who are often viewed as not-yet fully developed can also be categorized as less than fully human (Canella, 1999). These deficit perspectives operate at the intersections of identities and differentially lead to lower expectations for learning, restricted learning opportunities, and we fear reduced opportunities for dignity affirming experiences in learning contexts. Although deficit perspectives are leveraged against youth of color is different is critical ways from those leveraged against neurodivergent persons (Annamma et al., 2013) or young children, scholars are increasingly identifying patterns in how repertoires of practice for communicating, attending and observing, resisting and transforming, and inquiring across diverse communities co-constitute dignity-affirming learning contexts that expand and transform conceptualizations of typical developmental pathways.

We seek to spark conversation about how particular populations are/aren't positioned with dignity in consequential learning contexts through analysis of everyday activity. To do so, we present a framework addressing the need to attend to agency and affect when seeking to understand dignity-affirming learning contexts. The overview then provides a brief description of symposium organization. We then present four sets of junior-senior scholar-pairs as they engage together in analysis of junior scholars' data through the lens of senior scholars' work from diverse disciplinary perspectives (i.e. child development, cultural psychology, anthropology).

Conceptual framework: Affect and agency in dignity affirming learning contexts

We position those often framed as not-fully- or not-yet-human as multi-faceted beings engaged in making sense of the fullness of their humanity and their worlds. This at once feels like an obvious call and a radical push against oppressive conceptualizations of limited human capacity for those at the margins and not-yet-grown. It is a necessary move to understand the diversity of human learning (Gutiérrez & Rogoff, 2003; Philip et al., 2018).

We take up Espinoza, Vossoughi, Rose, and Poza's (2020) definition of educational dignity as "the multifaceted sense of a person's value generated via meaningful participation in substantive intra- and inter-personal learning experiences that recognize and cultivate one's mind, humanity, and potential" (p. 19). This definition recognizes a person's value is inherent in the person, but that such dignity is affirmed and fully realized only within social interaction. Thus, it is not enough to state someone has dignity; it must be enacted and affirmed. This framing of dignity is positioned within a sociocultural lens on everyday learning, being, and doing in the world. This lens on life recognizes that abstract ideas like dignity, agency, and affect are brought into being through persons-in-interaction (Blumer, 1954). Just as "dignity relies on social action for its manifestation" (Espinoza, 2020, p. 19), agency is also a collaborative endeavor (Damşa et al., 2010; Gresalfi et al., 2009), and affective stances help create the social order of interaction that affirms dignity (Goodwin & Cekaite, 2018). Thus, each scholar-pair examines these sociocultural understandings of persons-in-interaction in their analyses.

Our selection of dignity, agency, and affect is purposeful. Returning to our central construct of educational dignity, we recognize vulnerability between participants creates "emotional and cognitive conditions" that facilitate "sharing of histories and testing of ideas" (Espinoza et al., 2020, p. 14) in learning interactions. Each scholar pair examines how particular affective states (e.g., playfulness, wondering, love, curiosity) create contexts for learning, drawing on affect as central to learning as an emerging theme in Learning Sciences research (e.g., Jaber & Hammer, 2016). Agency as an interactional accomplishment, a core Learning Sciences conceptualization of agency in learning contexts (e.g., Damşa et al., 2010; Gresalfi et al., 2009), sheds light on processes supporting engagement in particular ways of knowing as well as their inquiries about knowledge itself. By this we mean that we wish to understand how young people already take initiative to create learning contexts (e.g., de León, 2015) and how learning designs can further position those who historically occupy social positions deemed to have less power (e.g., nonverbal neurodivergent individuals, Indigenous families, youth of color, young children) as agentic co-creators attending to "pressing philosophic concerns" (Espinoza et al., 2020, p. 18). In doing so, we hope to better understand how sharing agency may lead towards imagining new possibilities and transforming existing structures to achieve those possibilities (see Calabrese Barton & Tan, 2010). Taken together, we believe this framework will allow us to better understand how participants-in-interaction can respond with care—attending to another to enhance their wellbeing (Goodwin & Cekaite, 2018)—through dignity affirming interactions.

Format

We propose a non-traditional format based on a successful special session on the socio-political and ethical horizons of the Learning Sciences (Vakil et al., 2020) that was designed to support learning with and from junior and senior scholars. Scholars were matched with the intent of shedding light on the conceptual and methodological focus of junior scholars through the extensive bodies of work from senior scholars (Figure 1).

Chen	draws on	Cekaite's work to	explore how learning ecologies that uphold the communicative agency of autistic individuals occur through the creation of flexible sociomaterial spaces
Marin	draws on	Rogoff's work to	examine the role of attention and observation as Indigenous families with young children take walks through forest preserves together
Cortez	draws on	de León's work to	examine the ways non-dominant populations develop agentic and political stances as they leverage digital technology in their everyday lives
Keifert	draws on	Goodwin's work to	examine how adults respond to a child's spontaneous curiosity by following his lead to affirm his family occasioned knowledge exploration practice

Figure 1. Junior-Senior Scholar-Pairs and their Analytical Focus

Following a brief introduction (3min), junior-senior scholar pairs will present data from junior scholars' work and analysis based on foundational ideas from senior scholars' theory with a lens on dignity, affect, and agency (10min each). Scholar-pairs will then respond to prompts from our discussant (5min). Following these cycles of junior/senior scholar pairs (total 60min), our discussants, Drs. Kris Gutiérrez and Shiri Vossoughi will provide reflections (12min) before guiding our discussion with all attendees (15min). These pairings and the process for reflection provide avenues to expand disciplinary boundaries of LS and contribute centering educational dignity.

Significance

There continues to be a need to draw on research of interactions and learning in ways that support "humanizing creativity" (Espinoza et al., 2020, p. 9) requiring the continued development of research approaches that center diversity (Medin et al., 2017). This includes deepening understandings of how marginalized young people and those construed as not-yet-developed navigate the multiple communities in which they situate themselves. The analyses shared in this symposium as well as the scholarly pairings will support dialogue about how people collaborate in meaningful ways in their own learning, being, and doing in the world. In so doing, this work contributes to understanding the "diversity of human cognition and development beyond participants, methods, and purposes" rooted in White-dominant norms (Philip et al., 2018, 83). We present now our four scholar-pairs: Rachel Chen & Asta Cekaite, Ananda Marin & Barbara Rogoff, Arturo Cortez & Lourdes de León, and Danielle Keifert & Marjorie Harness Goodwin.

The transformative role of a stimming object in autistic interaction

Rachel Chen and Asta Cekaite

Autistic individuals form close, affective, sensorial relationships with objects (Conn, 2015). Many of these objects are involved in the enactment of repetitive movement (e.g. tapping, rocking, flapping), a category of behaviors that diagnostically defines Autism (DSM-5, 2013), otherwise termed *stimming* by the Autistic community (Kapp, 2013). Whereas autistic object usage is traditionally conceived as rigid and inflexible, especially if involved in stimming (Leekam, 2011), the prevalence of objects in children's sensory play suggests they may be used more creatively than previously assumed. The propensity to repeat and innovate is prevalent in neurotypical children's interactions, through playful recyclings of repetitive language (Cekaite, 2004) or locomotor imitation and elaboration (Hoey et al., 2018) as an affective context for play. Embracing the significance of objects in autistic interaction may reveal inventiveness that may otherwise be missed. This line of work has implications for Special Education and the creation of flexible sociomaterial environments that reveal, and thus celebrate the communicative agency of the Autistic student.

Background and methodology

The video data selected for analysis is of Matt, a 6-year-old non-speaking boy on the Autism spectrum, and his interaction with Ben, a 17-year-old family friend. The data come from a video ethnography corpus of naturally-occurring interactions between Autistic children and their families, educators, and friends. The object of focus in this extract is a plastic hair comb, which at the time of data collection, was Matt's most frequently held object. Due to its flat surface and its ergonomic size for Matt's hold, it became an object for his repetitive tapping (Figures 2-5). Prior to the start of the recording, Matt's sister finds his comb lying on the floor. She picks it up just before Matt runs towards it, and playfully passes it to Ben. This analysis focuses on the evolving role of the comb as the interaction unfolds.

Data analysis

Establishing new understandings of objects as something other than its original function requires complex interactional work (Cobb-Moore, 2010). Ben first transforms the function of the comb into the object of play by dangling it in front of Matt's face (Lines 21 and 26), lifting it beyond Matt's reach just as Matt attempts to grab it (Lines 23-25, 28-29). As the interaction unfolds, the comb's function is continuously transformed, and the emerging game between both participants traverses through different play genres. After Matt's many unsuccessful attempts to grasp the comb, Matt produces a surprising social action: He grabs Ben's wrist and brings the comb to his hair, pretending to enjoy having his hair combed. In a swift move, Matt raises his left hand and grabs the comb from Ben's hand, bursting into laughter when he is successful in this endeavor.

```
21  MATT       [d'wan']=
22        =((eyes on comb))
23         ((snatches comb))=
24  BEN   =|((brings it away))
25         |ooh↑.
26  MATT  H[h. hhhhh.
27  SIS    [hh. Hhhhh.
28  MATT  |°hoo°
29        |((tries to snatch comb))
30  BEN   M|m-ho:↑-|no:.
31          |((raises comb away))
                   |((lowers comb))
```

Figure 2. Matt and Ben interact together with the comb.

Figure 3. Matt pretends to comb hair.

Figure 4. Matt grabs the comb.

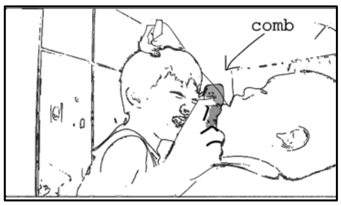

Figure 5. Matt laughs, lowering his hand.

From the object of a stim, to the object of a game, Matt uses the original function of the comb—for one's hair—as a means to 'win' the comb back from Ben. The transformative role of the comb reveals Matt's ability to be flexible and creative with his favorite object. By enacting the first transformation of the comb into the object of a game, and by through his interaction with Matt, Ben is creating a learning ecology where Matt and Ben can come into intercorporeal attunement, affective embrace, and creative transformation. This short analysis shows how a dignity-affirming learning context is constituted through affective (playful) collaborative transformations of the object-centered activities, spontaneously occurring in mundane interaction.

The multiplicities of dignity-affirming interactions: Accounting for multispecies ensembles as a context for the coordination of attention and observation

Ananda Marin and Barbara Rogoff

We bring the framework of dignity-affirming learning as meaningful participation in interaction that cultivates a person's value into conversation with our shared interest in learning through the coordination of attention and observation. We also extend the framework of dignity-affirming leaning to consider the role of more-than-human subjects in meaningful participation. Our individual research programs unite around a collective interest in foregrounding diversity in the cultural processes of learning. Over the last three decades, Barbara Rogoff and colleagues have iteratively articulated Learning by Observing and Pitching In to family and community endeavors, or LOPI, as a multifaceted approach to learning. This approach is common in Indigenous communities in the Americas (Rogoff, 2014). Three facets of LOPI are particularly germane to our consideration of the interactional accomplishment of dignity: (a) social organization of endeavors through collaborative, flexible ensembles (facet 3), (b) wide, keen attention and contribution to events (facet 5), and (c) communication based on coordination through a shared reference in collective endeavors (Rogoff, 2014). Marin (2020), building with this approach and Indigenous educational philosophies (Cajete, 2000; Simpson, 2011) has examined Indigenous families' forest walks as a context for understanding learning through *the coordination of attention and observation on the move.*

In this paper we ask: *how do young children along with adults coordinate attention and observation while on the move as they engage in flexible ensembles with more-than-human kin?* What patterns do we notice with engagement and how might this expand our understandings of LOPI? To ground our discussion of these questions we first review the scholarship of Rogoff and colleagues who have consistently found cultural differences in the organization of attention and collaboration. For example, in one study with Navajo children, López et al. (2012) have shown that when one child took lead and provided instruction for game play other children remained engaged. This finding has been replicated with Mexican-heritage children whose families come from communities with Indigenous history. In contrast, European-American children whose families have extensive history of participating in Western schooling follow a different pattern. For example, when three or more European-American children took part in a task making puzzles or model toys and one child took lead the others tended to go off task with more frequency. Importantly, the tasks which contributed to this body of work were primarily conducted in indoor settings where children were seated. We extend Rogoff's work on cultural patterns in multi-party engagement to further examine how research contexts inform our creation of developmental theory.

When we shift our analytical lens to consider the role of lands/waters in interaction then more-than-human kin as co-participants in ensembles becomes magnified. Moreover, children's engagement in flexible ensembles that include more-than-human kin can look quite different from children's participation and engagement with playing board games. We suggest that in the context of forest walks, staying engaged as people participate in flexible ensembles with more-than-human kin widens the perceptual field and consequently young children use a variety of combinatorial and multimodal formations for coordinating attention and observation. To further explore this work hypothesis, we present a case example from the forest walk of an Odawa (Native American) mom, and her two sons Jason (age 7) and Sam (age 4). They were asked to go on a series of walks, five in total, as a part of a case study on how families coordinate attention and observation as they learn about the natural world. On the family's third walk they made their way into the forest canopy where they noticed trails which Jason declared were made by an animal, setting up an affect stance for wondering together. A few minutes later, Jason says, noticed "fresh tracks." Amazed by the size of the track Jason commented "Ah, there's no such thing as an animal that bigga foot." His mom then asked what made the footprint and Jason responded with "some animal." This interaction highlights the role of affect in learning. Jason's amazement with his observation creates a context for multi-party engagement and collaborative storying of the environment. In this moment a multispecies ensemble is created that includes human and more-than-human kin. As the family moves to find their way, Jason, uses a stick to point out frog prints ("Hey look it, frog prints, these are..."). As he does this, his younger brother Sam orients his body so that he is facing Jason and both look down at the ground (Figure 6A). Jason then reorients and begins walking along the trail again (Figure 6B). Sam who is behind Jason says "I think there's frogs living in here." Sam, then says "I, go" as he bends his knees getting ready to jump. He jumps three times, each time saying "jump" before running ahead of his brother (Figure 6C). Meanwhile, Jason is still making sense of the foot prints. In a low voice, almost as if he is speaking to himself, he exclaims, "And the coyote caught it. Dropped it a couple times. That must be the story of the footprints."

A. B. C.

Figure 6. Images of Jason and Sam's unfolding action from the mother's wearable camera.

Recognizing the agency of more-than-human kin is a common practice among Indigenous communities (Bang & Marin 2015; Cajete, 2000; Kimmerer 2013; Simpson, 2011). In the case presented here we see young Indigenous children recognizing more-than-human kin (i.e., coyotes, frogs) as agents who like them are interacting with lands/waters. At the beginning of the interaction presented Sam and Jason are in a face to face formation that includes land. This formation provides an essential context for the coordination of attention and observation and engagement with the question at hand (who made the tracks?). Once this shared reference is achieved, the formation changes, with Jason and Sam in a tandem formation. This shift could be read as out of sync. Instead, we suggest that this is shift is dignity affirming. Both Sam and Jason explore their relationship to the particularities of the land they are walking. Sam embodies the movements of frog and Jason stories the interaction of frog and coyote. This new formation provides opportunities for both children to maintain their ensemble and participate in ways that support their ability to meaningfully contribute to walking, reading, and storying land. Taking this analytical approach helps to explicate how attention and observation are maintained in ways that include lands/waters and affirm the dignity of young persons in interaction with each other.

Agency, affect, and morality in virtual spaces of nondominant youth: Nuevas Expresiones de Amor y Empatía

Arturo Cortez and Lourdes de León

We extend the notion of dignity-affirming learning contexts to illuminate the development of moral and affective stances in the microlevel processes of non-dominant young people as they engage in everyday usage of digital technology and new media. Drawing on an ecological perspective, we contend that virtual learning environments create opportunities for young people to resist, rearticulate, and transform their cultural repertoires of practice (Gutiérrez & Rogoff, 2003) as they engage in socio-political critique and the micropolitics of affective exchanges in their virtual communities of practice. This engagement is enacted through video game play, romantic textual exchanges, and exchanges in virtual landscapes. In the following, we explore how we take up these examinations in our work and offer considerations for future inquiry.

In the context of social rebellion and global pandemic, digital technology and new media are increasingly leveraged as part of people's everyday practices of civic engagement, opening up "emerging forms of agency" (de León, 2017, p. 463), activism, socio-political critique, and other forms of resistance that can be imagined and enacted in our societies (de Kosnik, 2016; Lizárraga & Cortez, 2019). Online video game play has gained traction as a site of digital activism, especially in opening up new theoretical, methodological, and pedagogical possibilities for studying the ingenuity of young people (Gutiérrez, et al., 2017; Rivero & Gutiérrez, 2019). Mirra and Garcia's (2020) notion of speculative civic literacies highlights the development of "expansive, creative forms of meaning making and communication aimed at radically reorienting the nature and purpose of shared democratic life toward equity, empathy, and justice" (p. 297). Drawing from Mirra and Garcia (2020) and de León's (2017) examinations of digitally mediated practices as consequential for meaningful cultural and linguistic activity, Cortez's study examines the development of *speculative activist stances*—defined as a co-constructed repertoire of resistance practices, leveraged across digital and social media domains, oriented toward organizing new civic futures. Goodwin's (2007) participation frameworks illuminate the epistemic, moral, and affective stances that participants engage in as they develop new digital, social, and imaginary worlds. In particular, this study examines how speculative activist stances were co-constructed and enacted in an online gaming ecology, composed of young people from across the world as they organized a tribute and memorial to George Floyd, organized a protest of the endemic police violence against Black communities, while they played *Grand Theft Auto V*. Through the analysis of the microprocesses of multiple types of interactions (Figure 7: game moves, online streamed chat, and talk among the players) in video game play, this study argues that speculative activist stances illustrate how young people contend with, complicate, and rupture mainstream notions of activism. Here, young people are co-constructing new types of activist practices that bring together notions of care, love, solidarity, and aggression as they challenge hegemonic power structures in their microlevel practices. This study offers implications for the design of learning environments that could leverage video game play as a central site for the development of sociopolitical action and critique.

Figure 7. Screenshots of *GTA V*. (a) Funeral of George Floyd. (b) Protest at Police Station. (c) Memorial for George Floyd; cars lined up in "GF".

In a parallel fashion, de León examines romantic texting and ethnopolitical virtual landscapes among Mayan Tzotzil youth as discursive practices that have their effect in a contentious field of social activity, indexing micro-processes that contribute to the reconfiguration of new subjectivities, feelings, and moralities (Ahearn 2001). She argues that digital communication has not only produced new forms of courtship, affect, and ethnopolitics but has also fostered new technological, linguistic, and literacy skills that have significantly changed repertoires of identity (Kroskrity 2000), voice, and imagined possibility among Mayan youth (de León, 2017).

Both Cortez's and de León's projects reveal youth's ingenuity in crafting new social personas in the multimodal deployment of affectivities and moralities that enable new alignments, visions, and practices for social futures. We consider these virtual communities of practice as a potential site to understand how nondominant youth rearticulate socio-political critique and cultural repertoires of practice.

Cultivating educational dignity by following children's serendipitous curiosity

Danielle Keifert and Marjorie Harness Goodwin

How is educational dignity cultivated by following children's curiosity? Curiosity is a powerful affect central to being human. Occasioned knowledge exploration (OKE)—moments when people "extemporaneously connect new knowledge to existing knowledge in collaborative endeavors" (Goodwin, 2007, p. 97)—and family practices (Keifert, 2015) shed light on explorations of "fanciful worlds as well as more mundane actual situations" (Goodwin & Cekaite, 2018, p. 206). We wonder how noticing family OKE practices allows teachers to follow children's curiosity in school. Figure 8 summarizes two of Charlie's (2y10m) experiences recruiting adults to explore stories about which he was curious by animating—giving voice to (Goffman, 1979)—to characters.

C: **Did you talk about um Up come?**
M: And then Up started? An what part of Up do you want to talk about?
C: **An' an the dogs-...why did he eat his dinner?** *Charlie touching Mommy's arm.*
M: Oh, the dogs were eating the little kid's dinner? The little kid had a hot dog, huh.
M: n' you remember when you go to see Grandpa and Grandma sometimes.
C: Yeah.
M: And what's their dog's name? *Mommy tilts her head towards Charlie.*
C: Gem.
D: And what did Gem do to you once?
M: Does Gem every eat your food? *Mommy squints and makes a little face at Charlie.*
C: Yeah.
M: You have to be careful and be up high, huh.
C: Why?
M: Because Gem sees that food that thinks boy am I hungry, and boy does Charlie's dinner look good. And then she goes amnom nom nomnomnomnom and she eats it all up. *Mommy makes chomping gesture with her hand for each "nom".*
C: Why I don't like that. ((Charlie shakes his head no))
M: I know you don't like that. So you have to keep it away from her, huh...
M: But the kid in the movie doesn't know that an' so he doesn't keep his food away. And there's a::ll of those dogs in that house. And they all just keep coming up and saying, 'Hmm that looks good. I think I'll take a bite. Ohmp.' *Mommy moves her head and takes an exagerated bit of air with each "Ohmp."* And another one comes up and goes, 'Hmm, that looks look. I think I'll take a bite o that. Ohmp." And before you know it. It's all gone. They've eaten his whole dinner.
C: But, a-
M: And he's going 'Hey. Eah! Eah! Where's my food going?' And then his food's all gone.
C: Wha- is he hungry?
M: He's probably still hungry, huh.

TM: They made him king of a::ll the wild htings. And now cried Max, LET THE WILD RUMPUS START!
TM: There they are. Some wild rumpusing.
C: **Where's the little kid?**
TM: Max. Right there. ((pointing)) Here's some more wild rumpus action.
C: **Are they at ho- da home?**
TM: They're where the wild things live. And here they're having a wild rumpus parade.
C: I went to the parade.
TM: Or a procession. I know. We sat together.
C: Why did you see me at the parade?
TM: Cause...you came over and hang out with me.
C: We had french fries.
TM: And we had donuts.
C: I ate the little donut.
J: **Did I come an hang out with you?**
TM: You didn't. It was just Charlie.
TM: ((reading)) Now STOP! Max said and sent the wildlings off to bed without their supper.

KEY
Blue = Animating People in Story
Purple = Animating Dogs in Story
Red = Transitioning Between Stories
Bold = Children's Questions

Figure 8. Abbreviated talk. Left Mommy (M) and Charlie (C). Right Teacher Matt (TM) + Charlie (C).

At home, Mommy responded to Charlie's bid to explore Up (left) by shifting to exploring a prior experience through animating Gem. Charlie responded by animating his past-self before they repeated the pattern of Mommy animating the dogs in Up and Charlie animating the boy. In both stories, Charlie animated his past self, acting as an author in co-story telling. Charlie's bid for engaging in this family OKE of *exploring narratives together* was received positively by Teacher Matt two days later in his classroom (right). Charlie's questions were attended to, leading to explanations of Where the Wild Things Are, and giving Charlie the chance to connect to a prior experience. Both Charlie and Teacher Matt animated their past-selves. It was likely easy for Teacher Matt to follow Charlie's lead because Charlie's form of OKE was similar to literacy practices in the classroom. This is not always the case. A child the same age in Charlie's classroom, Catherine, was repeatedly rejected when she tried to engage in her family OKE practice (Keifert, 2015). In that case, Catherine's playful tone asking "What if the crickets got out [of the terrarium]?" was received with a concerned tone indicating that shouldn't happen for the crickets' safety. Catherine was not supported to engage in her OKE practice. Catherine's agency to pursue her curiosity through engaging in a familiar inquiry practice with her teacher closed down by her teacher.

The more adults look, the more opportunities they have to see children's brilliance. What happens when teachers give children agency to lead when they are curious? Charlie was positioned with agency to shape meaningful participation—he was positioned with educational dignity (Espinoza et al., 2020). Charlie's experience demonstrates affirming dignity for young children often construed as not capable (Cannella, 1999). Likely the more different a form of OKE is from those forms common to a context the more challenging following a child's lead may be (e.g., Heath, 1983). Yet, learning to recognize children's practices as relevant and attending to shared affective engagement is necessary. The centrality of curiosity to human experience demands educators learn to follow children's serendipitous curiosity to affirm educational dignity.

References

Ahearn, L. M. (2001). Language and agency. *Annual review of anthropology*, *30*(1), 109-137.

Annamma, S. A., Boelé, A. L., Moore, B. A., & Klingner, J. (2013). Challenging the ideology of normal in schools. International Journal of Inclusive Education, 17(12), 1278-1294.

American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). Washington, DC: Author.

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*(4), 530-544.

Barton, A. C., & Tan, E. (2010). We be burnin'! Agency, identity, and science learning. The Journal of the Learning Sciences, 19(2), 187-229.

Blumer, H. (1954). What is wrong with social theory? American Sociological Review, 19, 3–10. doi:10.2307/2088165

Cajete, G. (2000). Native science: Natural laws of interdependence. Santa Fe, NM: Clear Light Publishers.

Cannella, G. S. (1999). The scientific discourse of education: Predetermining the lives of others—Foucault, education, and children. *Contemporary Issues in Early Childhood*, *1*(1), 36-44.

Cekaite, A., & Aronsson, K. (2004). Repetition and joking in children's second language conversations: Playful recyclings in an immersion classroom. *Discourse studies*, *6*(3), 373-392.

Cekaite, A., & Kvist Holm, M. (2017). The comforting touch: Tactile intimacy and talk in managing children's distress. *Research on Language and Social Interaction*, *50*(2), 109-127.

Cobb-Moore, C., Danby, S., & Farrell, A. (2010). Locking the unlockable: Children's invocation of pretence to define and manage place. *Childhood*, *17*(3), 376-395.

Conn, C. (2015). 'Sensory highs', 'vivid rememberings' and 'interactive stimming': children's play cultures and experiences of friendship in autistic autobiographies. *Disability & Society, 30*(8), 1192-1206.

Damşa, C. I., Kirschner, P. A., Andriessen, J. E., Erkens, G., & Sins, P. H. (2010). Shared epistemic agency: An empirical study of an emergent construct. *The Journal of the Learning Sciences, 19*(2), 143-186.

De Kosnik, A. (2016). Rogue archives: Digital cultural memory and media fandom. Cambridge, MA: The MIT Press.

de León, L. (2015). Mayan children's creation of learning ecologies by initiative and cooperative action. In Advances in child development and behavior (Vol. 49, pp. 153-184). JAI.

de León, L. (2017). Texting Amor: Emerging Intimacies in Textually Mediated Romance Among Tzotzil Mayan Youth. *Ethos*, *45*(4), 462-488.

Espinoza, M. L., Vossoughi, S., Rose, M., & Poza, L. E. (2020). Matters of participation: notes on the study of dignity and learning. Mind, Culture, and Activity, 1-23.

Goodwin, C. (2007). Participation, stance and affect in the organization of activities. *Discourse & Society*, *18*(1), 53-73.

Goodwin, M. H. (2007). Occasioned knowledge exploration in family interaction. Discourse & Society, 18(1), 93-110.
Goodwin, M. H. (2017). Haptic sociality. *Intercorporeality: Emerging socialities in interaction*, 73-102.
Goodwin, M. H., & Cekaite, A. (2018). Embodied family choreography: Practices of control, care, and mundane creativity. Routledge.
Gresalfi, M., Martin, T., Hand, V., & Greeno, J. (2009). Constructing competence: An analysis of student participation in the activity systems of mathematics classrooms. *Educational Studies in Mathematics*, *70*(1), 49-70.
Gutiérrez, K. D., Cortes, K., Cortez, A., DiGiacomo, D., Higgs, J., Johnson, P., Lizárraga, J. R., Mendoza, E., Tien, J., & Vakil, S. (2017). Replacing representation with imagination: Finding ingenuity in everyday practices. Review of Research in Education, 41 (1), 30-60.
Gutiérrez, K. D., & Rogoff, B. (2003). Cultural ways of learning: Individual traits or repertoires of practice. Educational researcher, 32(5), 19-25.
Heath, S. B. (1983). *Ways with words: Language, life and work in communities and classrooms*. Cambridge university Press.
Hoey, E. M., DeLiema, D., Chen, R. S.Y., & Flood, V. J. (2018). Imitation in children's locomotor play. *Research on Children and Social Interaction*, *2*(1), 1-24.
Jaber., L. Z. & Hammer, D. (2016). Learning to feel like a scientist. *Science Education, 100*(2), 189-220.
Kapp, S. K., Steward, R., Crane, L., Elliott, D., Elphick, C., Pellicano, E., & Russell, G. (2019). 'People should be allowed to do what they like': Autistic adults' views and experiences of stimming. *Autism*, *23*(7), 1782-1792.
Keifert, D. (2015). Young children participating in inquiry: Moments of joint inquiry and questioning practices at home and in school (Doctoral dissertation). Northwestern University. Retrieved from Proquest. (3724286).
Kimmerer, R. (2013). Braiding sweetgrass: Indigenous wisdom, scientific knowledge, and the teaching of plants. Minneapolis, Minn.: Milkweed Editions.
Leekam, S. R., Prior, M. R., & Uljarevic, M. (2011). Restricted and repetitive behaviors in autism spectrum disorders: a review of research in the last decade. *Psychological bulletin*, *137*(4), 562.
Lizárraga, J. R., & Cortez, A. (2019). #gentrification, cultural erasure, and the (im)possibilities of digital queer gestures. In A. De Kosnik, K. Feldman (Eds.), #identity: Hashtagging race, gender, sex, and nation . Ann Arbor, MI: University of Michigan Press.
López, A., Najafi, B., Rogoff, B., & Mejía-Arauz, R. (2012). Collaboration and helping as cultural practices. In J. Valsiner (Ed.), *The Oxford handbook of culture and psychology* (pp. 869-884). New York: Oxford University Press.
Marin, A. M. (2020). Ambulatory Sequences: Ecologies of Learning by Attending and Observing on the Move. *Cognition and Instruction*, 281-317.
Medin, D., Ojalehto, B., Marin, A., & Bang, M. (2017). Systems of (non-) diversity. Nature Human Behaviour, 1(5), 1-5.
Mirra, N., & Garcia, A. (2020). "I Hesitate but I Do Have Hope": Youth Speculative Civic Literacies for Troubled Times. *Harvard Educational Review*, *90*(2), 295-321.
Philip, T. M., Bang, M., & Jackson, K. (2018). Articulating the "how," the "for what," the "for whom," and the "with whom" in concert: A call to broaden the benchmarks of our scholarship.
Rivero, E., & Gutiérrez, K. D. (2019). "You know what's glitching?": Emergent digital literacies in video game play. In *The Routledge handbook of digital literacies in early childhood* (pp. 158-168). Routledge.
Rogoff, B. (2003). The cultural nature of human development. Oxford University Press.
Rogoff, B. (2014). Learning by observing and pitching in to family and community endeavors: An orientation. *Human development*, *57*(2-3), 69-81.
Simpson, L. (2011). Dancing on our turtles's back: Stories of Nishnaabeg re-creation, resurgence, and a new emergence. Winnipeg, MB: Arbeiter Ring Publishing.
Vakil, S., Sengupta, P., Marin, A., Gutiérrez, K., Nzinga, K., Vadeboncoeur, J., Takeuchi, M. Nasir, N. (2020). Imagining Socio-Political and Ethical Horizons of the Learning Sciences: Learning With and From Junior and Senior Scholars. ICLS 2020 Learning and Identity Special Session.

Emotional Configurations Across Learning Environments

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Abstract: Building on Vea's (2000b) emotional configurations perspective, this symposium examines emotion and learning across a range of environments representing science education and explicitly politicized contexts. An emotional configurations perspective denaturalizes supposedly individual, internal, and discrete emotion states and instead foregrounds the ways that participants in social activity coordinate relationships between feeling, sense-making, and practice. In these four studies, we argue that emotionality should be more centrally interrogated in learning sciences research because it shapes what is learned and how learning unfolds, and itself becomes part of learning outcomes. The combined work makes theoretical contributions by interweaving emotion within sociocultural theories of learning and methodological contributions by sharing productive approaches to centering emotion as an object of analysis.

Framing and contribution: Emotion as more than a feeling

Emotion exhibits complex entanglements with thinking, activity, and learning. Building on Vygotsky, for example, Ratner (2000) conceptualized emotions as "thoughtful feelings" (p. 6). Roth (2007) emphasized that emotion serves as a "constituent element" of human activity (p. 45). And yet, the learning sciences have paid relatively little attention to the role emotion plays in learning processes. This symposium uses socioculturally oriented approaches to interrogate the role of emotion in shaping learning and sense-making in school-based and explicitly political out-of-school learning environments. We look across contexts to attend to if and how emotionality is centered in learning settings and what the consequences of explicit attention to—or refusal of—emotion does to shape the sense that is made of feelings and of conceptual cognition by learners and researchers.

As a starting point for our analyses, each paper in the symposium takes an emotional configurations perspective (Vea, 2020b). This perspective denaturalizes supposedly individual, internal, and discrete emotion states and instead foregrounds the ways that participants in social activity coordinate relationships between feeling, sense-making, and practice. Within this perspective, emotions are understood to be situated and grounded within particular social and cultural contexts (Boler, 1999; Zembylas, 2007). Emotion only becomes meaningful in contexts of activity. In this view, emotion is seen as inherently bound up in social practice—both as a form of practice, in the case of emoting and emotional management, and as entangled with other forms of practice. Ways of feeling can support the effective performance of other practices, such as when service workers use emotion to smooth capitalist exchange (Hochschild, 2012). Further, emotion is governed by norms and shaped by ideology and power relations, with implications for the futures that people can imagine and how they organize themselves to make those futures real. We assume that emotion is collaboratively constructed among members of a community, that emotion's meanings are shaped in and through sense-making processes in community, and that the sense that is made of emotion can, and often does, change as part of learning processes. From this perspective then, any learning endeavor will have emotion as a critical component.

Where and when is emotion in learning? Recent learning research shows concern for how affect and emotion support learning more broadly (DeBellis & Goldin, 2006; Ehret & Hollett, 2016; Gupta et al., 2010; Jaber & Hammer, 2016; Nemirovsky, 2011). Some learning researchers have also suggested ways that emotion may figure as part of learning outcomes, such as "affective know-how" (Hollett & Ehret, 2016) or "emotional engagement" (Sakr et al., 2016). Extending these conceptualizations, emotional configurations provide a way of seeing emotion as dynamic and always in process. Vea (2020b) argued that emotion serves in two modes: as a condition or quality of being that drives learning activity and as a learning target in its own right. The two modes can recursively flow into one another over the course of activity. For example, "epistemic affect" (Jaber & Hammer, 2016) and other forms of feeling can drive learning engagement as people attempt to resolve tensions or inconsistencies in phenomena and thinking. In the course of the same activity, educators and other social actors may cultivate ways of feeling in relation to sense-making and practice as part of learning goals. Emotion not only shapes what is learned and how it is learned—but is also itself part of the learning, iteratively re-shaping and resignifying the sense that is made (Vea, 2020b; Curnow & Vea, 2020).

In this symposium, we bring together two strands of developing scholarship. First, we identify emotion as an emergent issue in politically engaged informal learning environments. Vea's work has shown how "guided emotion participation" shaped whether and how animal rights activists became engaged in activist work. Through intentionally organized emotional experiences, activists came to make sense of relationships with nonhuman animals and with eating meat in particular ways, which shaped their political development by generating and giving meaning to strong emotional experiences. Curnow et al. (2020) examined the relationship between anger, snarky humor, and learning in youth climate activism. They argue that humor-infused expressions of anger enabled politicization of young women, as it opened space for grievance construction, problem solving, and community solidarity in ways that had been foreclosed in other spaces. Emotion became a mediating tool for expressing feelings that had gone un-named, and enabled participants to frame their emotions within the lens of feminism and anti-racism, making them politically salient within broader transformations of feminist practice, identity, worldview, and political analysis. Curnow & Vea (2020) also synthesize their respective work to argue that emotion is fundamental to processes of politicization. Additionally, we see a proliferation of work that attends to questions of belonging, trust, solidarity, and intimacy (Teeters & Jurow, 2018; Uttamchandani, 2020; Vakil et al., 2016), which gesture to the importance of felt experience, sense-making, and scale-making that is made possible through those relations. While their work does not explicitly orient to emotionality, it points to opportunities to more fully theorize emotional configurations that make feeling seen, feeling at home, feeling part of something bigger more likely, as it traces the impacts of those feelings (Vea, 2020a).

Second, similar threads are emerging in science education research, where there is increasing focus on emotion in children's, teachers', and scientists' disciplinary pursuits in a discipline often framed as unemotional, rational, and objective (Burbules & Linn, 1991). To larger discussions of how to support and design for science disciplinary practices in school and out of school contexts, there is an emerging understanding that emotions are part of what "instigates and stabilizes disciplinary engagement" in scientific pursuits (Jaber & Hammer, 2016), wherein learning science is intertwined in learning to feel and navigate feelings in new ways. Drawing on sociological studies of science as well as scientists' memoirs, Davidson and colleagues (2020) assert that emotions are "part and parcel" of the experiences of scientists, and should be recognized as integral to the experiences of science learners for children and adults alike. Likewise, this acknowledgement of the importance of emotion in the doing and learning of science may further push the field to consider the ways in which opportunities to learn through and at the level of emotion in science are afforded or constrained to populations who may be otherwise marginalized within the discipline (Bang et al., 2012).

When taken together, this work brings a key question relevant to the learning sciences into focus: When, for whom, how, and to what ends are emotions consequential for learning and research on learning? Each paper engages such considerations of emotionality differently: Curnow attends to how emotion shaped the sense-making process in the RadLab's analytic work, while Vea analyzes the emotional configurations embedded in animal rights activists' commitment to non-violence. Lanouette unpacks children's' emotions in a schoolyard ecology unit, while Davidson, Jaber, & Southerland examine the emotional configurations of scientists, teachers, and students. While we explore widely different contexts, from research spaces to activist contexts to school and after-school programs, across the work we attune to how emotion shapes the sense-making process. We find that emotion is present in all of these spaces, shaping what is learned, how, and by whom, and we find that emotion is almost always pushed aside rather than reckoned with as a mediator or target of learning and collaboration. Across the symposium contributions, we demonstrate the diverse ways emotion is consequential for learning. Taken together, the symposium makes three key contributions to emotion in the learning sciences: (1) it offers a range of theoretical enactments of emotional configurations across a wide range of learning environments, integrating emotional attunement into sociocultural theories of learning; (2) methodologically, it offers productive pathways forward for reckoning with emotion as an object of analysis in all learning environments; and (3) it argues that, across a range of learning environments, attuning to emotions can illuminate heretofore underexplored aspects of the learning process. Authors will present papers for 10 minutes each, followed by commentary by our discussants. Time will be reserved for discussion of how emotion should or could be taken up within the learning sciences, and the consequentiality of emotion for learning ecologies. Questions include: How might the learning sciences analyze emotion? What tools do learning scientists have in our repertoires for analyzing emotion, and how might we do so without reifying emotional practices and meanings? How do our own feelings shape how we read our data, participate as researchers, and engage in analysis and theorizing about learning?

Eating a kilo of chocolate as method: How emotional configurations of analysts shape data analysis and sense-making

Joe Curnow, University of Manitoba

In this paper, I examine the role of emotion in analyzing video data of emotionally charged debates. I argue that the emotional configurations of our research collaborative, the RadLab, were highly salient to our ability to conduct analysis of the significance of emotion in the data we analyzed, while also creating a complicated context for being immersed in the data. The RadLab is composed of activist researchers who were embedded in the Fossil Fuel Divestment campaign at the University of Toronto, and who co-designed and led the analysis of two years of video data. Our participation was both as research participants and analysts, drawing on Participatory Action Research frameworks (Brown & Strega, 2005), and militant ethnography (Scheper-Hughes, 1995). Fossil Free UofT was a student-run campaign aiming to convince the University of Toronto to divest from fossil fuels. From September 2014 to April 2016, Fossil Free UofT met weekly to plan events and coordinate strategy. Meetings lasted two to three hours, with facilitation responsibilities rotating between members. The group included undergraduate, masters, and PhD students. Through analysis of over 15000 minutes of multi camera video data (Derry et al., 2010), we analyzed how some participants came to understand themselves as radical activists. While we have used our content-logging, coding, and analysis in other places to make sense of the learning dynamics of the campaign, here we pause to reflect on the significance of emotion on our analytic process and ask: How do the emotional configurations of analysts matter when we are investigating emotionally messy learning ecologies?

This paper contributes to ongoing work in the learning sciences to analyze when and how emotion shapes learning processes and how learning shapes the felt experience of emotion. While recent work has examined guided emotion participation (Vea, 2020b), the consequences of emotionality for learning in social movements (Curnow & Vea, 2020), and the specific ways that humor, sarcasm, snark, and rage create conditions for politicization (Curnow et al., 2020) and educational intimacy (Uttamchandani, 2020), this work has focused on participant learning. Our work builds from this space, but attends to how our emotionality as analysts (and as participants in the data) shaped how we made sense of and re-experienced the emotion of our data in the analytic process. To do so, we draw on feminist and Indigenous research methodologies which stress relational accountability (Hampton, 1995; Wilson, 2008) and standpoint epistemologies (Collins, 1982; Harding, 2004) alongside theories of emotion and affect (Hochschild, 1979).

We collected video data from weekly meetings, actions, and debriefs during the campaign, and across this data, the meetings became increasingly emotionally intense. Toward the end of data collection, meetings often included yelling, crying, storming out, and other emotional expressions. Participation in the meetings was difficult—as was content logging, coding, and analyzing the data in detail, because of the emotion that it re-generated. As we watched video-data, our team of analysts often ended up feeling extremely upset, with some of our team lying on the floor in despair, while others ate entire kilos of chocolate bars. Rather than assume that scholars enter the data as emotionless and disinvested, we reflect on how our process of sense-making about the learning that unfolded through contentious politics was entangled in reconstructed emotional configurations of the data in a way that was felt during the data collection, as well as the layered sensemaking and feeling that happened in our collaborative data analysis sessions.

This analysis is significant for the learning sciences in a few ways. First, it builds on work around emotion by bringing our methods of analysis into focus and acknowledging that as thinking and feeling people, analysts' experience of emotionality in the analysis process happens and is significant to how we make sense of our data. This is both a methodological intervention and a political intervention, which converges with other work in the learning sciences that has increasingly sought to disavow the notion that objectivity and neutrality are either possible or desirable for our work studying learning contexts (McKinney de Roysten & Sengupta-Irving, 2020). In acknowledging the ways that our emotionality shapes the sense we make of our data, and the way that the sense that is made shapes how we feel about the data, this meta-analysis draws attention to how emotion shapes learning not only in the contexts we analyze, but in the very ways we conduct analysis and make sense of our research data.

Nonviolence past and present: Learning with an emotional technology in transit

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Tracing nonviolence's political history from Mohandas Gandhi, through Dr. Martin Luther King, Jr. and the Black Civil Rights Movement in the United States, to contemporary uses in animal rights activism, this paper asks how nonviolence supports particular emotional configurations in activist practice in socially and historically situated ways. Gandhi wrote in his autobiography, “Whereas a good deed should call forth approbation and a wicked deed disapprobation, the doer of the deed, whether good or wicked, always deserves respect or pity as the case may be” (Gandhi, 2012, p. 214). This idea was central to the practice of *ahimsa,* or nonviolence.

Writing about settler colonialism as a set of technologies, la paperson (2017) wrote, “Technologies are trafficked. Technologies generate patterns of social relationships to land. Technologies mutate, and so do these relationships” (p. 5). This paper takes as its starting point the idea that technologies also support the organization of emotional configurations (Vea, 2020b). An emotional configurations perspective treats emotion not as composed of universal states but rather of situated sociocultural phenomena (Lave & Wenger, 1991) embedded in complexes of social practice. Here, I examine nonviolent resistance, an emotional technology with many histories. I contend that nonviolence in fact names a set of relations between feeling, conceptual sense-making, and practice—in other words, an emotional configuration. Yet the patterns of relation that nonviolence generates are not identical across time and space. They mutate according to the particulars of their deployment, but they are always a matter of learning, of taking up particular ways of making meaning about emotion and what it is good for. From whence an emotional technology is trafficked itself becomes part of the relation.

This paper is part of a larger research project on learning in the context of animal rights activism (Vea, 2019, 2020a, 2020b). It presents empirical analysis of ethnographic fieldnotes and interviews (Emerson et al., 2011; Spradley, 1979). Thematic coding resulted in a focus on the social shaping of emotion and emotion’s embeddedness in other forms of activist practice. The activists of Direct Action Everywhere (DxE), an animal rights network of activists based in the San Francisco Bay Area, used nonviolence trainings and narratives about nonviolence as part of their political project. I examine the situated nature of those uses. However, in line with the conference theme, I examine the history of nonviolence as an emotional technology for learning. Historicity becomes part of its meaning, and the contemporary context of use also shapes possibilities for learning and social change.

Nonviolence directs anger away from perpetrators of injustice toward the larger systems of injustice that are understood as the root cause. As Satoshi, a nonviolence specialist who led trainings for DxE explained during one such event at a network-wide conference in 2017, “Teaching people not to be angry is very dangerous.” Martin Luther King, Jr. was “pissed off,” he said. What matters is where the anger is directed. When we take anger out on people, he said, they tend to react, and conflict escalates. Instead, anger should take the form of indignation toward unjust conditions. Satoshi gave the example of the beating of Civil Rights protesters by police on the Edmond Pettis Bridge in Selma, Alabama, on Bloody Sunday in 1965. The violence they endured without seeking retribution awakened the conscience of the public and resulted in growing support. In this way, the acceptance of suffering was both philosophical and pragmatic. One accepts violence against oneself because the creation of just conditions requires that the injustice of violence not be propagated further, by turning it against one’s adversaries. This moral demand also has strategic value, however, in that it inspires the sympathy of bystanders who may come to support one’s cause.

In these ways, nonviolence in DxE encompassed not only the absence of violence but also the disciplining, or guiding, of emotions in practice so that the ideals of the Beloved Community—the social manifestation of justice—may emerge. As such, nonviolence was not simply the means for achieving justice. Nonviolence was a technology that structured relations of thinking, emoting, and acting (one might say “being”) the manifestation of justice in the present. It was both the means and the ends. It was conceptually recursive, so that practicing justice is understood to make justice come to be. Interviews with DxE activists also showed how nonviolence was understood as a skill that required strengthening through repeated practice.

Historicizing nonviolence then adds complexity to these meanings. Explicitly and implicitly, DxE organizers’ references to previous nonviolent movements—and especially the Black Civil Rights Movement—were used to give moral and political legitimacy to the movement for animal rights. But where previous movement actors used nonviolence in part to establish their own humanity in the face of injustice, DxE’s more-than-human goals complicated the moral meanings of nonviolence. DxE activists, after all, were not fighting for their own humanization but rather for the moral standing of nonhuman others. Was it right to draw connections to the struggle for Black freedom? Further, the rise of European fascism and the dropping of the atomic bomb in Japan challenged Gandhi himself to reconsider whether nonviolence could be the universal solution to inhumanity he believed it to be (Devji, 2011).

For the learning sciences, this analysis provides an additional example of emotional configuration in the learning of social movement participants. Considering nonviolence as a kind of technology in transit clarifies the ways it structures the relations of meaning between feeling, conceptual sense-making, and practice. It also reiterates the importance of historical context for interpreting what emotional technologies for learning can do.

Emotion, data and place: Children's emotions emergent in ecologists' practices of sampling and data visualization

Kathryn Lanouette, William & Mary

Within the learning sciences and science education fields, there has been a growing focus on engaging young people in the construction and critique of data to support expansive learning opportunities (Wilkerson & Polman, 2020). Yet to date, such work has rarely focused on the emotional dimensions of these abstracting and authoring practices, particularly with children. In this paper, I focus on 10-11year old children's emotional experiences as they engage in sampling and data aggregation practices within an ecology unit centered around their schoolyard. I ask, what emotions emerge as children engaged in these practices and how does this intertwining of emotion, data and place shape their engagement in the practices and their reasoning about socio-ecological systems?

This work draws from a larger design-based research project that supported elementary students learning about complex socio-ecological systems and data using participatory GIS maps (Lanouette, 2019). Across ten weeks, 5th grade students studied the soil ecology literally underfoot in their schoolyard, exploring the question of "Who can thrive here?" by sampling invertebrates and soil samples in their schoolyard as well as recording above-ground human activities to understand the relationship among all these dimensions of the system. This design involved children in selecting sampling sites to study in detail, gathering data they were interested in and joining together to conjecture and contest relationships in collaboratively constructed visualizations of their aggregated data.

Through a longitudinal comparative case study analysis (Yin, 2017), I examine two student pairs' emergent emotions as they engaged in and adapted the ecologists' practices supported across the curriculum. Data sources include (a) video of class activity in one-on-one, small group, and whole group contexts and (b) paper and digital artifacts (children's note sheets, data visualizations). Analysis focuses on children's emotion within sampling practices (planning sites, selecting sites, collecting data at sites) and collectively assembled visualizations of their aggregated data (constructing bar charts and two-way tables). In coding emotion, I examined verbal expressions using emotion laden words (both in the moment and in reflecting on past events), multi-modal expression of emotion (Jaber & Hammer, 2016), and paralinguistic markers of emotion. By contrasting two pairs over time, I aim to illuminate not only the heterogeneity of emotions emergent within this design but also how children's emotions shaped how they selected schoolyard sampling sites, how they participated in collective constructions of their aggregated data and how they considered relationships within complex systems.

Several findings are noted here. Children's emergent emotions varied widely, ranging from delight and "love" of a schoolyard site to competition and exasperation, in turn shaping varying approaches to selecting sampling sites and representing data. For Amir and Marie, their joy in finding animals of any kind along with physically being in their favorite tucked away spot that Marie "just loves!" led the pair to repeat sampling at their site to see how the system might change over time (a key idea in ecologists' sampling practice) and to consider multiple interrelationships in the socio-ecological system. As they built a two-way data table with classmates showing all the invertebrate species discovered, their excitement for a mysterious animal they saw led them to insisting on showing it in the data, even though it was hard to categorize. In contrast, for Elena and Max, their focus on finding the most animals led them to constantly switch sampling sites that would ensure the highest counts. These feelings of competition emerged again as they were collectively building bar charts of earthworms counts, where the pair falsely elevated their data to ensure they had the highest earthworm counts among their peers.

Implications are twofold. First, these findings point to the import of attuning to the wide range of emotions emergent in constructing and contesting data, elevating not only children's warm emotions towards local places and more-than-human organisms within but also children's sharper emotions such as competition and exasperation. Given the larger norms, ideologies and power structures that shape emotional experience and expression (Vea, 2020b), this work suggests the import of making visible broader expressions in children's science pursuits as work in emotion, data and science practices continues. Second, these findings call for existing work in design-based research to more deliberately center children's emotions in the design of activities, the articulation of conjectures (Sandoval, 2014) and the study of learning processes.

Teacher learning in science labs: Affordances and constraints of emotional display rules

Shannon G. Davidson, Lama Z. Jaber, and Sherry A. Southerland, Florida State University

Science as a discipline has long been perceived as objective and, in turn, scientists have often been characterized as unfeeling or emotionless in relation to their work (Burbules & Linn, 1991). However, work of historians and sociologists of science and science education researchers provide ample evidence that affect is inherent in the doing of science (for examples, see Jaber & Hammer, 2016; Robbins, 1999) and that science is a social endeavor wherein emotional configurations (Vea, 2020b) are inherent. This affective dimension of science is not only part and parcel to professional science but central to the experiences of science learners. In order to support students' disciplinary engagement in science, teachers must understand and have facility with not only the conceptual and epistemic components of science, but also with the emotions that are part of disciplinary engagement (Davidson et al., 2020; Jaber et al., 2018). One context that aims to develop teachers' disciplinary understandings of and facility with science is that of Research Experiences for Teachers (RET) programs, in which K-12 teachers are immersed in extensive scientific research through work with scientists (Dixon & Wilke, 2007; SRI International, 2007). Although RET may provide teachers with firsthand emotional experiences in the doing of science (Davidson et al., 2020), teachers may not recognize these emotions as inherent to the discipline. Indeed, it is unclear whether RETs provide teachers a full grasp of science as a discipline, particularly with respect to recognizing the emotions that *scientists* experience in their work. To this end, our work considers the following question: What messages may be imparted to teachers about the role of emotion as an inherent dimension to the discipline of science through their encounters with scientists during an immersive research experience?

In this work, we argue that tacit yet influential emotional display rules (Diefendorff et al., 2006; Hochschild, 2012) may limit teachers' access to scientists' emotional experiences. Such rules shape how affect is or is not displayed in lab spaces, conveying meta-messages for teachers about what feelings and emotions are legitimate and acceptable in the doing of science. In turn, these tacit messages may actively shape the ways in which teachers come to develop their own attunement towards their emotional experiences in science and subsequently their students' emotions in the science classroom. To illustrate these dynamics and to explore the potential ways in which emotional display rules may moderate teachers' understanding of the affective dimension of science, we offer the example of Ava—a teacher participating in a six-week summer RET program at a national laboratory—and Dr. Ji, her mentor scientist. During one of the experimental cycles of Ava's research, there was a miscommunication of scheduling and a facility-wide routine power outage interfered with an overnight experimental trial that Ava and Dr. Ji were conducting. In reflecting on this moment in an interview, Ava noted:

> I felt really frustrated and upset when the furnace must have shut down during our trial run, --like what do we do? How can we fix this and run it again? But [Dr. Ji] was like 'No no no don't worry. This happens. This is part of it--part of, you know, science.' He didn't make me feel bad, but [rather] it's just part of science.

In this example, Dr. Ji makes moves to support Ava by normalizing the error as 'just part of science' and by telling her not to worry. In addition, as evidenced from field notes, Dr. Ji went on to tell Ava an anecdote of how this exact situation had happened to him once before when he was new to the lab. He described how he was 'confused' but once he'd realized the mistake he 'had to laugh and start over.' While Dr. Ji did make moves to support Ava by normalizing error and offering commiseration through the anecdote, he did not explicitly acknowledge Ava's frustration. Instead, his moves subdued those feelings. Additionally, Dr. Ji did not himself demonstrate any emotional reaction to this setback.

In light of these reactions from Dr. Ji, it is possible that Ava could walk away from this encounter with the understanding that scientists somehow lack emotion within their work or do not experience affect within the doing of science. Evidence for this internalization can be found in the observation that for most of the RET teachers, their own displays of emotions within lab spaces were very restrained and limited. Instead, these emotions (frustrations, vexations, excitements, and insecurities) were only expressed in other spaces (lunch times or social events) with fellow RET participants. This suggests that RET teachers may implicitly come to view their own emotions as somehow 'other' or unacceptable in science.

Emotional display rules related to science spaces have the potential to reinforce positivist views (Burbules & Linn, 1991) that science is an objective discipline which strips science—and those who do science—of their humanity. If teachers walk away from encounters with scientists that paint doers of science as emotionless, they may unintentionally reinforce this erroneous and stereotypical narrative in their classrooms, reproducing marginalizing ideas of who feels welcome in science and science spaces.

References

Bang, M., Warren, B., Rosebery, A, & Medin, D. (2012). Desettling expectations in science education. *Human Development, 55,* 302-318.

Boler, M. (1999). *Feeling power: Emotions and education*. Psychology press.

Brown, L. A., & Strega, S. (Eds.). (2005). *Research as resistance: Critical, indigenous and anti-oppressive approaches*. Canadian Scholars' Press.

Burbules, N. C., & Linn, M. C. (1991). Science education and philosophy of science: Congruence or contradiction? *International Journal of Science Education, 13*(3), 227–241.

Collins, P. H. (1986). Learning from the outsider within: The sociological significance of Black feminist thought. *Social problems*, *33*(6), s14-s32.

Curnow, J., Davis, A., & Asher, L. (2019). Politicization in process: Developing political concepts, practices, epistemologies, and identities through activist engagement. *American Educational Research Journal*, *56*(3), 716-752.

Curnow, J., Fernandes, T., Dunphy, S., & Asher, L. (2020). Pedagogies of snark: Learning through righteous, riotous anger in the youth climate movement. *Gender & Education*.

Curnow, J. & Vea, T. (2020). Emotional configurations of politicization in social justice movements. *Information and Learning Sciences.*

Davidson, S. G., Jaber, L. Z., & Southerland, S. A. (2020). Emotions in the doing of science: Exploring epistemic affect in elementary teachers' science research experiences. *Science Education, 104*(6), 1008-1040.

DeBellis, V. A., & Goldin, G. A. (2006). Affect and meta-affect in mathematics education: A representational perspective. *Educational Studies in Mathematics, 63*(2), 131–147.

Dennis, B., Uttamchandani, S., Biery, S., & Blauvelt, A. (2019). LGBTQIA+ youth as multicultural educators. *Ethnography and Education, 14*(3), 360-376.

Derry, S. J., Pea, R. D., Barron, B., Engle, R. A., Erickson, F., Goldman, R., ... & Sherin, B. L. (2010). Conducting video research in the learning sciences: Guidance on selection, analysis, technology, and ethics. *The Journal of the Learning Sciences, 19*(1), 3-53.

Devji, F. (2011). *The impossible Indian: Gandhi and the temptation of violence*. Harvard University Press.

Diefendorff, J. M., Richard, E. M., & Croyle, M. H. (2006). Are emotional display rules formal job requirements? Examination of employee and supervisor perceptions. *Journal of Occupational and Organizational Psychology, 79*(2), 273–298.

Dixon, P., & Wilke, R. A. (2007). The influence of a teacher research experience on elementary teachers' thinking and instruction. *Journal of Elementary Science Education, 19*(1), 25–43.

Ehret, C., & Hollett, T. (2016). Affective dimensions of participatory design research in informal learning environments: Placemaking, belonging, and correspondence. Cognition and Instruction, 34(3), 250–258.

Emerson, R. M., Fretz, R. I., & Shaw, L. L. (2011). *Writing ethnographic fieldnotes* (2nd ed.). University of Chicago Press.

Hampton, E. (1995). Memory comes before knowledge: Research may improve if researchers remember their motives. *Canadian Journal of Native Education*, *21*, 46-54.

Harding, S. G. (Ed.). (2004). *The feminist standpoint theory reader: Intellectual and political controversies*. Psychology Press.

Hochschild, A. R. (1979). Emotion work, feeling rules, and social structure. *American Journal of Sociology, 85*(3), 551-575.

Hochschild, A. (2012). *The managed heart: Commercialization of human feeling* (3rd ed.). University of California Press.

Gandhi, M. K. (2012). *The story of my experiments with truth*. Renaissance Classics.

Gupta, A., Danielak, B. A., & Elby, A. (2010). Understanding students' difficulties in terms of coupled epistemological and affective dynamics. In Proceedings - Frontiers in Education Conference (pp. 1–6).

Jaber, L. Z., & Hammer, D. (2016). Engaging in science: A feeling for the discipline. *Journal of the Learning Sciences, 25*(2), 156–202.

Jaber, L. Z., Southerland, S. A., & Dake, F. (2018). Cultivating epistemic empathy in preservice teacher education. Teaching and Teacher Education, 72, 13–23.

la paperson. (2017). *A third university is possible*. University of Minnesota Press.

Lanouette, K. (2019). The Potential of Place: Leveraging Children's Local Knowledge and Participatory GIS Mapping to Conceptualize Ecological Systems in Elementary Science Instruction. (Doctoral Dissertation. University of California Berkeley.)

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lutz, C. A., & Abu-Lughod, L. (Eds.). (1990). Language and the politics of emotion. Cambridge University Press.

McKinney de Royston, M., & Sengupta-Irving, T. (2019). Another step forward: Engaging the political in learning.

Nemirovsky, R. (2011). Episodic feelings and transfer of learning. *Journal of the Learning Sciences*, 20(2), 308–337.

Philip, T. M., Gupta, A., Elby, A., & Turpen, C. (2018). Why ideology matters for learning: A case of ideological convergence in an engineering ethics classroom discussion on drone warfare. *Journal of the Learning Sciences, 27*(2), 183-223.

Ratner, C. (2000). A cultural-psychological analysis of emotions. *Culture & Psychology*, *6*(1), 5–39.

Robbins, J. (Ed.). (1999). *The pleasure of finding things out: The best short works of Richard P. Feynman.* New York, NY: Basic Books.

Roth, W.-M. (2007). Emotion at work: A contribution to third-generation cultural-historical activity theory. *Mind, Culture, and Activity*, *14*(1–2), 40–63.

Sakr, M., Jewitt, C., & Price, S. (2016). Mobile experiences of historical place: A multimodal analysis of emotional engagement. Journal of the Learning Sciences, 25(1), 51–92.

Sandoval, W. (2014) Conjecture mapping: An approach to systematic educational design research, *Journal of the Learning Sciences*, 23:1, 18-36, DOI: 10.1080/10508406.2013.778204

Spradley, J. P. (1979). *The ethnographic interview*. Holt, Rinehart and Winston.

SRI International. (2007). Evaluation of research experiences for teachers (RET) program: 2001–2006. Prepared for The National Science Foundation, Division of Engineering Education and Centers. Retrieved from http://nsf.gov/eng/eec/EEC_Public/RET.pdf

Teeters, L. A., & Jurow, A. S. (2018). Relationships de Confianza and the organisation of collective social action. *Ethnography and Education*, *13*(1), 84-99.

Uttamchandani, S. (2020). Educational intimacy: Learning, prefiguration, and relationships in an LGBTQ+ youth group's advocacy efforts. *Journal of the Learning Sciences*, 1-24.

Vakil, S., McKinney de Royston, M., Suad Nasir, N. I., & Kirshner, B. (2016). Rethinking race and power in design-based research: Reflections from the field. *Cognition and Instruction*, *34*(3), 194-209.

Vea, T. (2019) The ethical sensations of immediacy: Embodiment and multiple literacies in animal rights activists' learning with media technologies. *British Journal of Educational Technology.*

Vea, T. (2020a). Friends for the movement: Emotion and learning in the balance of intrinsic and strategic relations. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 1* (pp. 230-237). Nashville, Tennessee: International Society of the Learning Sciences.

Vea, T. (2020b). The learning of emotion in/as sociocultural practice: The case of animal rights activism. *Journal of the Learning Sciences, 29*(3), 311-346.

Wilson, S. (2008). *Research is ceremony: Indigenous research methods*. Fernwood Publishing.

Wilkerson, M.H. & Polman, J. (2020). Situating data science: Exploring how relationships to data shape learning, *Journal of the Learning Sciences*, 29:1, 1-10.

Yin, R. K. (2017). *Case study research and applications: Design and methods*. 6th Edition. Sage

Zembylas, M. (2007). Emotional ecology: The intersection of emotional knowledge and pedagogical content knowledge in teaching. *Teaching and Teacher Education*, *23*(4), 355-367.

Science Learning with Virtual Experiments

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Abstract: This symposium explores multiple perspectives on integrating virtual experiments in science education. The papers report on virtual experiments as replacements for physical experiments or as supplements to physical experiments at several educational levels (i.e., preschool, middle school, and university) and for varied learning objectives. The six papers in the symposium analyze ways to design guidance and scaffolding for virtual laboratories; illustrate how virtual experiments could supplement physical experiments in a school science lesson; and assess how a combination of virtual and physical experiments affects learning. The symposium includes an interactive discussion of the implications of virtual experiments for the future of science education.

Acquiring knowledge and skills in the subject area of science is essential for full participation in today's knowledge society. The ability to understand and use scientific concepts and methods is a fundamental aim of science education (NRC, 2015). Implementing laboratory experiments in science education following inquiry-based learning scenarios can foster this understanding. To succeed, inquiry learning processes need adequate support (Lazonder & Harmsen, 2016). Recently, technological advances have entered classrooms. Digital technologies provide new possibilities and perspectives for virtual experimentation and interactive simulations. Typical experimentation in physical (hands-on) laboratories can be enhanced by virtual experiments that have both practical advantages and unique affordances for learning, e.g., faster manipulation of variables than in physical experiments, integration of multiple representations, the possibility to perform accurate measurements and the opportunity to make abstract or invisible objects and constructs observable for students. In order to effectively use virtual experiments for science learning, it is important to gather a deep understanding of learning with experiments, physical and virtual. This symposium provides a comprehensive overview of research on science learning with virtual experiments from multiple perspectives. Following the conference theme "Reflecting the Past and Embracing the Future", we consider learning with typical physical experiments as well as learning with virtual experiments. We report on high quality studies using qualitative and quantitative data. The six studies in this symposium deal with implementation, scaffolding, and combining physical and virtual experiments. They show how well-designed learning settings with virtual experiments can improve science education courses in the future.

First, Yvoni Pavlou, Marios Papaevripidou, and Zacharias Zacharia investigate the development of conceptual understanding in preschool children before, during, and after learning with either physical or virtual manipulatives using semi-structured interviews and combining quantitative and qualitative findings. They found no differences in conceptual understanding between students' learning with physical or virtual manipulatives. These results extend research with virtual manipulatives to preschoolers. Second, Sadhana Puntambekar and Dana Gnesdilow explore how virtual labs, in comparison to physical labs, support seventh and eighth grade students' ability to apply their knowledge to a real-world scenario and set up a subsequent, more complex physical lab.

They found that students working with virtual labs were better able to apply their knowledge and were also successful in setting up the subsequent physical lab. Third, Hasan Ozgur Kapici, Hakan Akcay, and Ece Ebrar Koca compare virtual and physical laboratories in the context of written argumentation of pre-service science teachers. They found that pre-service science teachers working with virtual or physical laboratories did not differ in their writing quality. Fourth, Yoana Omarchevska, Andreas Lachner, and Katharina Scheiter focus on supporting university students' inquiry learning using video modeling examples and monitoring prompts. They found that video modeling examples were beneficial for improving participants' hypothesis and argumentation quality and had no additional benefit from prompts. Fifth, Xiulin Kuang, Tessa H. S. Eysink, and Ton de Jong investigate how providing secondary school students with adaptive domain information can support their hypothesis generation and learning outcomes. Last, Salome Wörner, Jochen Kuhn, and Katharina Scheiter focus on how best to combine virtual and physical labs. In their study, seventh grade students worked with virtual and physical labs on the same topic in a different sequence, whereas the control group only worked with the physical lab. The discussant Marcia C. Linn will identify themes across the presentations and suggest next steps.

Comparing the impact of virtual and physical manipulatives on preschoolers' understanding in the domain of balancing a scale

Yvoni Pavlou, Marios Papaevripidou, Zacharias Zacharia

Introduction

Numerous studies have focused on investigating the impact of experimentation on learners' conceptual understanding (e.g., Zacharia et al., 2012) in various science domains and contexts with the use of Physical and/or Virtual Manipulatives (PM and VM respectively). In the context of balancing a scale, two critical variables are involved: the mass of the objects placed on the scale and their distance from fulcrum. Understanding the impact of the combination of the variables on the balance of a scale can lead to a rule/third defining variable, namely torque, which can be used for predicting the behavior of a scale. Children's performance with such type of activity provides insight into their complex thinking and how they combine variables (Pine & Messer, 2003). Despite the added value of experimentation, its integration in the learning process has not been investigated to the extent that researchers and educators could point to its optimum enactment, especially for early childhood education. Consequently, this study investigated whether the use of PM or VM during experimentation affects preschoolers' learning in the domain of balancing scale, by addressing the following research question: How does preschool children's development of understanding in the domain of balancing a scale compare before, during and after their exposition to PM and VM experimentation?

Method

The participants of this study were 88 preschoolers (age mean = 5,4) who were equally separated into two subgroups according to the type of experimentation (PM or VM) they used during a semi-structured interview. The interview followed the Predict-Observe-Explain (POE) strategy. The first part of the interview included an initial evaluation which was orally administered. The second part involved the experimentation with VM or PM and the third part was the oral re-administration of the same assessment items of the first part (final evaluation) for both groups. The PM experimentation involved the use of concrete instruments and objects (balance scale and weights). VM experimentation involved the same instruments and objects used in the PM condition, but in a simulation environment that retained the features and interactions of the subject domain of the study as PM did. The only difference between the two conditions was that only the PM condition offered actual, active touch sensory input, whereas in the VM condition only visual feedback was available. Data sources involved participants' responses to the clinical interviews. The data were treated both qualitatively and quantitatively. Open coding was followed for the qualitative treatment of participants' responses to identify their ideas. The quantitative treatment involved scoring through rubrics the pre- and post-test and participants' responses during experimentation. Non-parametric tests were used for the analyses.

Results and discussion

Participants' most frequent ideas during the three interview phases are summarized in Table 1 and are elaborated in the following. Comparisons within the conditions showed statistically significant ($p < .05$) variations (increase or decrease) of the use of an idea during the three phases. The most predominant idea during the initial evaluation concerned the mass of the objects (i.e. *"the scale tilts towards the side of the heaviest weights"*). In the experimentation phase there was a statistically significant decrease of the use of the mass-related idea, whereas the use of the distance-related idea (i.e. *"the scale tilts towards the side in which the weights were placed in a* *greater distance from the fulcrum"*) increased significantly before and after experimentation. These findings indicate an initial understanding of mass as a factor affecting the behavior of a scale and the development of understanding of the effect of distance as a result of experimentation. The more complex idea (torque) appeared during the experimentation and final evaluation in both conditions but not as frequently, indicating that children at this age tabletend to focus on one variable to predict and explain the behavior of the scale. The comparison between the conditions revealed that even though both VM and PM were conducive to student learning, no statistically significant differences were found learning-wise before, during and after the experimentation ($p > .05$).

Table 1: Percentage of appearance of most frequently used ideas during the three phases of the interview and the statistical significance of the comparison of the impact of PM and VM

Main ideas	Initial evaluation		Experimentation		Final evaluation	
	PM	VM	PM	VM	PM	VM
Mass	60%	47%	22%	42%	48%	39%
Distance	16%	17%	42%	39%	39%	39%
Torque	0%	0%	17%	13%	9,5%	7,6%

Overall, the findings of this study designate that preschoolers can develop understanding through experimentation for each variable affecting the balance of a scale independently, whereas the understanding of the interaction between the variables (torque) is a much more complex process. Also, there was no prevalence of PM or VM on students' conceptual understanding in this domain, a finding which indicates that VM could be used as means for experimentation under certain conditions even at preschool level as well.

The effect of physical and virtual labs in supporting middle school students' application of science ideas

Sadhana Puntambekar, Dana Gnesdilow

Introduction

Research comparing students' learning from physical versus virtual labs has shown that engaging students in virtual labs supports their science conceptual learning as well as or better than physical ones (D'Angelo et al., 2016). However, few studies have explored if there are any drawbacks from learning from virtual experiments when it comes to applying the ideas learned to new situations. Further, few physical versus virtual studies have assessed students' learning of practical skills, such as the ability to conduct subsequent physical labs (Brinson, 2015), so that students can not only learn science ideas "but can also apply them to explain phenomena or solve problems" (NRC, 2015, p.20). We explored whether doing a virtual versus a physical lab supported students' ability to apply what they learned to a real-world scenario and to set up a subsequent, more complex physical lab. Our questions were: 1) Are students who conduct virtual labs able to apply what they learned to explain the science behind a novel, real-world scenario as well as students who conduct physical labs? and 2) If students conduct a virtual lab, are they able to set up a subsequent, more complex physical lab as well as students who conducted the first lab physically?

Method

Five hundred and fifty-two seventh and eighth grade students from two different school districts in the midwestern United States participated in this study. We randomly assigned each of the participating seven teacher's in-tact classes to the Physical Lab (PL) or Virtual Lab (VL) condition. We used data from a total of 385 students (PL $n = 180$; VL $n = 205$) for this study. Students participated in a two week-long pulley unit. After taking a pretest, students were presented with a pulley challenge and engaged in cycles of inquiry to set up and test pulley systems with physical or virtual materials. They took a post-test at the end of the unit. We assessed students' learning of science concepts, as well as their ability to apply their knowledge to a new context or set-up a physical lab. First, we used a 15-question pulley content test to assess students' understanding of pulleys. We analyzed the test scores using an Analysis of Covariance (ANCOVA). Second, we assessed students' ability to apply what they learned during a physical or virtual lab to a new context using the *real-world scenario application questions*, which asked students to examine three pictures of a well with different pulley systems and explain which pulley system gave the most mechanical advantage. Students' reasoning was coded based on a rubric of how pulley systems can affect mechanical advantage. Students earned one point for including any accurate reason (Cohen's Kappa of .945 on

20% of data). We then used Chi-Squared tests of homogeneity of proportions to understand if the number of students who provided the correct answer on the real-world scenario as well as the types of reasons provided were different by condition. Further, to see whether students in the VL or PL condition provided more or less reasoning in their answer, we calculated a total explanation score by condition and conducted an Analysis of Variance (ANOVA). Finally, we tracked how long it took 133 student groups (PL groups = 66; VL groups = 67) to set up a complex pulley system in our *physical application task* and averaged time data by condition and analyzed it using an ANOVA.

Results and discussion

We found that students in the VL condition learned more about the physics ideas related to pulleys than students in the PL condition with a small effect size ($F(1,384) = 4.307$, $p = .039$, $\eta^2 = 0.011$). We also found that a significantly higher proportion of students in the VL condition answered the real-world scenario application question correctly (VL 91% vs. PL 80%, $z = 8.16$, $p = 0.004$). Further, a significantly higher proportion of students in the VL condition provided reasoning about the following: i) the pulley had more mechanical advantage because you would need to pull a greater distance, i.e., the force–distance trade off; (VL 7.3% vs. PL 2.2%, $z = 5.45$, $p = 0.02$); ii) stated the correct amount of MA, (VL 5.4% vs. PL .6%, $z = 5.84$, $p = 0.0016$) and iii) included more reasons to back up their ideas than students in the PL condition (VL mean explanation score(SD) = 0.93(0.2); PL explanation score(SD) = 0.64(0.77); $F(1,383) = 12.50$, $p < 0.000$). Finally, the average time it took for student groups in the PL versus VL condition to set up a more complex pulley in our physical application task showed that there were no significant differences between the two groups (PL mean time(SD) = 20.64(8.49) minutes; VL mean time(SD) = 20.13(8.62) minutes; $F(1,131) = .732$, $p = 0.732$).

Our findings further establish virtual experiments as effective instructional tools to support learning. In line with prior research we found that students who performed a virtual versus physical lab learned significantly more science content. However, we also found that conducting virtual labs may also better support students' ability to apply their ideas to a new real-world scenario as well as to provide scientifically accurate reasons in their explanations, without negatively affecting their ability to set up and conduct a subsequent physical experiment. While physical experiments are essential for helping students to truly learn science (Lehrer & Schauble, 2015), our findings may give practitioners greater confidence in using virtual simulations as meaningful and effective tools to support students' learning and application of scientific knowledge.

Assessing the written arguments developed in hands-on and virtual laboratories

Hasan Ozgur Kapici, Hakan Akcay, Ece Ebrar Koca

Introduction

The goal of the current study is to examine the characteristics of arguments (e.g., quality of claims, questions, evidence, and multiple representations) created by pre-service science teachers (PSTs) by using the science writing heuristic (SWH) approach in a virtual laboratory and comparing it to the hands-on laboratory. Based on the goal, the main research questions for the study were the following: (i) what are the features of PSTs' written arguments based on the experiments in a virtual laboratory?, (ii) what are the features of PSTs' written arguments based on the experiments in a conventional hands-on laboratory?, and (iii) What are the similarities and differences between PSTs' written arguments based on the experiments in a conventional hands-on laboratory and a virtual laboratory?

Method

A quasi-experimental research design was used in this study. Two groups were included in the current study: One of them designed and implemented their experiments in the conventional hands-on laboratory and wrote their arguments on the paper-based laboratory worksheet; the other group did their investigations through the virtual laboratory and used the online learning platform to write their arguments. The study was done with 52 PSTs (40 female, 12 male; $M = 21$ years, $SD = 1.30$) from a public university in Turkey. There were 28 PSTs in the control group, where conventional hands-on laboratories were used to design and implement experiments and laboratory worksheets were used to write their arguments. In the experimental group, there were 24 PSTs, who used the virtual laboratories to design and implement their experiments, and the online platform was used to write their arguments. The writing template, developed based on the SWH approach by Choi (2008), was used in the study. The template involves five main elements as following: preparation for experimentation, predictions, investigation, results, and discussion. First of all, two theoretical approaches (argumentation and writing to learn) were discussed with the PSTs. After this, PSTs worked in the laboratory environments for his/her group's assigned condition. Each PST designed and implemented his/her own experiments and wrote arguments alone for four different experiments, related to solutions, acid and base, electricity, and buoyancy force, respectively. PSTs' writing samples were collected over a period of four weeks. Both of the groups had the same amount of time for each experiment (90 min per experiment). The main difference between the two groups was the laboratory environment. The same instructor taught both of the groups. An open inquiry-based learning approach was used in this study. The main topic was provided to the PSTs and then they followed the sections of SWH approach individually. At the end of the study, PSTs writings for four experiments were collected and analyzed based on the SWH approach. The PSTs' science writings were transformed from qualitative data to quantitative data by using the rubric developed by Choi (2008).

Results and Discussion

The results showed that the features of written arguments created by PSTs from both of the laboratory environments were at an intermediate level. The written arguments for both in the hands-on and virtual laboratory environments showed that whereas the highest average score was found for the section about claims-evidence relationship (3.85/5.00 for the ones in the hands-on lab; 3.89/5.00 for the ones in the virtual lab), the lowest score was found for the multimode section (1.86/5.00 for the ones in the hands-on lab; 2.34/5.00 for the ones in the virtual lab). Furthermore, PSTs who used the virtual laboratory posed better testable questions ($F(1, 207) = 2.391$; $p = .018$; $d = 0.34$), presented strong and valid evidence ($F(1, 207) = 2.093$; $p = .038$; $d = 0.30$), and used multiple representations better ($F(1, 207) = 3.318$; $p = .001$; $d = 0.47$) than their counterparts in the hands-on laboratory. For posing better testable questions, computer technology or the Internet can be reasons for this result because the PSTs in the virtual laboratory had the opportunity to design more complicated experiments. For presenting strong and valid evidence, being able to use online scaffolding tools, which enabled PSTs to correlate their findings with their questions or claims, can be a source for this outcome. For the multimode representations, indeed, PSTs in both of the groups used multiple representations occasionally. Even so, whereas PSTs in virtual laboratory environments were able to show data in graphs or tables, PSTs in the hands-on laboratory environments mostly focused on writing rather than drawing tables or graphs. All these findings show that an important conclusion of the current study is that the SWH approach can be used well in virtual laboratory environments as much as in hands-on laboratory environments.

Supporting learning with virtual experiments using video modeling examples and monitoring prompts

Yoana Omarchevska, Andreas Lachner, and Katharina Scheiter

Introduction

Scientific reasoning and argumentation are crucial facets of scientific literacy and their development has become a fundamental aim of science education. Students often have deficits in scientific reasoning, in particular with developing hypotheses and designing experiments to test them. One explanation for these deficits is that scientific reasoning and self-regulation are rarely integrated. Guided inquiry learning (using instruction or scaffolds) can be more effective than traditional teaching methods for enhancing scientific reasoning. Video modeling examples (VME) are effective for teaching scientific reasoning (Kant et al., 2017). We combined VME with prompts to activate the prior strategies taught in the VME and to foster monitoring of scientific reasoning activities during inquiry. Against this background, we tested the effectiveness of combining support measures which integrate self-regulation and scientific reasoning. We compared participants' hypothesis and argumentation quality in two tasks between conditions. We hypothesized that 1) students who received VME and monitoring prompts (VMEP) would have higher hypothesis and argumentation quality than students who received VME only, and that 2) VMEP and VME would outperform students who received no VME and prompts (control).

Method

Participants were 127 students from a University in Southern Germany (26 males, $M = 24.3$ years, $SD = 4.81$) from various study programs. In the videos, a female model explained how to formulate a good hypothesis and what is important before collecting data. Then, she conducted several experiments and evaluated the results. We used a coping model, which initially made a mistake, but then corrected herself to model metacognitive monitoring. We used three virtual experiments from Gizmos: *Archimedes' principle, Photosynthesis*, and *Energy Conversion*. In each task, participants were given a research question. They wrote down a hypothesis, collected data using the virtual experiments, and wrote down an answer on an experimentation sheet. We created three monitoring prompts (P), which guided students to specific scientific reasoning activities. In the VMEP condition, participants watched the VME and received the prompts (P) during the training task. Then, they solved the transfer task. The VME condition had identical procedure, excluding the monitoring prompts. In the control condition (unguided inquiry), instead of watching the VME, participants solved the same task as the model using the same virtual experiment. Hypothesis quality was measured by its testability and correctness (0-4). Argumentation quality was scored based on quality of the claim, evidence, and reasoning (0-6). Two independent raters coded the entire dataset containing two hypotheses and two answers for each participant. They discussed all disagreements until 100% consensus was reached. Screen captures and think aloud protocols were used during participants' inquiry learning to obtain process data on self-regulation and scientific reasoning. We combined findings from two process analyses (epistemic network analysis and process mining) to investigate the processes of self-regulation and scientific reasoning in different conditions.

Results and discussion

Compared to the control group, VMEP and VME had higher hypothesis quality, $F(2, 124) = 3.79$, $p = .025$, $\eta^2 = .05$, and argumentation quality $F(2, 124) = 3.43$, $p = .035$, $\eta^2 = .06$ in the training task. In the transfer task, VMEP and VME had higher hypothesis quality, $F(2, 124) = 4.71$, $p = .011$, $\eta^2 = .07$ than the control condition, but the three groups did not differ in argumentation quality, $F(2, 124) = .60$, $p > .05$, $\eta^2 = .01$. The two VME conditions did not differ, indicating no added benefit of the monitoring prompts. Similarly, on the process level, we found significant differences between the two VME conditions and the control condition, but no differences between the two experimental conditions. Detailed process results will be presented at the conference.

The aim of this study was to test the effectiveness of VME and monitoring prompts for enhancing hypothesis and argumentation quality. Our results indicate that VME improved hypothesis quality in the training and transfer tasks. Watching VME improved argumentation quality in the training task, but this improvement could not be replicated in the transfer task. We found no added benefit of the monitoring prompts. On the process level, we observed a similar pattern of results - we found differences between the two VME conditions and the control condition, but no differences between the VME conditions. Our findings highlight the potential of VME for supporting scientific reasoning during inquiry learning. Thus, teachers and educational practitioners can benefit from using VME in combination with virtual experiments to teach scientific reasoning.

Effects of providing adaptive domain information on facilitating hypothesis generation in simulation-based inquiry learning

Xiulin Kuang, Tessa H. S. Eysink, Ton de Jong

Introduction

Hypothesis generation is widely regarded as a central process of inquiry learning (de Jong & van Joolingen, 1998; Zimmerman, 2007). It triggers students to mindfully consider a problem to be addressed and to consciously organize their tentative explanation or solution to the problem into testable statements. The logic expressed in testable hypotheses can guide conscious processing in subsequent inquiry processes, such as experiment design, data collection, and data interpretation. One principle of inquiry learning is for students to actively develop knowledge about a domain that they are relatively unfamiliar with (Lazonder et al., 2009). But how can we realistically expect students to generate hypotheses if they are novices of a domain? Noticing what important variables to be considered, and what possible relationship can happen between variables requires basic domain knowledge, which students may lack. Empirical studies have confirmed that providing domain information to students with low prior knowledge can facilitate students' knowledge acquisition on the domain and encourage more hypothesis-driven behavior (Lazonder et al., 2010). Yet in practice, students in the same class may have different levels of prior knowledge. The expertise reversal effect, promoted by Kalyuga et al. (2003), argues that instructional formats that are effective for learners with low prior knowledge could be ineffective, or even deleterious for learners with high prior knowledge. Providing fixed, identical domain information to all the students may not end up with the same positive outcome. Information technology makes it possible to automatically provide information adaptive to different inputs. The effect of providing adaptive domain information based on students' level of prior knowledge on facilitating their hypothesis generation process is a question not addressed by earlier studies. Hence, the present study aims to detect whether providing adaptive domain information is an effective way to foster students' hypothesis generation and knowledge acquisition in simulation-based inquiry learning.

Method

Participants were 153 secondary school students (11-13 years old) from Italy (n = 70) and Romania (n = 83). Students from each class of the target schools were randomly assigned to two conditions, either with or without the adaptive domain information. Students worked with a sequence of learning phases in a simulation-based inquiry learning environment on a physics topic force and motion. These learning phases covered all the major inquiry processes, including presenting an inquiry question, hypothesis generation, experiment design, data collection, and drawing conclusions. The adaptive domain information was provided after presenting the inquiry question and before students write their hypotheses. The domain information was made adaptive by two steps. First, a list of both relevant and irrelevant variables on force and motion was shown in a Selection tool. Students were asked to select variables that they thought were important to be taken into consideration to answer a given question. To identify decent selection, students were also asked to indicate general relations between variables by dragging lines between variables. Second, based on students' variable selections and indicated relations, domain information that varies in levels of detail about each variable was automatically shown. The domain information is adaptive in the sense that different students may be presented with an introduction of a variable in three different levels of detail: a full introduction, a less extensive introduction, or no instruction. As for a full introduction, the definition of a variable will be firstly introduced by referring to a common phenomenon of daily life and/or showing a picture, and then some practical information or examples about how to measure or how to record the variable will be included. The less extensive introduction will only include the latter part of the full introduction. No instruction means no further information will be shown to students. Three aspects were taken into account to decide which level of domain information to be presented: whether a variable is relevant or not, whether a variable is selected or not, and whether possible general relations were correctly indicated or not. Students' knowledge acquisition will be assessed by comparing their score of knowledge tests before and after the inquiry learning task. A coding scheme will be designed to code the testability and complexity of students' hypotheses.

Results and Discussion

Data collection is currently taking place. The results and the discussion based on the results will be presented at the conference.

Combining physical and virtual experiments in physics education

Salome Wörner, Jochen Kuhn, Katharina Scheiter

Introduction

The ability to understand and use scientific concepts and methods has become a fundamental aim of science education. To improve the understanding of both science content and scientific practices, the use of experiments for inquiry-based learning can provide valuable learning opportunities for students. Digital technologies can enhance learning from traditional physical (hands-on) experiments (PE). Virtual experiments (VE), for example, provide further observation and modelling opportunities while still allowing interactive and self-directed experimentation and manipulation of variables. On the other hand, VE lack the hands-on experience and the authenticity of the PE. Thus, VE and PE have complementary affordances, which may have unique benefits for learning. In line with this reasoning, de Jong et al. (2013) and Kapici et al. (2019) showed that students who learn with combinations of PE and VE in most cases outperform students who learn with PE only or VE only. They conclude that well-designed combinations of PE and VE allow students to gain a more nuanced understanding of scientific phenomena. However, there is little evidence so far on how those 'well-designed combinations' should ideally look like to maximize the learning outcome during inquiry learning. Therefore, this study provides a first step towards addressing this question by investigating whether the sequence of the experiments (VE first or PE first) influences the students' conceptual understanding of the lessons' topic. Additionally, the combination of the experiments was compared with a control group of students who conducted the same experiments, but as PE only.

Method

In this study N = 124 students from five seventh grade classes from the highest track of the German school system participated. However, due to missing data for some students this number decreases to n = 80 complete data sets (pre-test, worksheets, and post-test). The topic of the lesson was converging lenses (physics, geometrical optics) and the refraction of light rays through a converging lens which forms an image of the object. In the VE we used for this study the following variables can be manipulated using sliders: thickness of the converging lens, height of the object, and distance between object and lens. These variables can also be varied in the PE. However, the VE is more abstract showing a schematic view of the lens, the object, and the image of the object. Additionally, the path of light refracting through the lens and the three construction lines can be observed in the VE. The students worked with the VE on iPads. All participants were randomly assigned to one of three conditions within classes (between-subjects design): (1) PE only (control condition) or (2) sequence VE – PE or (3) sequence PE – VE. Before the experimentation phase all participants received an introductory lesson on the converging lens and its functions. During the following experimentation phase participants worked together in groups of two to three students, guided by a worksheet detailing the tasks that students had to perform. These tasks required the students to investigate how the thickness of the lens, the height of the object, and the distance between object and lens affect the image resulting from using the converging lens. Each participant completed a test of conceptual understanding three times: one week before the intervention (the physics lesson) as a pre-test to measure the prior knowledge of the students, one day after the intervention (immediate post-test) and approx. eight weeks after the intervention (follow-up-test). Items are constructed in a way that they address well-known misconceptions of students. Process data was collected through video and audio recordings of students during the experimentation phase as well as recordings of the iPads' screens during the VE and analysis of the students' worksheets.

Results and discussion
Results and discussion of this study will be presented at the ISLS Annual Meeting 2021.

References

Brinson, J. R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. *Computers & Education, 87*, 218-237.

Choi, A. (2008). *A study of written argument using the science writing heuristic approach in inquiry-based freshman general chemistry laboratory classes.* (Doctoral dissertation). Retrieved from https://search.proquest.com/docview/304609585

D'Angelo, C. M., Rutstein, D., & Harris, C. J. (2016). Learning with STEM simulations in the classroom: Findings and trends from a meta-analysis. *Educational Technology, 56,* 58-61.

de Jong, T., Linn, M. C., & Zacharia, Z. C. (2013). Physical and virtual laboratories in science and engineering education. *Science, 340*, 305–308.

de Jong, T., & van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research, 68*(2), 179-201.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38*(1), 23-31.

Kant, J. M., Scheiter, K., & Oschatz, K. (2017). How to sequence video modeling examples and inquiry tasks to foster scientific reasoning. *Learning and Instruction, 52*, 46–58.

Kapici, H. O., Akcay, H., & de Jong, T. (2019). Using hands-on and virtual laboratories alone or together – Which works better for acquiring knowledge and skills?. *Journal of Science Education and Technology, 28*, 231-250.

Lazonder, A. W., Hagemans, M. G., & de Jong, T. (2010). Offering and discovering domain information in simulation-based inquiry learning. *Learning and Instruction, 20*(6), 511-520.

Lazonder, A. W., & Harmsen, R. (2016). Meta-analysis of inquiry-based learning: Effects of guidance. *Review of Educational Research, 86*, 681–718.

Lazonder, A. W., Wilhelm, P., & van Lieburg, E. (2009). Unraveling the influence of domain knowledge during simulation-based inquiry learning. *Instructional Science, 37*(5), 437-451.

Lehrer, R., & Schauble, L. (2015). The development of scientific thinking. In R. M. Lerner, L. S. Liben, & U. Mueller (Eds.), *Handbook of child psychology and developmental science*, Vol. 2, 7th edition, (pp. 671-714). John Wiley & Sons Inc.

National Research Council (NRC). (2015). Guide to Implementing the Next Generation Science Standards. The National Academies Press.

Pine, K., & Messer, D. (2003). The development of representations as children learn about balancing. British *Journal of Developmental Psychology, 21*(2), 285-301.

Zacharia, Z. C., Loizou, E., & Papaevripidou, M. (2012). Is physicality an important aspect of learning through science experimentation among kindergarten students? *Early Childhood Research Quarterly, 27*(3), 447-457.

Zimmerman, C. (2007). The development of scientific thinking skills in elementary and middle school. *Developmental Review, 27*(2), 172-223.

Embodying STEM: Learning at the Intersection of Dance and STEM

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Abstract: This symposium addresses dance as a site for STEM learning. We present papers from five research projects that each sought to engage youth in embodied STEM learning using dance, exploring the power of creative embodied experiences and the body's potential as an expressive tool and resource for learning. We show how dance activities expanded access to STEM and supported sense-making; how dancer and dance-making practices were leveraged to support computational thinking, modeling, and inquiry; and how moving bodies in creative ways helped to generate new insights by allowing for new perspectives. Across our work, we seek to understand the multiple, rich learning opportunities that emerge from working across the arts and sciences, dance and STEM. Together our research shows that attending to opportunities for STEM engagement and learning through dance practices can broaden access to learning and engagement in STEM for all.

Session overview

"We want to dig down deeply in understanding movement as a site of knowledge, so that dance is placed at the center rather than the periphery of interdisciplinary dialogue"
- Norah Zuniga Shaw, Synchronous Objects Project

The notion that thinking is an "embodied" activity, that the active human body as a whole, not just the brain, is involved in how we conceptualize situations, has been developing for decades in the writing of philosophers, cognitive and learning scientists (Merleau-Ponty, 2002; Lakoff, 2012; Varela, Thompson, & Rosch, 1991; Goodwin, 2000; Streeck, Goodwin, & LeBaron, 2014). However, embodied cognition literature has yet to explicitly address movement as a creative, cultural, and expressive medium. A notable absence of thought remains around ideas of the body and bodies as conversational and expressive, and a particular gap exists when it comes to STEM learning through creative-expressive-embodied dance activities. Each paper in this symposium contributes to a collective re-conception of STEM embodiment by focusing on how youth use expressive movement to engage with ideas as they explore STEM in formal and informal learning environments.

Embodied cognition in the learning sciences has focused on important work in which body movements augment technological environments to support deep disciplinary learning. Rooted in gesture studies, this work situates intuitive embodied experiences as a developmental beginning towards internalizing concepts cognitively (Abrahamson & Lindgren, 2014). We offer an alternative framing of embodiment where the expressiveness of full-bodied coordinated movements themselves are the means and ends of learning (Marin et al., 2020). This new framing of embodiment allows us to see dance as a medium for engaging in STEM-based inquiry. Dance invites us to move in solidarity with one another, exploring our world through our whole bodies and our whole selves, the cognitive, creative, emotional and the logical. It affords multiple ways of bodily knowing, access to multiple perspectives, as well as physical, emotional and affective stimuli, and dance practices can be valuable resources for inquiry and problem solving. The challenge of *Reflecting the Past and Embracing the Future* extends to us the opportunity to understand STEM learning as it is and imagine it as it could be, as creative and embodied.

Through this symposium, we invite participants to explore the power of creative embodied experiences and of the body's potential as an expressive tool and resource for learning. We hope to engage in a broader conversation about embodiment by sharing data that shows how dance activities can expand access to STEM and support STEM sense-making; how dancer and dance-making practices can be leveraged to support computational thinking, modeling, and inquiry; and how moving bodies in creative ways can help to generate new insights by allowing for new perspectives. We have organized the presenters temporally, working from 2017 up through 2020 when the global COVID pandemic upended our ability to move in co-present spaces, as we acknowledge how the virtual re-mediation of our lives has impacted our understandings of the body now and for the future. The symposium will be organized as follows: (1) co-chairs will lead an embodied warm up to contextualize issues across projects (5 min); (2) each project will present (12 min); (3) the co-discussants will pose questions and implications across the collective work (10 min); (4) we will take questions from the audience (15 min).

Dance/Making: Integrating STEM and arts across 3 dimensions

Dionne Champion, University of Florida

Dichotomous ways of thinking that privilege science over art, thinking over doing, the immaterial over body and logic over emotion or creativity have led to narrow perceptions of science as disembodied, emotionless, objective, and lacking creativity (Bowman, 2004; Brickhouse, 2001) and to equally narrow perceptions of art as frivolous, irrational and non-cognitive. Despite research that has begun to recognize the value of learning at the intersection of science and arts and of embodied science learning (Johnson-Glenberg et al., 2014; Abrahamson & Lindgren, 2014; Root-Bernstein et al., 2011), there have been few studies focused on understanding dance as a creative-expressive-embodied resource for STEM problem-solving and sense-making.

This paper explores dance as a resource for STEM learning in the dance makerspace, a 4-week summer program that challenged youth (ages 9-14) to engage in dance/Making, a process of making with movement, materials and bodies. Youth in the dance makerspace choreographed projects that explained science phenomena using movement and music, physical and computational tools, kid-friendly electronic elements (i.e. LED lights, Arduino boards, conductive clay), and other materials. The design-based research intervention was developed to explore the affordances of dance as an interest, a creative practice, and a way of knowing and to explore the relationships between "making to learn" and movement and dance for African American youth who often experience marginalization around science and technology and end up positioned as disinterested in science.

Utilizing a lens of representational mediators and practices (Danish et al., 2007), video data from the 4th and final iteration of the study was analyzed to understand how youth drew on STEM practices to inform their creative dance/Making process and how the process of dance/Making expanded their engagement with science and technology. Findings show that the process of dance/Making supported interdisciplinary problem solving, sense-making and sustained science inquiry. The following example featuring one project group, *Stardust* (a group of five girls who developed a choreographic representation of Saturn), demonstrates three ways that youth blended artistic and scientific practices to support science sense-making: integrating dance and technology to develop their choreographic explanations, developing an integrated art/science practice of modeling (Enyedy et al., 2014; Root-Bernstein et al., 2011), and combining narrative and analytical ways of thinking in their choreographic explanations (Bruner, 1987).

Dance and Technology. To develop a choreographic explanation of the formation of Saturn, its rings, and Roche limit (the invisible barrier around the planet; the minimum distance at which an object can approach without being disintegrated), Stardust created a representation that used dance and technology to highlight many essential ideas. They designed and constructed a foam model of Saturn mounted on a rotating electric motor with LED light dust and ice particles. They used dancers to play the role of gases and heavier elements drawing together under the force of gravity to form the planet and its Roche Limit. They utilized technology to enhance the ideas they articulated with their bodies (representing the particulate nature of the rings with LED lights while representing orbit with movement); interacted with it as a prop to help explain the phenomenon (spinning model of Saturn as the planet); and integrated it into their movement phrases ("becoming" Saturn as a way to switch the motor on). Embedded in their attempt to bring their choreographic ideas to life were design conversations that required them to attend to and understand the technologies they wanted to employ (e.g., how to wire and power the LED lights and fan motor needed to represent ice and dust particles of Saturn's rings). Their representational choices reflected their understanding of the phenomenon and offered opportunities to develop technical skills related to engineering, circuitry, and design through the dance/Making process.

Blending Art and Science Practices. To create their project, Stardust engaged in the practice of modeling; however, this practice could not be defined as simply science, engineering, or art because it integrated science, engineering and art. It was a STEAM making practice that involved exploring science ideas using both STEM and arts as tools for making and investigation. Modeling as a dance/Making practice served a variety of purposes. The girls made models to provide inspiration for choreography, to brainstorm new ideas, develop prototypes, solve problems, figure out technical design features, work through their developing understanding of the scientific explanation of the phenomenon, and to represent aspects of planet formation in their final representation. They tried many different choreographic ideas as they thought through the best way to model the formation of Saturn's rings, embodying the objects that approach the planet and disintegrate into particles that would form rings. Modeling the phenomenon and iterating on their ideas impacted how they thought about the phenomenon, offering opportunities to experience aspects of it from multiple perspectives, and about the representational possibilities by prompting discussions about which features of the phenomenon were essential and which could be left out of their final representation.

Narrative and Analytical Ways of Thinking. As the girls began developing project ideas, they researched the process of planet formation as a way to inform their choreography. Their research raised new questions and new directions for exploration and provided opportunities to become familiar with the symbols scientists used to describe the phenomenon, which led to new knowledge that they used to make representational decisions. Science supported storytelling through dance, and the act of developing a narrative was a tool for understanding the science. In dance, narrative is a tool that can be used to structure the development of choreographic compositions (Wright, 2003). It allowed for flexibility in storytelling and the simultaneous exploration of multiple ideas. The girls used their choreography to simultaneously explain processes, causes and effects, and relations among aspects of the phenomenon, all placed within the context of a story about the formation of the planet. Dance in this context became a representational medium for both narrative and analytical (or paradigmatic) thinking, providing rich opportunities for integration of these explanatory approaches.

Dance/Making using materials, tools, and bodies to express and support their developing understanding of phenomena created opportunities for youth to shift how they engaged with and understood the science they studied. Youth explored science content and experienced STEM practices in the context of dance/Making, and as a result, were pulled into science phenomena in ways that became personally and physically engaging. This work has the potential to broaden and expand how we think about STEM learning by identifying ways in which embodied creative processes like dance/Making can be resources for science learning and ways that STEM can be a resource for creative thinking. This is critical for understanding learning in informal creative spaces, learning driven by movement, and learning for populations for whom movement and the body are valued cultural resources.

Exploring opportunities for embodied learning in dance/STEM with black girls

Folashade Solomon, TERC

The notion that thinking is an "embodied" activity – that the active human body as a whole, not just the brain, is involved in how we conceptualize situations – has been developed in the writing of philosophers such as Maurice Merleau-Ponty (2002) and of cognitive scientists such as George Lakoff (2012). Other researchers developing the field of embodied cognition have used evidence from linguistics, psychology and cognitive science-among other fields-to argue that all human cognition is embodied action (Lakoff & Johnson, 1980, 1999; Varela, Thompson, & Rosch, 1991). These researchers argue that both our most simple conceptualizations and our most complex problem solving are influenced by our bodies and are enacted in constant interaction with our physical environments. Building on this work, anthropologist Tim Ingold argues that whole body movement has not been deeply explored in the literature on embodied cognition and suggests that dance is an important type of embodied cognition (Ingold, 2011). Our paper explores the ways in which dance is a type of embodied cognition as well as an art form and affords access to cultural practice. The importance of dance in Black culture positions the artform as a site of rich identity and confidence for Black girls. In this paper, we examine the role of dance as an embodied resource for physics learning and explore how this culturally and personally expressive medium can expand access to physics for Black girls. We look closely at youth interactions in the Embodied Physics Learning Lab (EPLL), a program that invited 15 Black high school girls from two community-based dance centers to engage in embodied activities that combined dance and dance-making practices with physics to better understand how interdisciplinary approaches present opportunities to enhance engagement, provide additional lenses for meaning-making, and foster meaningful connections to physics.

We engaged in an iterative process of design, observation and analysis of the Embodied Physics Learning Lab, utilizing design-based research (DBR) (Cobb et al., 2003) and responsive design approaches to design the lab and qualitative interpretive methods to understand participant perspectives and experiences (Denzin & Lincoln, 2008). Building on sociocultural perspectives, we designed an environment that recognized, respected and recruited youths' prior knowledge, cultural identities and practices to engage them in the study of physics. There are few studies that look at STEM learning environments, embodiment, and identity with underserved students. It is here that we situate our work - at the intersection of dance and informal science learning and identity studies primarily involving Black girls.

This paper focuses on project findings that show different uses of embodied learning in Dance/STEM to explore scientific phenomena. We share three types of embodied learning activities that enabled physics engagement and inquiry among teens in the learning lab as they used their bodies to think, investigate and model physics concepts and ideas: embodied imagining, kinesthetic experience and re-presentation. Embodied imagining involves exploring physics content through dance-making structures and practices; for example, engaging in sense-making through improvisation and imagery, (i.e. mobilizing dance to animate concepts in particle and quantum physics). Kinesthetic experience involves sense-making through one's own bodily experiences (i.e. exploring gravity's effect on your one's body by jumping while being lifted). Re-presentation, as defined by Champion (2018), involves interpreting, combining, reformulating, and translating ideas that were researched and collected about a phenomenon to create a new representation to re-present it in a new embodied form. Through a close analysis of the resources youth drew from in their interactions in the Embodied Physics Learning Lab, we show that movement, bodies, emotions and culture can be rich resources that, while sometimes seen as deficits, can be useful in supporting understanding and engagement with physics ideas. We argue that when repositioned as strengths, dance practices can act as powerful funds of knowledge for accessing these resources, giving Black girls new paths forward into physics.

Traditionally, physics is too often presented as a set of abstract and disembodied concepts. Engaging youth in learning approaches that leverage embodied sense-making allows them to use a fuller set of meaning-making resources to understand ideas, formulate descriptions, and express their understandings. Non-traditional forms of participation can encourage all students, especially those who might not otherwise participate, to enter academic conversations (Ballenger, 1997; Varelas, et.al., 2010; Warren & Rosebery, 1996). This work offers approaches for fostering more effective participation of underrepresented populations in art-based learning and STEM fields.

Dance as scientific inquiry: How does improvisational movement support collaborative sensemaking for young children?

Lindsay Lindberg, UCLA & Noel Enyedy, Vanderbilt University

Despite the growing momentum behind the STEM to STEAM (STEM + Arts) movement in K-12 education (Maeda, 2013), dance and other body-based artforms are rarely considered part of canonical science learning. However, research shows that dance adds a distinct layer of sense-making tools with which students and scientists can make sense of multidimensional scientific phenomena with their bodies (Ochs et al., 1996; Nasir, Rosebery, Warren, & Lee, 2006; Myers, 2012). Previous work has addressed using dance as a tool to represent already-learned knowledge (Zohar & Abrahamson, 2015; Myers, 2012), but those studies run the risk of discounting the role that active dance-making can play in supporting science sense-making. Rather than positioning dance as solely "an instrument for science communication" (Myers, 2012 p. 159), this analysis positions young science learners using their bodies and dance as "experimental media to generate insight into molecular forms" (Myers, 2012 p. 172). This analysis builds on the Learning in Embodied Activity Framework (LEAF) (Danish et al., 2020), and positions dance as a discipline and culturally specific practice that is distinct from, and intentionally supports collaborative science learning.

This analysis is part of a larger, multi-year design based research study (Design Based Research collective, 2003), iSTEP (Interactive Science Through Technology Enhanced Play). The project focuses on the ways in which young children (ages 6-7) engage with science learning in an embodied mixed reality setting through inquiry and embodied play (Danish et al., 2020; Enyedy et al., 2015). A seven-day unit explored particle behavior of both micro- and macro-states of matter using OpenPTrack technology which tracked students' speed and location, and communicated that to a projected simulation. Throughout the intervention, students learned that particulate matter in a solid moves slowly (vibrates in place), liquid particles move at a medium speed, and gas particles move quickly. This analysis looks closely at video data from the seventh and final day of data collection, wherein groups of four students choreographed and performed dances representing a state change (i.e., from liquid to gas). Using inductive methods and interaction analysis (Jordan & Henderson, 1995), we track the choreographic process and embodied activities of one group of 4 students and 1 researcher representing a state change from liquid (water) to solid (ice).

Our analysis demonstrates the multiple ways students make sense of and represent a scientific concept-water particle behavior as a liquid. Throughout the choreographic process, students' verbal descriptions of particulate behavior remained stable, while their movements demonstrated nuanced explorations of water particles in a liquid form. They generated and iterated movement ideas nine times over two minutes, representing particles while moving at both a medium speed and at a medium distance away from each other. Students used levels in two ways (standing high on tiptoes, squatting low towards the floor) to explore ways that particles could be standing in the same place "medium" distance apart. This analysis shows students using dance as one way to deepen their engagement with the science material, not to merely represent their already sealed canonical content knowledge about states of matter. Indeed, the process of choreographing scientific ideas, even when students have previously embodied the phenomena as a group, involves opportunities for new noticings that support learning. Dance is not simply a tool to present previously learned knowledge, but an opportunity to deepen understanding of canonical science content.

Students used multiple bodily movements and positions to represent the same verbal descriptions - "medium" speed and distance from each other. This matters because by limiting what we recognize as canonical science, we miss out on nuance that students pick up, embody, and express while engaged in dance as a sense-making process. This analysis shows students applying their embodied science knowledge to their choreographic processes, furthering past research that positions dance performance as a tool for students to develop their sense-making and argumentation around science (Lindberg et al., 2019). Dance added affective and embodied depth to the students' conceptualization of the canonical science knowledge, which is worthy of future investigation.

Developing computational double awareness through rule-based dance games

Lauren Vogelstein a ndCorey Brady, Vanderbilt University and Rebecca Steinberg and Curtis Thomas, Independent Dance Artists

Professional dancers' execution of choreography entails that dancers understand both how it feels to execute movement from within an ensemble of moving bodies and what the entire ensemble looks like to an outside viewer. This phenomena, referred to by dancers as "double awareness," gives dancers an intrinsic perspective from within while maintaining an extrinsic perspective without being an outside viewer. In this paper we explore how the practices of professional dancers can be leveraged for middle schoolers to develop a double awareness of computational agents by engaging together in rule-based dance games. This speaks to the importance of taking multiple perspectives in learning about the computational components of complex systems (Olson, 2015; Papert, 1980; Wilensky & Reisman, 2006; Wilensky & Resnick, 1999) and expands it through design based research (Design Based Research collective, 2003) that leverages the expressive practices of professional dancers engaging their whole bodies in movement together (Vogelstein, 2020).

This work reports on the design process and implementation of a one-week art and coding camp for middle schoolers. The camp was co-designed by the authors (one learning scientist and two professional dancers) and four math teachers with a goal of leveraging mathematical and computational connections between choreography and programming in an agent based modeling environment (NetLogo). Video recordings of designing and implementing the camp were analyzed using Interaction Analysis (Jordan & Henderson, 1995; Hall & Stevens, 2015) to explore the micro and multimodal nature of sense-making in interaction.

As an art and coding camp, our goal was for students to explore the expressive potential of computational environments physically and digitally. The soup game, a rule-based dance game suggested by Steinberg & Thomas, provided campers the opportunity to develop choreography quickly as an ensemble while co-developing an understanding of computational concepts (e.g. code specificity, agent interpretation, procedures, and conditional statements). Setting up the game involved campers creating a set of rules to follow (e.g. Rainbow Muffins meant everyone walked forward a random number of steps less than 21 in whatever direction they happened to be facing at that moment). Playing the soup game involved freely moving about until an outside leader called out a rule that was then instantly followed. When campers developed rules they had to show players what it meant to follow it. This raised important questions from peers about specificity, asking questions like "How long do we wiggle for?" or "How many steps forward do we take? Are they in a certain direction?" These calls for specificity exemplify the role that double awareness played in the campers' understanding of both activities--writing and interpreting code as well as choreographing and being choreographed for. These noticings stemmed from students taking the perspective of what they as human agents/dancers would have to enact in the game, while responses took into account what it would mean for an individual to enact a rule and what the group might look like enacting this rule together. As campers played the soup game over the course of the week the complexity of their rules and ability to enact them as an ensemble visibly increased as their double awareness developed and supported their computational fluency.

Through this work we are beginning to understand how an experience of being inside a structure and forming it in relation to others supports new understandings of the structure itself. Based on these findings, we argue dancers' engagement in double awareness can be leveraged for computational learning, supporting students' understandings of the expressive potential of computation.

DanceON: Exploring embodiment in a dance computing learning application

Kayla DesPortes, William Payne and Yoav Bergner, NYU

Computing technology presents opportunities to examine the ways in which data on and about the body can be sensed, represented, and interacted with to support dance practices while also supporting learning about computing. Dance education engages learners with their physical, intellectual, and emotional selves (Bannon, 2010) while providing practices tied to “self-expression and interpretation through motion” (Koff, 2000). Developing learning experiences across computing and dance enables us to examine how we can leverage embodied ways of knowing about the self and computing technology grounded in our understanding of our perceptual representations and bodily states within a social environment (Lawrence, 2008). In this research, we examine how computing technology can be designed for a dance computing educational environment to diversify the embodied ways of knowing and learning.

Prior work at this intersection has examined the potential for learners to leverage knowledge of their bodies as they problem-solve and program virtual avatars (Leonard et al., 2020). For example, Leonard et al.’s work explored the idea of body syntonicity (Papert, 1980) as they identified how some learners approached a challenge of programming a virtual avatar to dance through moving their real bodies and translating the knowledge from physical movement into code (2020). We build on this work exploring opportunities for embodiment in a dance computing tool called danceON (dance Object Notation) (Payne et al., *In Press*).

We developed danceON through a collaborative design-based research investigation (Design Based Research Collective, 2003) consisting of semi-structured interviews and weekly design meetings with STEM From Dance, a community organization that specializes in developing computing experiences for young women of color to expose, interest and engage them in STEM disciplines. The technology was developed in the midst of the COVID-19 pandemic, thus developed in ways that aligned with the need to engage with learners in a remote environment. danceON pairs a declarative, reactive programming environment (Krishnamurthi & Fisler, 2019) with built-in pose detection. The system enables learners to program animations that respond to the pose data of their bodies. These animations are then rendered on top of a coordinate pixel plane of their uploaded video data or webcam footage. Through this integration of body data, the learner’s own movement and position become the subject of most programming statements in danceON. Thus, common programming constructs are embodied and reasoned through with movement. For example, learners can trigger animations based on conditional statements that explicitly describe body positions, e.g. “if my left wrist is in the top left position of the screen”, “if my right knee is above my right hip,” etc. Literature on embodiment suggests the importance of being able to ground the meaning of words and actions into the lived experience of the person (Glenberg, 2008).

We discuss our findings from an analysis of four artifacts created with danceON that encompassed music videos with original choreography and programmed animations, co-developed by learners and instructors within a STEM From Dance summer camp. The artifacts encompassed themes related to girl power, the Black Lives Matter movement, and self-love. We reflect on the ways the code represents how learners were able to explore body position and movement within their creations and examine how computing technology could further support embodied learning experiences and expressivity. Our analysis demonstrates how learners were able to: (1) identify, quantify, and define specific movements and poses; (2) explore mappings of animations to their bodies; (3) augment choreography with animations that represent specific lyrics and visually convey narrative; and (4) experience and overcome the affordances and constraints of computer vision algorithms that occasionally produce missing or inaccurate data.

References

Abrahamson, D., & Lindgren, R. (2014). Embodiment and embodied design.

Ballenger, C. (1997). Social identities, moral narratives, scientific argumentation: Science talk in a bilingual classroom. Language and Education, 11(1), 1-14.

Bannon, F. (2010). Dance: the possibilities of a discipline. Research in Dance Education, 11(1), 49-59.

Bowman, W. (2004). Cognition and the body: Perspectives from music education. In Knowing bodies, moving minds (pp. 29-50). Springer, Dordrecht.

Brickhouse, N. W. (2001). Embodying science: A feminist perspective on learning. Journal of research in science teaching, 38(3), 282-295.

Brown, N. C. (2001). The meaning of transfer in the practices of arts education. Studies in Art Education, 43(1), 83-102.

Bruner, J. (1987). Life as narrative. Social research, 11-32.

Champion, D. N. (2018). The STEAM dance makerspace: A context for integration: An investigation of learning at the intersections of STEM, art, making and embodiment (Doctoral dissertation, Northwestern University).

Daily, S. B., Leonard, A. E., Jörg, S., Babu, S., & Gundersen, K. (2014, March). Dancing alice: Exploring embodied pedagogical strategies for learning computational thinking. In Proceedings of the 45th ACM technical symposium on Computer science education (pp. 91-96).

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: a sociocultural framework for embodied cognition. *Int. J. Comput. Support. Collab. Learn.*, *15*(1), 49-87.

Danish, J. A., & Enyedy, N. (2007). Negotiated representational mediators: How young children decide what to include in their science representations. Science Education, 91(1), 1-35.

Design-Based Research Collective. (2003). Design-based research: An emerging paradigm for educational inquiry. Educational Researcher, 5-8.

Enyedy, N., Polman, J. L., Graville-Smith, C., Bang, M., Warren, B., Rosebery, A., ... & Halverson, E. R. (2014). Learning and Becoming Through Art-Making: Relationships among tools, phenomena, people, and communities in shaping youth identity development. Boulder, CO: International Society of the Learning Sciences.

Enyedy, N., Danish, J. A., & DeLiema, D. (2015). Liminal blends: How students blend symbols, experiences, and their own bodies together in order to co-construct meaning in a collaborative augmented-reality learning environment. International Journal of Computer Supported Collaborative Learning.

Glenberg, A. M. (2008). Embodiment for education. In Handbook of cognitive science (pp. 355-372). Elsevier.

Goodwin, C. (2000). Action and embodiment within situated human interaction. Journal of pragmatics, 32(10), 1489-1522.

Hall, R., & Stevens, R. (2015). Interaction analysis approaches to knowledge in use. In Knowledge and Interaction (pp. 88-124). Routledge.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. Harvard Educational Review, 84(4), 495-504.

Ingold, T. (2011). *Being Alive: Essays on Movement, Knowledge and Description*. Abingdon, Oxon, U.K.: Routledge.

Johnson-Glenberg, M. C., Birchfield, D. A., Tolentino, L., & Koziupa, T. (2014). Collaborative embodied learning in mixed reality motion-capture environments: Two science studies. Journal of Educational Psychology, 106(1), 86.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. The journal of the learning sciences, 4(1), 39-103.

Koff, S. R. (2000). Toward a definition of dance education. Childhood Education, 77(1), 27-32.

Kritzmire, J. A. (1993). Value-based arts education: Agenda for advocacy. Arts Education Policy Review, 94(3), 18-22.

Krishnamurthi, S., & Fisler, K. (2019). Programming paradigms and beyond. The Cambridge Handbook of Computing Education Research, 37.

Lakoff, G. (2012). Explaining embodied cognition results. Topics in cognitive science, 4(4), 773-785.

Lakoff, G. & Johnson, M. (1999). *Philosophy in the Flesh: The embodied mind and its challenge to Western thought*, University of California, Berkeley, and University of Oregon. New York: Basic Books.

Latulipe, C. (2013, June). The value of research in creativity and the arts. In Proceedings of the 9th ACM Conference on Creativity & Cognition (pp. 1-10).

Leonard, A. E., Daily, S. B., Jörg, S., & Babu, S. V. (2020). Coding moves: Design and research of teaching computational thinking through dance choreography and virtual interactions. Journal of Research on Technology in Education, 1-19.

Lindberg, L., Keifert, D., Enyedy, N., & Danish, J. (2019). When Words Are Not Enough: What Student Gestures and Embodied Responses Tell Us About Understanding Science Through Dance. In *13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019*, Volume 2 (pp. 953-954). Lyon, France.

Maeda, J. (2013). STEM + Art = STEAM. *STEAM J.* 1:34. doi: 10.5642/steam. 201301.34

Marin, A., Taylor, K. H., Shapiro, B. R., & Hall, R. (2020). Why Learning on the Move: Intersecting Research Pathways for Mobility, Learning and Teaching. *Cognition and Instruction*, 1-16.

Merleau-Ponty, M. (2002). Husserl at the Limits of Phenomenology.

Myers, N. (2012). Dance your PhD: Embodied animations, body experiments, and the affective entanglements of life science research. *Body & Society*, *18*(1), 151-189.

Nasir, N., Rosebery, A., Warren, B., & Lee, C. (2006). Learning as a cultural process: Achieving equity through diversity. In K. Sawyer (Ed.), The Cambridge handbook of the learning sciences (pp. 489–504). New York, NY: Cambridge University Press.

Ochs, E., Gonzales, P., & Jacoby, S. (1996). " When I come down I'm in the domain state": grammar and graphic representation in the interpretive activity of physicists. *Studies in Interactional Sociolinguistics*, *13*, 328-369.

Olson, I. C. (2015). Situating complexity: Relational epistemologies and complex systems thinking (Doctoral dissertation, Northwestern University).

Papert, S. (1980). Mindstorms: Children, computers, and powerful ideas. Basic Books, Inc..

Payne, W., Bergner, Y., West, M.E., Charp, C., Shapiro, B., Szafir, D.A., Taylor, E.V., & DesPortes, K. (*In Press*). danceON: Culturally Responsive Creative Computing. In *Proceedings of the 33rd Annual Conference on Computer-Human Interaction.*

Root-Bernstein, R., & Root-Bernstein, M. (2013). Sparks of genius: The 13 thinking tools of the world's most creative people. HMH.

Root-Bernstein, B., Siler, T., Brown, A., & Snelson, K. (2011). ArtScience: integrative collaboration to create a sustainable future.

Streeck, J., Goodwin, C., & LeBaron, C. (2011). Embodied interaction in the material world: An introduction. Embodied interaction: Language and body in the material world, 1-26.

Varela, F., Thompson, E., & Rosch, E. (1991). The embodied mind (Vol. 2). Cambridge, MA:MIT Press.

Varelas, M., Pappas, C. C., TuckerRaymond, E., Kane, J., Hankes, J., Ortiz, I., & Keblawe Shamah, N. (2010). Drama activities as ideational resources for primary grade children in urban science classrooms. Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching, 47(3), 302-325.

Vogelstein, L. (2020). Physical Research: Professional Dancers Exploring Collective Possibilities in a Solidifying Substrate. In *14th International Conference of the Learning Sciences, Nashville, TN*.

Warren, B. and Rosebery, A.S. (1996). 'This question is just too, too easy!' Perspectives from the classroom on accountability in science. In L. Schauble & R. Glaser (Eds.), Innovations in learning: New environments for education, pp. 97-125. Hillsdale, NJ: Lawrence Erlbaum.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through

Wright, S. (2003). Ways of knowing in the arts. Children, meaning-making and the arts, 1-33.

Zohar, R., Bagno, E., Eylon, B. S., & Abrahamson, D. (2017, September). Motor skills, creativity, and cognition in learning physics concepts. In *1st annual meeting of Movement: Brain, Body, Cognition, July* (pp. 9-11).

Expansive Modeling: Broadening the scope of modeling in K-12 education

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Abstract: Modeling is generally recognized as the core disciplinary practice of science. Through examinations of rich learning environments which expand the boundaries of modeling and the practices connected to it, researchers are broadening what modeling means in disciplinary settings. This interactive session brings together a diverse spectrum of scholars to share the practices they have used to expand modeling, how they were used in their curriculum, and the impact they had on learning. This session will serve as a rich opportunity for discussion to help advance the state of the field around what counts as modeling and the role it can play in learning.

Motivations and objectives

Since a fundamental objective of science is explaining phenomena through model construction, science educators and researchers have increasingly called for science instruction to be organized around models and modeling. These calls have rightfully emphasized directing learner's conceptual activity towards *disciplinarily accepted* forms of inquiry (Lehrer, 2009). However, more recently, scholars have begun to push on the boundaries of modeling to include learners' everyday practices and funds of knowledge. The papers in this symposium present work that expands what modeling can look like in formal and informal settings by drawing on a range of repertoires of practice including dance and movement (Vogelstein et al; DeLiema et al; Fridman et al), storytelling and drama (Reimers & Brady; Wagh & Dickes), discursive and linguistic resources (Farris et al; Pierson & Brady), and cultural and historical ways of knowing (Lam-Herrera et al). We collectively refer to this line of work as *expansive modeling* - broadening the ways we see value in modeling and the practices that can be connected to it. We see this work as critically important because it expands the field's understanding of what can count as modeling and the role it can play in sense-making thereby making it inclusive of and accessible to a wider range of learners. Themes explored include: (1) the practices which became an integral component of the modeling repertoire, (2) the curricular and methodological decisions taken to expand modeling, and (3) what impact these expanded practices had on learning. The goal of this symposium is to showcase how various efforts approach expansive modeling, its role on learning and to provide a knowledge base to build on and be inspired by.

Session format

To promote active and productive discussion, the symposium will be conducted as an interactive poster session. Following brief teaser introductions on each project, attendees will be invited to view presenters' posters. This will provide attendees ample opportunities to examine and discuss curricular and methodological decisions made by the presenters, and how they may be adapted for attendees' own designs in a way that traditional talks do not allow. The symposium will close with an open discussion, in which the discussant will engage presenters and attendees in discussion around the main themes and any areas of interest that emerge during the session.

Theatrical modeling of planetary systems: Expanding the role of perspective in modeling

Jackson Reimers & Corey Brady

We present results from design-based research investigating the potential of engaging students in embodied activities at the intersection of participatory theater and agent-based modeling, focusing on planetary systems phenomena. We were motivated to see how a group of students might come together to physically constitute a representational infrastructure for modeling that supports dynamic perspectival understandings (Greeno & van de Sande, 2007). We saw this possibility as especially propitious for the study of *planetary systems*, which afford a variety of meaningfully distinct perspectives yet can be captured using a relatively small number of interacting agents. Given these motivations, we drew inspiration from both participatory theater (e.g., *Theatre of the Oppressed* (Boal, 1985)) and agent-based modeling (Wilensky & Rand, 2015) as collaborative, socially distributed structures for engaging participants' perspectives in a sense-making endeavor.

Over six successive implementations of a planetary systems unit, designed and facilitated in partnership with a 5th grade STEM teacher, we explored this rich design space. Analyzing our designs, we have articulated initial principles of *theatrical modeling*. While these principles are still tentative, they suggest the power of theatrical modeling in itself and as an expansive addition to the multi-modal modeling enterprise. We identified activity designs that foster multiple modes of thought, ranging from *subjunctive, "What if?" thinking*, enlisting imagination, to *subjective, "What would it mean?" thinking*, enlisting story. These operate in flexible conjunction with the *objective "What is it?"* or *"How does it work?"* thinking more commonly associated with modeling practices, ultimately broadening what it means to know, ask, claim, and interpret in modeling practice.

In theatrical modeling, the modelers *are* the model. Participants simultaneously enact their understandings about the planetary bodies they represent, while also interpreting each others' enactments in this light. This setting is rich in opportunities for collective ideation, argumentation, contestation, and sense-making. Negotiating both "what we just did" and "how we can improve it" thus calls for coordination across perspectives. Theatrical modeling also blends process and product. The model (as product) is a coordinated performance, a collective action that is both a demonstration and a new occasion for question-posing. Re-enacting the model provokes inevitable variation and new observations. Thus, to instantiate a theatrical *model* is to engage in another round of model*ing*. Furthermore, participants' enactments are *polysemic*—they often express more or different ideas than the participant explicitly intends—and these "surplus" meanings fuel the interpretive work of the group, suggesting possible shifts in target phenomena or uncovering unexpected facets of planetary dynamics. These elements of theatrical modeling offer a new set of affordances and constraints for students' modeling practices. We see this most strongly in light of Goodwin's notion of a substrate for co-operative action (2018). Theatrical modeling engages students in using a broader set of semiotic resources, de-settling academic notions of legitimacy and subverting disciplinary boundaries at the interactional level.

Decolonizing complexity: An axiological reorientationfrom a Mayan perspective

Marilu Lam-Herrera, Women Weavers Community Council of Santo Domingo Xenacoj & Pratim Sengupta

In this research, we illustrate how agent-based modeling of emergent phenomena can be re-imagined through the lens of decolonization by partnering with Indigenous Mayan women weavers, high school teachers, and the Ixkoj Ajkem Council (Women Weavers Community Council) in Xenacoj, Guatemala. Research on complex systems emphasizes the importance of understanding emergent phenomena through building progressively complex relationships among individuals and between individuals and their environments (Dickes, et al., 2016; Wilensky & Resnick, 1999). However, modeling complex systems from embodied and agent-based perspectives can also be synergistic with Indigenous ways and forms of knowing and support interdisciplinarity in ways that value cultural historical forms of knowing (Aikenhead & Mitchel, 2011). Furthermore, partnering with Indigenous communities also call for an axiological reorientation of what forms of knowing are *valued* disciplinarily from the perspective of the community (Bang, 2020).

Through our ongoing partnership, we have been designing Grafemos (Lam-Herrera et al, 2019), a modeling environment for learning about emergence. The Grafemos modeling device is a physical "computer" in the shape of a dodecahedron, with slots for images that are soaked in ink and then imprinted on paper as the device is rolled. The images represent agents and interactions and are based on combinations of traditional Mayan motifs used in weaving practices. Modeling with Grafemos is also a communal activity, in which a small group must participate together, while each participant models from the perspective of a specific element in the system. Methodologically, we have adopted *Methodological Métissage* (Lowan-Trudeau, 2012), which is centered on: a) emphasizing Indigenous practices and traditions such as storytelling and symbolizing, and b) working with the elders and members of the community during all stages of the research. We believe that *Métissage* is foundational to enacting axiological reorientation of Western scientific approaches that largely dominate the Learning Sciences. Using the constant comparative method, we present an analysis of a month-long study in which we worked with six high school teachers and two members of the Ixkoj Ajkem Council in Xenacoj, Guatemala. Meeting 3-4 times a week, we worked together on modeling complex phenomena that the teachers and Council members identified as relevant to their lives as well as to the high school science curricula. We used Grafemos, embodied modeling activities, as well as the ViMAP (Sengupta et al., 2015) block-based programming environment. Data collected included video recordings of each session and participants' work.

Our analysis highlights a) how engaging in each form of modeling supported mid-level (Levy & Wilensky, 2008) and multi-level reasoning (Wilensky & Resnick, 1999), b) the axiological reorientation was evident in the kinds of phenomena (e.g., plastic contamination, systemic violence, etc.) that community members valued as scientific topics relevant to their lives as well as the curriculum, and c) how this axiological reorientation was supported through embodied and multimodal representations beyond the computer, that in turn, were intertwined with cultural forms (e.g., clotheslines and fabric motifs). Overall, our work illustrates how modeling with Grafemos offered a space for *Métissage* by bringing together cultural forms, participatory and embodied learning, as well as agent-based representations of complexity, while the axiological reorientation allowed teachers and community members to center events and concerns in their communities as topics of scientific and computational inquiry.

Storymaking and Storytelling: Exploring the affordances of narrative in computational modeling

Aditi Wagh & Amanda Dickes (equal contribution)

Jerome Bruner (2005; 2010) has argued that narrative, or story, is a uniquely human way of making sense of the world; an avenue to explore "possible worlds" and the vehicle through which we frame accounts of our own experience. In this sense, the act of storymaking and storytelling affords narrators opportunities to connect past, present and "imagined" worlds, and define relationships between seemingly disconnected events (Ochs & Capps, 1996). In this paper, we argue that storytelling and storymaking can provide a rich and meaningful context for theory building in science - particularly when situated within the medium of computational modeling - and potentially transform how students come to see and know in science. In particular, we draw on work that positions stories as "nascent theories" (Ochs et al, 1992) that scaffold and normalize practices such as perspective-taking, critical thinking, and abstraction; practices long argued as crucial components of scientific thinking and knowing.

We identify four narrative discursive practices that we believe can be useful in science learning: (1) Employing figurative language, specifically metaphor, as a tool to illuminate qualities of less understood objects (or natural phenomena) by drawing lines of association between the unknown object and objects that are already understood (Quale, 2002); (2) Considering and reconciling competing perspectives by coordinating between different understandings to identify solutions to confusing and challenging narrative problems (Ochs & Capps, 1996); (3) Identifying and contextualizing narrative problems along a temporal dimension to construct a theory of events for how and why problems emerge and how they might impact future events (Ochs & Capps, 1996); and (4) Constructing collaborative meaning through co-authorship, interpretation, and multiple retellings of narrative events. We see these practices as congruent and complementary with the practice of modeling in science and conjecture that the inclusion of narrative as a parallel practice in investigations of natural systems can scaffold learners' use and interpretation of computational models which represent those systems.

In this session, we report on a pilot design study which follows a group of upper elementary grade students' explorations of an invasive species and its impact on local species within the Gulf of Maine through parallel storymaking, storytelling and computational modeling activity. Our analysis describes how students drew on narrative practices, such as temporal fluidity and metaphor, to cohere the disparate elements of the natural system into a "plot" comprising character and conflict, and the role that this narrative work played in supporting their work on modeling that same system. Finally, we discuss the tensions that arose between employment of a narrative frame and more normative scientific frames, and how those tensions were reconciled.

Expansive embodied modeling: Inviting and leveraging students' ideas and linguistic resources

Ashlyn Pierson & Corey Brady

Computational modeling is a powerful tool for helping K-12 students explore and learn about complex systems (Dickes et al., 2013; Sengupta et al., 2013; Wilensky & Reisman, 2006). Yet due to barriers arising both from the syntax and concepts of computational representations, computational thinking and modeling can be challenging for both students and teachers. In response, researchers have worked to design programming environments and learning activities that make computational modeling more accessible. One such approach to support computational modeling is embodiment or enactment. In an embodied model, students role-play agents in a system (e.g., plants and animals in an ecosystem) to explore agent actions and interactions as well as system-level, emergent phenomena from the perspective of these agents (Danish, 2014; Forrester, 1961). To enact agents, students typically follow rules, which are sometimes framed as the "code" or "program" for the agents in the embodied model.

In addition to these affordances of embodied modeling, we propose that embodied modeling activities could be designed to invite and leverage students' linguistic resources and multimodal representations, in turn supporting learning and participation particularly for students classified as English Learners (ELs). Research in bilingual education and science education shows that multilingual students benefit from deploying their full range of meaning-making resources in classrooms (García & Kleyn, 2006), including linguistic resources as well as other semiotic resources (nonlinguistic modes, like images, gestures, actions, symbols; Blackledge & Crease, 2017; Li, 2018). Building upon this work, we explored how embodied modeling activities could be enriched with additional representations beyond embodied actions, including both canonical representational forms (e.g., Cartesian graphs) and students' everyday resources (e.g., gestures, student-generated language), along with social interactions.

In the context of an iterative design-based research project in a 6th grade STEM classroom studying ecosystems and population dynamics, we explore how embodied modeling can expand opportunities for participation and for learning about complex systems. We illustrate how embodied modeling activities were refined with each cycle of our design to offer students distinct ways of understanding their computational models and the ecosystems they represented. We describe three iterations of the design, which positioned embodied modeling successively as: (1) a rehearsal for the computational model, in which each students' unique contributions and perspectives were essential for shared meaning-making, (2) a space for active and collective modeling, as students "remixed" (modified) the code to test their own ideas, and (3) a full-fledged component of the classroom's system of models of ecological phenomena, supported by linked representations drawn from their computational models and from students' everyday linguistic resources. We argue that these approaches to augmenting embodied modeling show promise for supporting participation and complex systems learning, particularly for students classified as ELs.

Meadow bees, hive bees, and a moving sun: Tensions and affordances in learning between embodied point of view and spatial frames of reference

David DeLiema, Noel Enyedy, Joshua Danish, & Francis Steen

A robust educational research literature around complex systems documents how reasoning about systems involves a delicate act of balance between agent perspectives (e.g., viewing the scene from the perspective of one component) and aggregate perspectives (e.g., pulling back to see patterns among multiple components) (Wilensky & Reisman, 2006). Even with third-person, cartesian graphs in mathematics, students might spontaneously embody in gesture the first-person viewpoint of a graphed component (Nemirovsky & Monk, 2000). More recently, with augmented reality technologies that track and display full body movement (Danish et al., 2020), the dynamic of being multiple components in a model all while tracking aggregate connections creates a public process of *coordinating point of view and spatial reasoning*.

Building on a case study of the friction that arises during this coordination process (DeLiema & Steen, 2014), we examine the Science through Technology Enhanced Play's (STEP) unit on bees to document how 1^{st} and 2^{nd} graders and their experienced teacher navigate multiple points of view (bees in the hive; bees in the meadow) and spatial reasoning (bee waggle dance identifying location of valuable flowers). To anchor our multimodal interaction analysis, we draw on gesture research around character and observer *points of view* (Stec, 2012), the notion of layered or *laminated* semiotic resources in interaction (Goodwin, 2018), and *spatial frame of reference* terms such as figures, anchors, and grounds (Levinson, 1996). We strategically selected one video-recorded episode from the six-session unit in which the teacher and two students encounter spatial (in)congruence at the intersection of multiple points of view in order to investigate how participants *notice* this tension between viewpoints within a system and how they *publicly draw on* embodied, material, and interactional resources to resolve the tension.

The analysis documents why material infrastructure (e.g., a flower icon on the floor) that grounds imaginative play across points of view at once *confounds* (e.g., a bee in the hive could never presently see a meadow flower) and *supports* (e.g., a meadow bee can now see it would not arrive at a flower) complex systems reasoning. In addition, the analysis examines how the participants' public efforts to make spatial anchors and grounds more explicit surfaces friction between viewpoint and spatial reasoning, and then become the very resource that clarifies the participants' inquiries (e.g., the bee's "diagonal to the left" flight starts "*from there*"). These clarifying moves laminate gesture, full body movement, talk, and material and imagined objects in sequences of conversational repair to help the participants converge on their understanding of the system. This analysis raises key considerations for designers of material and embodied spaces in which students move across roles or viewpoints in the setting. Most importantly, the analysis shows that tensions between spatial reasoning and viewpoint are not a deficit, but rather, an inherent part of modeling that participants can notice, argue about, and clarify to arrive at a shared understanding of the system.

The collective and discursive nature of model-based reasoning: Discussion as means for thinking together in preservice professional learning and elementary mathematics education

Amy Voss Farris, Rachel Wolkenhauer, Gwendolyn Lloyd, & P. Karen Murphy

Engaging in model-based reasoning is fundamentally interdependent with generating explanations that are justifiable and critiqued by others. Models are a type of purposeful explanation of some phenomenon or process and make reasoning evident by way of letting one thing "stand in" for something else (Lehrer & Schauble, 2010). However, what counts as acceptable forms of evidence and reasoning in particular disciplines is often not made explicit to educators or to students (Manz et al., 2020). Our focus in this poster is on how teacher educators and preservice teachers (PSTs) engaged in discussion-based pedagogy to support authentic forms of questioning and argumentation in three cross-disciplinary contexts: (1) a course called Classroom Learning Environments, which focuses on teachers' inquiry and equitable pedagogical praxis in contexts of complex social and political discourses, (2) a methods course for elementary mathematics, and (3) PSTs' facilitation of mathematics discussions with children in their field classrooms. We argue that explicit attention to questioning and argumentation in discussion-based pedagogy across disciplines supported PSTs' early facilitation of mathematics discussions in their field placements.

We partnered with teacher educators within the Penn State Professional Development School (PDS) to adapt and enact the *Quality Talk* discussion approach. Quality Talk is a small-group, teacher-facilitated discussion approach that has been shown to foster K-12 students' reasoning and content-area learning (Murphy & Firetto, 2017). Teacher educators learned to use Quality Talk discussions to support preservice teachers (PSTs) in methods coursework so that, in turn, PSTs can use the approach in discussions about pedagogy and mathematics and while teaching mathematics in their field experiences. Expectations included eliciting student-generated questions about mathematics, student-initiated responses to peers' questions that include evidence or mathematical reasoning, and collective sensemaking about mathematical tasks. The authors and other PDS school- and university-based TEs co-developed and integrated five discourse lessons and related discussions in the Classroom Learning Environments (CLE) course and methods for teaching mathematics course during the Fall 2019 semester. A series of assignments supported PSTs in preparing to facilitate small group mathematical discussions with elementary students.

Our poster will provide an overview of how teacher educators learned to support PSTs' development of pedagogies for elementary students' mathematical argumentation within the Quality Talk small group discussion approach and offer an illustrative discourse analysis of a discussion with second grade students that was facilitated by one PST, named Laura. In this discussion, Laura demonstrates command of discourse features she learned in her CLE course and operationalized her belief that students, positioned with interpretive authority concerning the task, the mathematical concepts, and one another's ideas, can productively learn together. Within the discussion, the students solve a novel mathematics problem by discursively modeling a problem context in which the cost of green beans is a rate per unit length. They question their own problem representations when one student proposes subtraction as a way to solve the problem. The case illustrates productive connections between learning about discussion-based pedagogy in preservice teacher education and novice teachers' preparation to support critical-analytic discourse in an elementary mathematics task.

From social and embodied modeling to computational modeling in the "Computational Modeling in Science" (CMS) project

Chani Fridman, Sharona T. Levy, & Hagit Hel-Or

The CMS approach to scientific modeling in schools expands the scope of computational modeling to include embodied & social modeling. Embodied & social role-playing activities have the students represent entities in a system by physically moving about the classroom and interacting with other students and objects. This expansion of computational modeling is based on a number of principles: (1) role-playing simulations, which are familiar to teachers', provide a natural bridge into computational modeling (McSharry & Jones, 2000); (2) enabling students to ground scientific and computational abstractions in their bodies and movement, as described by embodied learning theory (Lindgren & Johnson-Glenberg, 2013); (3) having students communicate their ideas in social co-dependent participatory simulations can be a highly effective form of learning (Levy, 2017); (4) providing students with multiple access points into scientific modeling making modeling more inclusive.

The research was structured as a quasi-experimental pretest-intervention-posttest design with a comparison group. The topic of the learning unit included Kinetic Molecular Theory (KMT) and Gas Laws, along with several other related phenomena. First, teacher-led embodied-social modeling occurred with students enacting the rules of particles in a system. Next, similar student-led modeling had students suggesting questions, creating and exploring their embodied model. Finally, students engaged in computational modeling with the Much.Matter.in.Motion (MMM) platform (Levy, Saba & Hel-Or, 2020), which enables modeling many physics- and chemistry-based phenomena. The rules underlying particle behaviors, such as "change direction when you collide", are elicited in these simulations and are later presented as computational blocks in the model coding environment.

In terms of overall learning, there was no difference between the experimental and control groups, both showing increased knowledge on the topics; however, concepts related to the micro-level were learned better by the experimental group. Students' confidence in their answers increased in the experimental group, while they did not do so for the students in the comparison group. An analysis of the students' pictures of perfume spreading in the air showed three types of depictions, successively increasing in sophistication; the analysis showed that the experimental group, but not the comparison group, advanced from pretest to posttest in the sophistication of their understanding of gas behavior. Analysis of the classroom embodied simulations and computational models showed two themes: (1) a close relationship between ideas expressed at the beginning of the learning and the embodied social simulations, and (2) confusions between micro-and macro-levels were gradually resolved along the learning unit. We summarize that the approach we have developed does not show a significant advantage over normative learning when looking at the students' overall conceptual understanding scores. However, when detailed concepts were considered, it was found that the micro-level concepts relating to KMT were learned significantly better with the CMS activities. The students also grew more confident in their answers through the activities, an important feature that may contribute to students' perceived self-efficacy. We conjecture that the embodied social simulation provides a window into students' thinking as they enact their ideas dynamically with their bodies, and also provides the feedback necessary for helping them revise non-scientific concepts.

Flares in the soup game: Improvisational collective choreography and computational expressivity

Lauren Vogelstein, Corey Brady, Rebecca Steinberg, & Curtis Thomas

We share our design and analysis of an activity called "The Soup Game" for a middle school camp integrating computation, mathematics, and art ("Action Camp"). The activity leveraged embodied sensemaking to provide entry points for conceptualizing agent-based programming as a creative performance space. By iteratively proposing and enacting choreographic elements together, student participants constructed, interpreted, and executed sequences of movement they later expressed computationally in NetLogo (Wilensky, 1999), eventually orchestrating hybrid human-computer performances. To study students' embodied ideation processes, we look specifically at *flares*, movements that spread through regions of the group as they developed and enacted choreographic rules. We argue that flares offer one form of evidence of creative group-level thinking.

We identified connections across our diverse research and teaching experiences, in themes of exploring the expressive potential of groups (Vogelstein, 2020) and engaging young learners to position themselves as *creators* of valued works, whether in the domain of dance, mathematics, or computational thinking. We came to see many similarities between creating movement scores for people to perform and writing code for agents ("turtles") to perform. Steinberg & Thomas brought the seed of The Soup Game from activities they had used to give dance students opportunities (a) to experience how simple rules can generate complex choreographies, and

(b) to practice using their voice as leaders in creative collaboration. In the game, groups devised and named movement rules (e.g., “craziness” meant “spread out while always moving”) that would later be called out to form performance scores. Bridging to computation, we leveraged parallels between movement rules and computational procedures; and we connected the *leader* calling out named rules to NetLogo’s *observer* communicating commands to turtles. Our design also built on research showing the power of *syntonic learning* (e.g., “playing turtle,” (Papert, 1980)), and group role play (e.g. participatory simulations, (Brady et al, 2016)).

We focus on the spread of movement ideas when campers jointly created movement rules and worked out how to enact them. Video recordings from multiple camera angles captured different perspectives on the activity (Hall, 2000). We augmented Interaction Analysis (Hall & Stevens, 2015) with newer, embodied forms of reenactment and analysis (Vogelstein et al., 2019), which we also extended. We found that participants often interpreted others’ movements as invitations to move, themselves—as *proposals* to respond to (cf., Vogelstein, 2020). Movements spread as flares within regions of the participant group when generating rules. Flares served to clarify and extend emerging choreographic elements in *shape*, *space*, and *time*—physically performing ideas, and observing others, afforded new noticings (Kirsh, 2010). Flares also revealed compositionally rich possibilities that *stretched the meanings* of rules. We show how flares provide evidence of collective sensemaking: physical proposals and responses allowed the group to explore its expressive potential and the enacted meanings of commands they generated.

References

Ackermann, E. (1996). Perspective-taking and object construction: Two keys to learning. *Constructionism in practice: designing, thinking, and learning in a digital world, Lawrence Erlbaum, Mahwah, NJ*, 25-35.

Aikenhead, G., & Michell, H. (2011). Bridging cultures: Indigenous and scientific ways of knowing nature. Don Mills, Ontario, Canada: Pearson Education.

Bang, M. (2020). Learning on the Move Toward Just, Sustainable, and Culturally Thriving Futures. *Cognition and Instruction*, *38*(3), 434-444.

Blackledge, A., & Creese, A. (2017). Translanguaging and the body. *International Journal of Multilingualism*, *14*(3), 250–268.

Brady, C., Weintrop, D., Anton, G., & Wilensky, U. (2016). Constructionist learning at the group level with programmable badges. In *Proceedings of Constructionism* (pp. 61-68).

Boal, A. (1985). *Theatre of the Oppressed*. *Theatre Communications Group*.

Bruner, J. (2010). Narrative, culture, and mind. *Telling stories: Language, narrative, and social life*, *46*, 49.

Danish, J. A. (2014). Applying an activity theory lens to designing instruction for learning about the structure, behavior, and function of a honeybee system. *Journal of the Learning Sciences*, *23*(2), 100–148.

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: a sociocultural framework for embodied cognition. *International Journal of Computer-Supported Collaborative Learning, 15*(1), 49-87. doi:10.1007/s11412-020-09317-3

DeLiema, D. & Steen, F. F. (2014). Thinking with the body: conceptual integration through gesture in multiviewpoint model construction. In M. Borkent, B. Dancygier, Hinnell, J. (Ed.) *Language and the Creative Mind* (pp. 275-294). Stanford, CA: CSLI Publications.

Dickes, A. C., & Sengupta, P. (2013). Learning Natural Selection in 4th Grade with Multi-Agent-Based Computational Models. *Research in Science Education*, *43*(3), 921–953.

Dickes, A. C., Sengupta, P., Farris, A. V., & Basu, S. (2016). Development of Mechanistic Reasoning and Multilevel Explanations of Ecology in Third Grade Using Agent-Based Models. *Science Education*, *100*(4), 734–776.

Forrester, J. W. (1961). Industrial Dynamics. MIT Press.

García, O., & Kleyn, T. (2016). Translanguaging with multilingual students: Learning from classroom moments. New York, NY: Routledge.

Goodwin, C. (2018). *Co-operative action*. New York, NY: Cambridge University Press.

Greeno, J. G., & Van De Sande, C. (2007). Perspectival understanding of conceptions and conceptual growth in interaction. *Educational Psychologist*, *42*(1), 9–23. https://doi.org/10.1080/00461520709336915

Hall, R. (2000). Video recording as theory. In D. Lesh & A. Kelley (Eds.) Handbook of Research Design in Mathematics and Science Education (pp. 647-664). Mahweh, NJ: Lawrence Erlbaum

Hall, R., & Stevens, R. (2015). Interaction analysis approaches to knowledge in use. In *Knowledge and Interaction* (pp. 88-124). Routledge.

Kirsh, D. (2010). Thinking with the body.

Lehrer, R. (2009). Designing to develop disciplinary dispositions: Modeling natural systems. *American Psychologist*, *64*(8), 759.

Lehrer, R., & Schauble, L. (2010). What kind of explanation is a model? In *Instructional explanations in the disciplines* (pp. 9-22). Springer, Boston, MA.

Levy, S. T., & Wilensky, U. (2008). Inventing a “mid level” to make ends meet: Reasoning between the levels of complexity. Cognition and Instruction, 26(1), 1–47.

Levy, S.T. (2017). Learning about Complex Systems from the Bottom Up: Role-playing Together in a Participatory Simulation. I. Levin & D. Tsybulsky (Eds.), *Digital Tools and Solutions for Inquiry- Based STEM Learning*. A volume in the Advances in Educational Technologies and Instructional Design (AETID) Book Series. Hershey, Pennsylvania: IGI Global.

Lowan-Trudeau, G. (2012). Methodological Métissage: An interpretive Indigenous approach to environmental education research. *Canadian Journal of Environmental Education (CJEE)*, *17*, 113-130.

Li Wei. (2018). Translanguaging as a practical theory of language. *Applied Linguistics*, *39*(1), 9–30.

Lindgren, R., & Johnson-Glenberg, M. (2013). Emboldened by embodiment: Six precepts for research on embodied learning and mixed reality. *Educational Researcher*, 42(8), 445-452.

Levinson, S. C. (1996). Frames of reference and Molyneux's question: Crosslinguistic evidence. In P. Bloom, M. A. Peterson, L. Nadel, & M. F. Garrett (Eds.), *Language and space* (pp. 109-170). Cambridge, MA: MIT Press

Manz, E., Gibbons, L, Okun, A, Chalmers-Curren, J., & O’Connor, C. (2020). Exploring elementary teachers’ classroom discussion puzzles: A cross-disciplinary analysis. In Gresalfi, M. and Horn, I. S. (Eds.). (2020). *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 4.* Nashville, Tennessee: International Society of the Learning Sciences.

McSharry, G., & Jones, S. (2000). Role-Play in Science Teaching and Learning. S*chool Science Review*, 82(298), 73-82.

Murphy, P. K., & Firetto, C. M. (2017). Quality talk: A blueprint for productive talk. In P. K. Murphy (Ed.), *Classroom discussions in education* (pp. 101–133). New York: Routledge.

Nemirovsky, R., & Monk, S. (2000). “If you look at it the other way…”: An exploration into the nature of symbolizing (pp. 177-221). In P. Cobb et al. (Eds.), *Symbolizing and communicating in mathematics classrooms: Perspectives on Discourse, Tools, and Instrumental Design* (pp. 177-224). New Jersey: Erlbaum.

Ochs, E., & Capps, L. (1996). Narrating the self. *Annual review of anthropology*, 19-43.

Ochs, E., Taylor, C., Rudolph, D., & Smith, R. (1992). Storytelling as a theory-building activity. *Discourse processes*, *15*(1), 37-72.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas*. Basic Books, Inc..

Saba, J., Hel-Or, H., & Levy, S. T. (2020, June). "When is the pressure zero inside a container? Mission impossible" 7th grade students learn science by constructing computational models using the Much. Matter. in. Motion platform. In *Proceedings of the Interaction Design and Children Conference* (pp. 293-298).

Sengupta, P., Kinnebrew, J. S., Basu, S., Biswas, G., & Clark, D. (2013). Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education and Information Technologies*, *18*(2), 351–380.

Stec, K. (2012). Meaningful shifts: A review of viewpoint markers in co-speech gesture and sign language. *Gesture, 12*(3), 327-360.

Vogelstein, L. (2020). Physical Research: Professional Dancers Exploring Collective Possibilities in a Solidifying Substrate. In *14th International Conference of the Learning Sciences, Nashville, TN.*

Vogelstein, L., Brady, C., & Hall, R. (2019). Reenacting mathematical concepts found in large-scale dance performance can provide both material and method for ensemble learning. *ZDM*, *51*(2), 331-346.

Wilensky, U. (1999). NetLogo. Evanston, IL: Center for Connected Learning (CCL), Northwestern University.

Wilensky, U., & Reisman, K. (2006). Thinking Like a Wolf, a Sheep, or a Firefly: Learning Biology Through Constructing and Testing Computational Theories—An Embodied Modeling Approach. *Cognition and Instruction*, *24*(2), 171–209. http://doi.org/10.1207/s1532690xci2402_1

Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*. MIT Press.

Quale, A. (2002). The role of metaphor in scientific epistemology: A constructivist perspective and consequences for science education. *Science & Education*, *11*(5), 443-457.

Learning and Teaching about COVID-19: Engaging Students, Teachers and Families in Understanding Infectious Disease Epidemiology

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Abstract: The global COVID-19 pandemic outbreak has put front and center the need for learning and teaching about epidemics, as the participation and actions of all citizens are critical in containing and preventing the spread. In this symposium we are presenting current, on-going research on learning and teaching about infectious diseases that examines (1) K-12 students' understanding of infectious diseases such as COVID-19, (2) family interactions around making sense of COVID-related science information, (3) game designs to address COVID misconceptions, (4) computational modeling tools to help students understand disease vectors, and (5) virtual epidemics to provide students with online experiences about disease spread and prevention. Panelists will present findings from their on-going studies and discuss what research directions learning sciences can take to promote health literacies for teachers, students, their families and communities. Our discussant will review overarching themes then open up the panel to Q&A.

Keywords: COVID-19, K-12 digital learning, educational technology, gamification, epidemiology

COVID-19 follows a flurry of previous infectious disease outbreaks—such as Avian Flu, Ebola, MERS, SARS, and Zika—revealing the threat that epidemics pose in the age of global travel. While much attention in the current COVD-19 pandemic has focused on schools' move to online education, in particular highlighting the lack of access and challenges in home learning, much less attention has been given to what teachers, students, and families need to know about infectious diseases and their prevention. Learning about infectious diseases is not even explicitly addressed in current national science standards guidelines in the United States (NGSS, 2013) and for that reason has received little attention in current K-12 science education and research. Infectious disease epidemiology (Straif-Bourgeois, Ratard & Kretzschmar, 2014) includes an understanding of not only of biological concepts such as germs and infection, but also of processes such as incubation and immunity within larger ecological contexts and, most importantly, of community factors that contribute to or hinder epidemic outbreaks. This need has become so urgent that a call for a "microbial literacy" (Timmis et al., 2020) has been issued and this is where K-12 learning sciences research can make a critical contribution.

This symposium brings together researchers from different fields in the learning sciences (i.e., science education, psychology, game studies, and computer science) who began studies in the midst of and motivated by the COVID-19 outbreak. A first group of presentations will examine different facets of students and their families' understanding of infectious disease epidemiology. While K-12 students' basic biological understanding of what happens with germs in their bodies expands with age, they struggle to comprehend the interconnected nature of epidemiologic spread on an ecosystem level. Concepts such as incubation, infectious, and symptomatic periods of an infectious disease are not well understood . We will also examine what roles families and caretakers play in promoting understanding, often serving as the first point of contact for children about this information (e.g., Jones and Rua, 2009; Toyama, 2019). Little is known about how family members negotiate such understanding, what kind of conversations take place, or how scientific information promoted in social media and news is approached .

A second group of presentations will focus on students' learning about infectious disease epidemiology. While textbook studies of historical cases about infectious diseases and epidemic outbreaks have been a mainstay in science education, in the last two decades digital games, epidemic simulations, and participatory virtual epidemics have been added to the instructional repertoire (Kafai & Dede, 2014; Wilensky & Rand, 2015). We will discuss how these technological tools engage students with critical aspects of infectious disease epidemiology, how teachers have used these tools in their classes, and how students make connections between virtual and real epidemics.

Each of the presenting teams will address critical questions about understanding and learning about infectious disease: *What are students' beliefs about different aspects of infectious disease epidemiology? How and what science do people learn about COVID-19, when they may have little to no science preparation or previous interest in the topic? How do students' interactions with games, simulations and virtual epidemics promote better understanding of critical aspects of infectious disease epidemiology? What unique barriers and opportunities exist for learners approaching infectious disease subjects for the first time while simultaneously experiencing the COVID-19 pandemic?* Each team will present updates from their on-going research with teachers, students, and families. Our discussant, Jim Slotta from University of Toronto, will review overarching themes and then open up the panel to Q&A with the audience.

Learning rapidly: Youth data activism in the 2020 multi-pandemic

Angela Calabrese Barton, Day Greenberg, Chandler Turner, Za'Mani Roper, Carmen Turner, Devon Riter, Leslie Herrenkohl, Elizabeth A. Davis, Tammy Tasker

Through long-term research-practice partnerships (RPPs) in the midwestern and western US, we sought to understand what/how community partners learn about and take action on COVID-19 and justice-related concerns. In this study, we investigated how minoritized youth engage in data activism in relation to their meaning making around COVID-19 and its intersections with economic and racial injustice. We define data activism as social practices that take a critical approach to "big data" (Milan & Velden, 2016), in response to justice-related concerns of pandemic datafication. As datafication introduces new challenges of representation and positioning of people and the world, we give witness to youth resisting, disrupting, and transforming such challenges during/through innovative digital navigations of crisis events (Goldkind et al., 2018).

We draw upon theories of digital agency and youth data activism as forms of consequential learning through critical social practice within communities (Milan & Velden, 2016). Consequential learning focuses on what counts as valued learning, and how processes of learning can disrupt or transform normative patterns of participation towards new and just forms of expertise and social relations (Gutierrez et al., 2017; Jurow & Shea, 2015).

Using a historicized and future-oriented participatory methodological approach, we give witness to and learn with youth and community. We center youth voices, placing importance on open-ended methods with co-determined protocols, co-analyzed findings, and co-written manuscripts. To attend to power in our remote methods, we further drew upon practices of critical witnessing and being with—practices toward conscientization, social transformation and the public good of communities historically marginalized by systemic inequities. We seek to amplify possibilities for coalition building and learning in "daily, (extra)ordinary, and intentional" work (Villenas, 2019, p. 153). Since late-March 2020, we engaged in multiple rounds of dialogic critical ethnographic conversations and experience sampling methods with 62 participants (20 adults & 42 youth/young adults) in two urban communities with whom we have long-term collaborations. Dialogic conversations (60-240 minutes/participant/round) focused on: COVID-19 information accessed/applied towards decision-making, and how/why; how efforts were situated within personal/community COVID-19 experiences/networks. Data were co-analyzed with participants using critical inquiry in a constant comparative, continuities and contradictions approach (Charmaz, 2017).

Youths' enactment of critical data practices shaped how they negotiated between coming-to-know and coming-to-act in the multi-pandemic. We operationalize c*ommunity-engaged critical practices* as what people do in socially-mediated and culturally-embedded ways with, in relation to, and oriented around data and data infrastructures in support of more equitable everyday living and communities. These practices arose from tensions in the youth's engagement with data as they mobilized big and small data from different epistemological and social origins towards meaning-making, action-taking and communicating. These tensions shaped how and why youth: *Re-mixed data practices* and authored new hybrid ones for socially/critically navigating, understanding and repurposing data into/of their worlds; *Critiqued and recontextualized data and data narratives* for re-imagining data about their worlds and hoped-for-futures; and *Re-positioned oneself and one's world into data*. For example, Jazmyn, used social media apps as a gateway to the CDC's COVID-19 databases. She paid attention to posts where the individuals looked like her and were posted from verified science-related accounts. She participated in her city's racial justice protests wearing a mask and social distancing after a complex analytical process of weighing different data inputs such as comparative efficacy of risk mitigation behaviors, patterns of infection/spread in her region, predicted numbers of participants, and photos of other recent protests to gauge how many participants looked like they took safety precautions.

Elementary school children's beliefs about viral transmission of COVID-19 and the common cold

Danielle Labotka, Sophie R. Martel, Susan A. Gelman

In the COVID-19 crisis, effective means of educating children about disease transmission is paramount. Contrary to earlier reports, evidence suggests school-age children can contract and spread COVID-19 (e.g., Szablewski et al., 2020). Children often play a role in viral transmission, given how frequently they put things in their mouths, touch their faces, etc. Public health recommendations include teaching children best practices (e.g., hand-washing) to reduce transmission, yet research indicates children are unlikely to engage in these practices without understanding the mechanisms underpinning transmission processes. Understanding COVID-19 transmission is particularly challenging, given many non-obvious transmission factors like asymptomatic carriers, long incubation periods, and seemingly innocuous transmission behaviors (e.g., singing). This talk reports on a study of children's and adults' understanding of COVID-19 transmission (and the common cold, as comparison), with a comprehensive, cross-age assessment with U.S. families.

We developed a survey with 40 close-ended and 13 open-ended questions to assess four components: (1) understanding that viral transmission processes are non-obvious; (2) knowledge that viruses are quasi-living agents that operate via certain biological processes (e.g., can replicate); (3) how coherent understanding of transmission processes relates to biological beliefs; and (4) how beliefs regarding COVID-19 compare to those of the common cold.

Study 1 (N=240, completed, pre-registered) tested a national sample of adults via an online survey. Analyses are ongoing. Preliminary results indicate adults generally have basic knowledge of COVID-19 transmission (e.g., transmissibility; incubation period), but there is variability in understandings of the underlying mechanisms by which viruses operate. Whereas some adults have a biologically coherent understanding of viruses—discussing viruses as requiring a host, reproducing, and evoking immune system responses—others have vaguer understandings (e.g., “It takes time to do whatever it does to make you sick”), refer to viruses as bacteria, or report that viruses eat, grow, and move.

Study 2 (projected N=160, current N=146, pre-registered) investigates the same questions as Study 1 in a child-friendly format. Children (5-12 years old) are interviewed via video conferencing. Interviews are recorded, transcribed, and coded. Initial testing indicates children may recognize some non-obvious features of COVID-19 transmission (e.g., asymptomatic carriers) at lower rates than adults. Furthermore, preliminary evidence suggests children may overbiologize viruses, often reporting they can grow and move on their own. This tendency to overbiologize may influence children’s understanding of viral transmission, with some children describing viruses as tiny creatures that “crawl” around and anthropomorphizing viruses by assigning them agency, character, and desire. Intercorrelations among children's performance across tasks will assess whether understanding consists of piecemeal facts vs. coherent understandings.

Findings from the project will provide information regarding gaps and misconceptions in children's understanding of the transmission of COVID-19 and viruses more generally, providing data on how to target efforts to improve children’s scientific literacy and adherence to public health guidelines. It will also provide theoretically significant data relevant to STEM education regarding the coherence of children's biological theories over development, and children's informal biological theories in the context of an ongoing pandemic.

Applying gamification to correct COVID-19 misconceptions among the general public

Greg Trevors, Eric Brenner, Cierra Chong, Danielle Graham, Justin Kogler, Farhaan Ladhani, Kevin Melo, Ornab Momin, Jordan Morello, Tanya Whyte, Sean Willett, Kara Wilson Oliver, Ben Windeler, Sam Wollenberg

Compounding the public health challenges posed by the COVID-19 pandemic is an *infodemic* of misinformation regarding risks, prevention, and treatments (WHO, 2020), which may lead to serious and irreversible harm to individuals and communities. However, several prior attempts to refute misconceptions about controversial or emotionally laden topics like COVID-19 have failed (Trevors & Duffy, 2020). Refutation failures may undermine important collective actions needed in a pandemic, such as vaccine-acquired immunity. This study leveraged unique strengths of cognitive research on belief change and design principles of gamification to develop a new digital game to correct COVID-19 misconceptions to overcome specific limitations of direct refutations.

From May-June 2020, 19,493 Canadian participants were recruited to engage with a non-game control version of the online platform, which contained 13 content pages that presented one fact or misconception about COVID-19 (e.g., “COVID-19 has caused fewer deaths than the flu (influenza) would typically cause in a year”). Participants swiped left or right to indicate their agreement or disagreement with the claim. The following screen presented immediate feedback that followed evidence-based practices for belief revision (Trevors & Kendeou, 2020). Following feedback, participants reported their emotional reactions to the content (i.e., happy, angry, anxious, or skeptical). From August-November 2020, 67,072 participants played the gamified platform (Figure 1), which contained 12 of the original 13 claims plus 11 new claims. Overall, the digital game was designed to motivate and positively engage learners as they processed corrective feedback via game elements and mechanics (e.g., challenge, personalized experience, visible progress). In both control and gamified versions, participants also reported their support for public health policies (e.g., wearing masks in public) and in the gamified platform, their personal willingness to receive a COVID-19 vaccine when one becomes available.

Figure 1. Screenshots of digital game.

In separate regressions, beyond the effects of prior knowledge (i.e., number of claims answered correctly), happiness and anxiety were positive predictors of public health policy support ($\beta_{hap} = .115$ / $\beta_{anx} = .074$) and vaccine uptake intention ($\beta_{hap} = .116$ / $\beta_{anx} = .075$), whereas anger and skepticism were negative predictors of policy support ($\beta_{ang} = -.049$ / $\beta_{skp} = -.183$) and vaccine intention ($\beta_{ang} = -.034$ / $\beta_{skp} = -.201$). Happiness and anxiety were higher and anger and skepticism lower in the game version compared to the control (p's < .0001, d's = .049-.201), which held true even after controlling for prior knowledge.

The current proposal represents a new digital approach to misconception correction that may augment how individuals cognitively and affectively interact with challenging educational content and may overcome limitations of prior direct routes of science communication. We found that positive and negative emotional reactions to corrective feedback were significant predictors of subsequent policy support and vaccine uptake intention beyond the large effect of prior knowledge. This supports our central contention that increasing positive and decreasing negative affective engagement of belief correction content via gamification may be important and opposite drivers of promoting acceptance of controversial socio-scientific content.

A block-based modeling curriculum for teaching middle grade science students about COVID-19

Veronica Catete, Madeline Hinckle, Tiffany Barnes, and Eric Wiebe

The COVID-19 pandemic has amplified the critical need for science literacy for an informed citizenry. As with all public health crises, the lack of a strong consensus around an actionable scientific model has led to unnecessary suffering and death. Now more than ever, it is crucial to provide students with factual information about how diseases spread and how their own actions can impact that spread. Computational modeling provides an excellent vehicle for raising scientific awareness of the emergent understanding of COVID-19. In order to both encourage computational thinking (CT) skills and build scientific knowledge of the COVID-19 pandemic, we have created a series of programming activities through which students construct their own computational models based on the emerging scientific consensus around COVID-19.

This unit was adopted from a unit on epidemic modeling developed as part of an NSF-funded CT integration project (Cateté et al., 2018; Lytle et al., 2019). The models utilize an agent-based modeling approach (Wilensky & Rand, 2015) where a conceptual scientific model is re-represented by students as an interactive block-based simulation of the interaction of agent-people who are in various physiological states. Students are able to model everyday situations such as being in a crowded area or going to stores while unknowingly infected, and immediately see the consequences of those actions. Students can explore the differences in direct versus indirect transmission, as well as symptom severity, and their effects on the model outcomes. By including accurate scientific variables such as the reproductive number of the virus, incubation period, and period of communicability, students are able to create their own epi-curves that demonstrate the severity of the disease and provide students with visual representation of how quickly COVID-19 spreads. We also use the scientific model and associated modeling activities to reinforce best practices at home and in the community.

Teachers involved in the development of the original epidemic modeling unit also reviewed the COVID-19 units and indicated their promise for use in middle grades science classrooms. Pilot testing of the units is underway with anecdotal evidence sparking new questions about balancing students' inquiry and play with understanding the gravity of certain topics. We will use the CEO model (Lytle et al., 2019b) to evaluate the materials in formal classroom settings during the epidemics science unit and will compare the data to our past flu-themed implementations regarding engagement and understanding.

Virtual epidemics for promoting students’ immersion and inquiry into pandemic outbreaks

Yasmin Kafai, Deborah Fields, Colby Tofel-Grehl, Michael Giang, Jen Sun, Amanda Strawhacker, and Tyler Hansen

Investigating middle-school students’ understanding of infectious disease in the context of a virtual epidemic connects youths’ interests in socializing online with modeling approaches promoted in professional epidemiology. Our approach builds on two prior studies that investigated the outbreak of virtual epidemics called WhyPox and Dragon Swooping Cough in Whyville.net, a virtual world with millions of registered players. The virtual epidemic affected two key aspects of online players’ social lives: (1) *appearance,* in which dots or scales would appear on players’ avatars, intensifying and then receding as the disease faded away, and (2) chat *interactions* consisting of the random interruption of chats with an “Achoo.” Key findings from these two previous virtual epidemic studies with thousands of online participants revealed that the virtual epidemics not only promoted science talk (Kafai & Fields, 2013) and argumentation practices (Kafai & Wong, 2008) but also strongly affected players’ physical and social actions in the virtual world (see Kafai et al., 2007; Fields et al., 2017) including increased preventive behaviors.

Figure 2. (a) Whyville players with personal protective equipment, and (b) Whyville CDC testing site.

In designing SPIKEY-20, we modeled a respiratory disease outbreak similar to COVID-19 but with an important distinction: SPIKEY-20 caused no deaths. Infected players were covered with spikes during the symptomatic period, with coughs, shaking, and lack of salary for the three most severe days of infection. Further, there was a period of non-symptomatic contagion and options to prevent the disease through behavior (e.g., covering their mouth prior to coughing) and by wearing personal protective equipment (e.g., face masks and full body "bubbles") (see Figure 2a and b). In addition, players have access to unlimited, free testing (with false positives and negatives, see Figure 2b) as well as a community infection graph (see Figure 3a) with daily updates. Players can use epidemic simulators (see Figure 3b) for testing different disease vector configurations. The initial launch of SPIKEY-20 in October 2020 resulted in a full-fledged outbreak. We collected logfiles of online interactions before, during, and after the SPIKEY-20 outbreak as well as pre- and post-surveys from over 300 players.

Our investigation of player participation in the virtual epidemic SPIKEY-20 relates to critical aspects of infectious disease epidemiology (Straif-Bourgeois, Ratard & Kretzschmar, 2014), in particular students' understanding of processes such as incubation and immunity within larger ecological contexts and, most importantly, community factors that contribute to or hinder an epidemic outbreak. Using logfile data, we looked at changes in (1) *Engagement with information*: players increased their visits to Whyville's virtual Center for Disease Control, community infection graphs, and information pages (see Figure 3a); (2) *Use of epidemic simulators*: We found that both the frequency and systematic usage of simulator use increased *among classroom participants* (not the general population) during the SPIKEY-20 outbreak (see Figure 3b); and (3) *Preventive behaviors:* The SPIKEY-20 epidemic outbreak resulted in increased use of protective measures and preventive actions (e.g., handwashing, using protective equipment, and getting tested for the virus repeatedly).

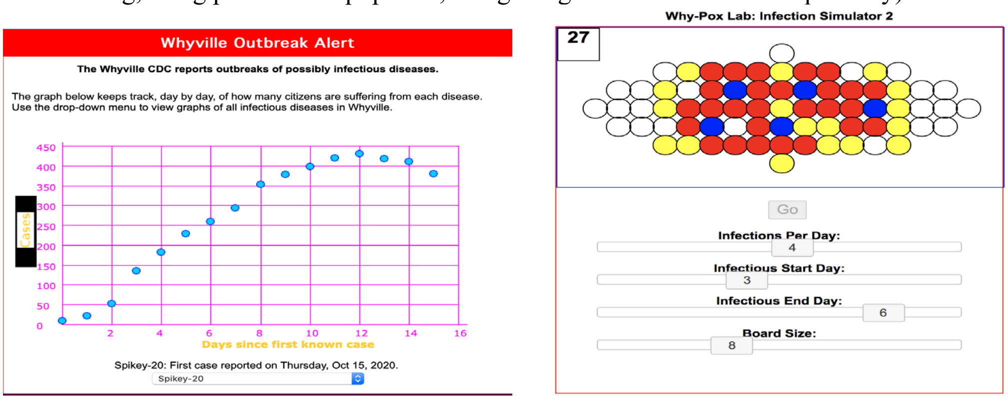

Figure 3. (a) Community infection graph, and (b) Small-scale epidemic simulator within Whyville.net.

Our analysis also includes survey results that connect actual online behaviors with self-reported behaviors and knowledge of real infectious diseases. Analysis of select high school classroom student writings complement our analyses and provide context for actions and comparisons students made between real life experiences of COVID-19 and virtual experiences with SPIKEY-20. These initial observations help us understand patterns of participation and engagement in virtual worlds, and how the educational opportunities for learning about infectious disease offered in Whyville could be further enriched if combined with instructional guidance from science teachers.

References

Cateté, V., Lytle, N., Dong, Y., Boulden, D., Akram, B., Houchins, J., ... & Boyer, K. (2018, October). Infusing computational thinking into middle grade science classrooms: Lessons learned. In *Proceedings of the 13th Workshop in Primary and Secondary Computing Education* (pp. 1-6).

Charmaz, K. (2017). The Power of Constructivist Grounded Theory for Critical Inquiry. *Qualitative Inquiry, 23*(1), 34–45. https://doi.org/10.1177/1077800416657105

Fields, D. A., Kafai, Y. B., Giang, M. T., Fefferman, N., & Wong, J. (2017). Plagues and people: Engineering player participation and prevention in a virtual epidemic. In *FDG'17, International Conference on the Foundations of Digital Games*, Hyannis, MA, USA, August 14-17, 2017. New York, NY: ACM, Article 29.

Goldkind, L., Thinyane, M., & Choi, M. (2018). Small Data, Big Justice: The Intersection of Data Science, Social Good, and Social Services. *Journal of Technology in Human Services, 36*(4), 175–178. https://doi.org/10.1080/15228835.2018.1539369

Gutiérrez, K. D., Cortes, K., Cortez, A., DiGiacomo, D., Higgs, J., Johnson, P., Lizárraga, J. R., Mendoza, E., Tien, J., & Vakil, S. (2017). Replacing Representation With Imagination: Finding Ingenuity in Everyday Practices. *Review of Research in Education*, 41(1), 30-60. doi:10.3102/0091732X16687523

Huang, c-Y., Tsai, Y-S., & Wen, T-H. (2010). Simulations for epidemiology and public health education. *Journal of Simul*ations, 4(1), 68-80. doi:10.1057/jos.2009.13

Jones, M.G. & Rua, M.J. (2008), Conceptual Representations of Flu and Microbial Illness Held by Students, Teachers, and Medical Professionals. *School Science and Mathematics, 10*8, 263-278.

Jurow, A. S., & Shea, M. (2015). Learning in equity-oriented scale-making projects. *Journal of the Learning Sciences*, *24*(2), 286-307.

Kafai, Y. B. & Dede, C. (2014). Learning in Virtual Worlds. In K. Sawyer (Ed.), *Cambridge Handbook of the Learning Sciences,Second Edition* (pp. 522-544). New York, NY: Cambridge University Press.

Kafai, Y. B. & Fefferman, N. (2010). Virtual epidemics as learning laboratories in virtual worlds. *Virtual Worlds Research, 3* (2). Available at: https://journals.tdl.org/jvwr/index.php/jvwr/article/view/1888

Kafai, Y. B., Quintero, M., & Feldon, D. (2010). Investigating the "Why" in Whypox: Explorations of a Virtual Epidemic. *Games and Culture, 5*(1), 116-135.

Kafai, Y. B. & Wong, J. (2008). Real Arguments about a Virtual Epidemic: Conversations and Contestations in a Tween Gaming Club. In V. Jonker, A. Lazonder, & C. Hoadley (Eds.) *Proceedings of the 8th International Conference of the Learning Sciences*, Vol. 1 (pp. 414-421). Utrecht, Netherlands.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex Publishing Corporation.

Lytle, N., Cateté, V., Boulden, D., Dong, Y., Houchins, J., Milliken, A., ... & Barnes, T. (2019, July). Use, Modify, Create: Comparing Computational Thinking Lesson Progressions for STEM Classes. In *Proc. of the 2019 ACM Conf. on Innovation and Technology in CS Education* (pp. 395-401).

Lytle, N., Cateté, V., Dong, Y., Boulden, D., Akram, B., Houchins, J., ... & Wiebe, E. (2019b, May). CEO: A Triangulated Evaluation of a Modeling-Based CT-Infused CS Activity for Non-CS Middle Grade Students. In *Proc. of the ACM Conference on Global Computing Education* (pp. 58-64).

Milan, S., & Velden, L. V. (2016). The Alternative Epistemologies of Data Activism. *Digital Culture & Society, 2*(2), 57–74. https://doi.org/10.25969/mediarep/991

Neulight, N., Kafai, Y., Kao, L., Foley, B. & Galas, C. (2007). Children's participation in a virtual epidemic in the science classroom: Making connections to natural infectious diseases. *Journal of Science Education and Technology, 16*(1), 47-58.

Oultram, S. (2013). Virtual plagues and real-world pandemics: reflecting on the potential for online computer role-playing games to inform real world epidemic research. *Medical Humanities, 39,* 115-118.

Straif-Bourgeois S, Ratard R, Kretzschmar M. (2014). Infectious disease epidemiology. In W. Ahrens and I. Pigeot (Eds.), *Handbook of Epidemiology* (pp. 2041–2119). New York, NY: Springer.

Szablewski, C. M., Chang, K. T., Brown, M. M., Chu, V. T., Yousaf, A. R., Anyalechi, N., ... & McDaniel, C. J. (2020). SARS-CoV-2 transmission and infection among attendees of an overnight camp—Georgia, June 2020. *Morbidity and Mortality Weekly Report, 69*(31), 1023.

Timmis, K., Timmis, J., & Jebok, F. (2020). The urgent need for microbiology literacy in society: children as educators. *Microbial Biotechnology,* https://doi.org/10.1111/1751-7915.13619

Toyama, N. (2015). Adults' explanations and children's understanding of contagious illnesses, non-contagious illnesses, and injuries. *Early Child Development and Care, 186*(4), 526-543.

Trevors, G., & Duffy, M. C. (2020). Correcting COVID-19 misconceptions requires caution. *Educational Researcher, 49*, 538-542.

Trevors, G. & Kendeou, P. (2020). The effects of positive and negative emotions on knowledge revision. *Quarterly Journal of Experimental Psychology*, 73, 1326-1339.

Villenas, S. A. (2019). Pedagogies of being with: Witnessing, testimonio, and critical love in everyday social movement. *International Journal of Qualitative Studies in Education*, *32*(2), 151–166.

WHO (2020). Coronavirus disease 2019 (COVID-19): Situation report 85. Retrieved May 11, 2020, from https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200415-sitrep-86-covid-19.pdf?sfvrsn=c615ea20_4

Wilensky, U., & Rand, W. (2015). *An introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*: MIT Press.

Movement, Authority, and Knowledge: Examining the Relationships in Embodied and Social Positioning for STEM Learning

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Abstract: This symposium explores the empirical relationship between two theoretically distinct uses of the construct of *positioning* in the learning sciences. To do so, it brings together different studies that examine teaching and learning in STEM classrooms that incorporate both embodied and social aspects of positioning. These examples contribute to answering the question: How does simultaneously considering students' and teachers' embodied movements and social positioning offer new insights into studies of STEM classroom learning? Together, these studies show how different types of positioning are tightly related to one another, suggesting that more research is needed to understand the complex relationships between the physical, social, and epistemic positions in research and design of learning environments.

Introduction

Research in the learning sciences has used the construct of *positioning* in a variety of forms to understand teaching and learning in classrooms, often using theoretical perspectives of individual cognition or the sociocultural practices of the classroom community (Cobb & Bowers, 1999). Two common uses of the construct of positioning include embodied cognition, which foregrounds the individual cognition perspective, and social positioning, which foregrounds the sociocultural perspective. Research on these different forms of positioning has previously been separate from one another, taking up one perspective or the other.

Embodied cognition theorizes that human reasoning, no matter how abstract, is ultimately rooted in sensorimotor experience. Past research in this tradition highlights the role of *physical* positioning in teaching and learning. Findings in this area suggest that bodily movement is often inextricably linked to understanding and communicating concepts in algebra (Walkoe, 2015), geometry (Roth & Thom, 2009), chemistry (Flood et al., 2015), and physics (Lindgren et al., 2016), among others. Currently, researchers are using the principle of embodiment to design novel activities that promote mathematical (e.g., Abrahamson et al., 2020) and scientific learning and engagement (e.g., Danish et al., 2020; Lindgren et al., 2016).

In contrast, research on social positioning situates learning as occurring within the context of complex social and interactional dynamics of a classroom. Research from this tradition takes up the idea of positioning *metaphorically* in relation to teaching and learning. As such, this research investigates teachers' and students' social and epistemic roles in interaction in terms of framing, identity, authority, agency, and power. Researchers using this lens have found that opportunities for student learning in STEM classrooms may be afforded by curricular design through redistributed epistemic agency (Ko & Krist, 2019) or constrained by social and epistemic authority assumed by teacher and peers (Langer-Osuna, 2016).

While each perspective offers distinctive views of learning, the notion of position, both physically and metaphorically, is central to embodied cognition and social positioning research. Education researchers have begun to ask questions across these traditions while investigating teaching and learning in K-12 STEM classrooms. For instance, how might a teacher's physical position and movement within the classroom space contribute to shifts in the epistemic framing of tasks? (Kelly, 2020). However, research that meaningfully integrates positioning across cognitive and sociocultural theoretical perspectives remains rare. We argue that this integration is important for understanding and designing for learning in STEM classroom environments that account for these connected aspects of positioning.

This symposium brings together research on learning and teaching in STEM classrooms that investigates positioning by integrating multiple perspectives. Collectively, we acknowledge embodied aspects of thinking and acting, while also recognizing the role of interaction in teaching and learning. Individually, we each offer a unique way in which we bring together notions of embodiment and social positioning through theoretical framing and methodological considerations. The session will begin with introductory remarks followed by the presentation of five papers, described below. Then, our Discussants, Dr. Soo-Yean Shim and Dr. Robb Lindgren, will co-lead a discussion around the question: How does simultaneously considering students' and teachers' embodied movements and social positioning offer new insights into studies of STEM classroom learning? Ultimately, this symposium will advance the field of learning sciences by envisioning possibilities for new lines of research that better integrate these distinct traditions through theoretical and methodological bricolage (Cobb, 2007).

Who gets to hold the counting cubes?: Exploring authority relations among peers during collaborative struggles in K-2 mathematics

Jennifer Langer-Osuna, Rosa Chavez, Jim Malamut, Faith Kwon, Emma Gargroetzi, Kimiko Lange, and Jesse Ramirez

Student-led collaborative mathematical activity involves relationships of power. Relational power among peers, such as status (Cohen & Lotan, 1997) and authority (Langer-Osuna, 2011, 2016), can shape not only who participates and in what ways (Wood, 2013), but also the nature of the mathematical discussions (Esmonde & Langer-Osuna, 2013), the construction of a mathematical solution (Kostopoulous, 2014; Langer-Osuna, 2016), and the development of identities as learners (Anderson, 2009; Bishop, 2012). Yet, the study of relational power in peer-led collaborative learning has been relatively small.

The early elementary years is a time of both introduction to schooling and significant changes in children's socio-emotional development. Studies of how young children come to dominate social situations reveal both prosocial and coercive ways they garner influence with peers (Bohart & Stipek, 2001; Hawley, 2002; Ostrov & Guzzo, 2015). Ostrov and Guzzo (2015) found that the most influential children were the ones who readily shared with others and did so in the absence of a teacher directing them to do so. These findings suggest that the construction of influence among peers can both promote or disrupt possibilities for productive and equitable collaborative learning, depending on the strategies deployed. More disruptive forms of domination serve to marginalize peers rather than regulate shared activity (Langer-Osuna, 2011).

The social construction of influence or marginalization in collaborative learning, in particular, can help to illuminate the processes by which students come to build mathematical knowledge, while accounting for issues of equity. We draw on the Influence Framework (Engle, et al., 2014; Langer-Osuna, 2016), which posits that influence arises from the social negotiation of: (a) the conversational floor and (b) interactional space, (c) the perceived merit of ideas and behaviors, and (d) being positioned with authority. We apply this framework to illuminate young learners' relations of power and how they shape collaborative mathematics learning activity. This paper focuses, in particular, on key moments of interactional struggle and makes visible the sources of authority students drew on to influence the actions of their peers.

This study is situated within a broader Research-Practice Partnership between a university research team and an instructional team of five teachers at an elementary school in Northern California that served predominantly bilingual Latinx and Pacific Islander students. The goal of the broader partnership was to support teachers in implementing student-led collaborative mathematical activity, using the Contexts for Learning Mathematics (CFL) instructional units (Fosnot, 2007) as a curricular resource (see Table 1). The teachers involved in the study worked to create classroom contexts in which students were expected to author and evaluate mathematical ideas and to share this authority with one another productively and inclusively.

We focus on a total of 22 videos of student-led table work across three K-2 classrooms (see Table 1). The research team (authors) created analytic content logs of each video at the 5-minute level, focused in particular on describing student talk, bodily orientation and gaze, and distribution of resources. Each video was content logged by two researchers and reviewed by the entire research team in iterative rounds of discussion and development. We then identified all moments of interactional struggle and inductively coded the struggles by type, resulting in the following categories of struggle: students' access to: (a) materials, (b) the conversational floor, and (c) interactional space, as well as struggles around (d) roles and (e) task expectations. We then coded all moments of struggle for (a) their named source (i.e., teacher, other adult, self, peer) and (b) the response to the directives (i.e., taken up, ignored, resisted).

Table 1: Data Sources and Classroom Context by Grade Level

Teacher	Grade	Unit	Number of Videos
Ms. Bene	Kindergarten	Bunk Beds and Apple Boxes	7
Ms. Kim	1st	Bunk Beds and Apple Boxes	10
Mrs. De Waal	2nd	Double Decker Bus	5

Preliminary findings show that drawing on adult sources of authority tended to constrain or dismantle collaboration, while drawing on student sources of authority supported sustained engagement through resolution of interactional struggle. For example, during partner work in a kindergarten classroom, two students were working together when one decided that the other partner should be doing the work, and threatened to tell the teacher that he was behaving inappropriately, resulting in the partner ceasing to participate entirely and folding his body into himself on the desk. In a first grade classroom, one student challenged his partner's authority after a series of slights, to which she responded by singing the lines, "Gonna find out who's naughty and nice," resulting in the student shifting away from the partnership both intellectually and physically. These examples show how students' deployment of adult authority through the perceived threat of getting in trouble can overpower peer resistance and shut down possibilities for shared work. In a second grade small group, one student positioned as slow and hindering completion of the task by his peers consistently resisted his peers' directives by claiming his own competence and right to learn, which sustained his engagement in the task through interactional struggle.

Teachers' awareness of student multimodal thinking

Janet Walkoe and Margaret Walton

Teacher noticing/ teacher responsiveness has been a focus of math and science teacher learning for the past decade (e.g., Sherin, Jacobs, & Phillip, 2011; Robertson, Scherr, & Hammer, 2015). Working to elicit, attend and interpret the disciplinary substance of students' ideas have been identified as important aspects of teaching. Not only do these practices support student inquiry and learning, it is an activity that is productive for teacher learning (e.g., Franke & Kazemi, 2001). The majority of the work on teacher noticing has foregrounded teacher noticing of student's spoken and written ideas. One example is in video club work (e.g., van Es & Sherin, 2008; Walkoe, 2015). Video club PD involve teachers coming together (usually with a facilitator) to discuss classroom video clips. Video clubs have been effective in supporting teacher noticing of student thinking, in particular, because the video allows teachers to discuss a classroom scene. The video allows teachers to watch and discuss a common classroom scene. In the majority of video club work, teachers watch the video and are given a written transcript of the video to use as reference during the discussion of the student thinking they noticed in the video. The use of a transcript largely focuses teachers' attention to student thinking that is expressed verbally. While this has been productive, the work on student learning makes explicit the role of gesture, action, and other multimodal thinking (e.g. Hall & Nemirovsky, 2012). For instance, gesture can be used not only to communicate student thinking but to help children make sense of ideas (Roth & Thom, 2009). Attending to multimodal student thinking opens up learning opportunities for students in one-on-one tutoring situations (e.g., Flood et al., 2015) and in classrooms (e.g., Shein, 2012). For this reason alone, we should include multimodal thinking when discussing teacher noticing, though it has not been the primary focus thus far. In addition, recent work on multimodal teacher noticing (MMTN) (Walkoe, Williams-Pierce, Flood, & Walton, in progress) has found that when teachers attend to students' gesture in mathematics PD, they also shift the types of questions they pose from a focus on math facts to more open-ended, resources-based questions.

In this talk we will demonstrate how student gesture and action can be deeper windows into their thinking in the classroom. We will present a short video clip to demonstrate student geometric and algebraic thinking that is visible primarily through gesture and action.

We will then provide an example of a video club that was designed to utilize a video annotation tool (www.anotemos.com) to support teachers' noticing of multimodal student thinking. This was the first time the teachers participated in a video club and we found that their discussions about student thinking were productive and consistent with what we have seen in more advanced video club work. In particular, the teachers took time discussing specific instances of student thinking, as opposed to jumping around from idea to idea. Additionally, they delved deeply into the student thinking they noticed and the discussions were substantial. In prior video club work, we have not seen these rich ways of discussing student thinking until further into the video club sessions (e.g., Walkoe, 2015). The video tagging format also seemed to support teachers in noticing a range of student thinking, including thinking expressed through gesture.

Finally, we will discuss work in progress, that continues to investigate the effectiveness of video clubs designed to support MMTN and the connection between a multimodal focus on teacher noticing and the richness of teacher noticing and video club discussion.

Social positioning in collective embodied models in an elementary STEM classroom

Nitasha Mathayas, Joshua Danish, Xintian Tu, Mengxi Zhou, and Morgan Vickery

In this paper, we examine the collective embodied activity of students in an elementary science classroom to explore how their dynamic movement within the classroom shifts their social positions as knowledge creators. A core focus of our research is on collective embodied learning: how students' collaborative embodiment of scientific concepts acts as a physical and conceptual tool that mediates their collective efforts to construct understanding about the phenomena they are modeling (Danish et al., 2020). Our research is framed within Cultural Historical Activity Theory as we see classroom learning as inherently sociocultural and imbued with cultural and historical meanings that influence how teachers and students learn in interaction (Engeström, 2018). A key element of this is *social positioning*, which describes how joint interaction dynamically positions participants in different roles during activity, and highlights how these roles are imbued with differing levels of power to make epistemic decisions, even when participants are not consciously aware of them (Davies & Harré, 1990; Miller et al., 2018). In this paper, we explore how first and second-grade learners' knowledge building activities in a mixed reality environment were shaped by their constantly shifting physical and social positioning as they explored states of matter at the particulate level.

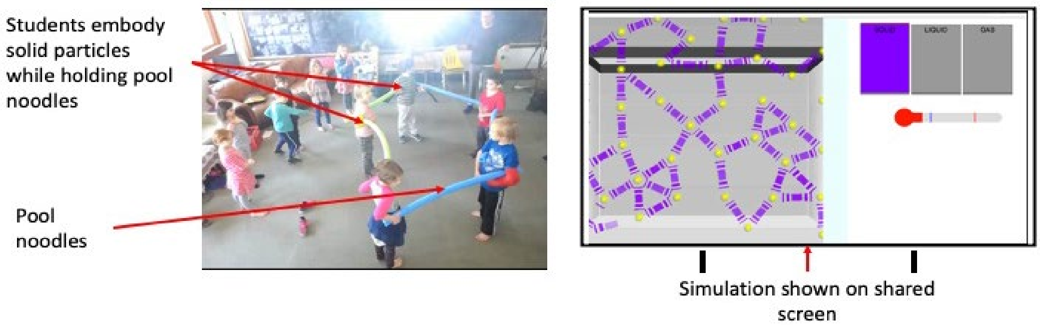

Figure 1. Students-as-particles embody a solid (ice) while holding pool noodles to represent bonds between them. The instructors and other students observe the group and the simulation.

Our current analysis focuses on a seven-day unit about energy and states of matter using a mixed reality simulation called Science through Technology Enhanced Play (STEP; Danish et al., 2020) that was implemented in a mixed first and second grade classroom in a private school in an urban Midwestern city (Tu et al., 2020). STEP lets students explore the relationship between particle behavior and states of matter by collectively enacting how they think particles respond to different amounts of energy and simultaneously observing their movement as molecules in the simulation (see Figure 1). In the unit, students explored different characteristics of molecular movement and intermolecular bonds by acting as molecules and using props such as foam pool noodles to support their collective enactment. Using methods of interaction analysis (Jordan & Henderson, 1995), we analyzed video recordings of the classroom interaction and the simulation across the unit and focused on how students' social and physical positions changed and influenced each other.

Our analysis shows how movements within the collective model simultaneously impact and are shaped by the current social positioning that those very same movements appear to help construct. For example, the instructors shifted at times from taking a "typical" directive teacher role standing outside the model offering suggestions, to actively participating as a particle in the space. When they were in the external teacher role, students tended to listen attentively to them. However, as soon as students began moving, the teachers' role as "external" to the model was reified as the learners oriented toward each other and the projected simulation, limiting the impact of the teacher on their collective modeling until they paused. This led the students to explore their own ideas about particle behavior in-the-moment, and the teacher was limited to helping them reflect on those realizations after-the-fact. Similarly, when one teacher joined in the model as a particle, they began by offering suggestions about the model that led the students to move in response, however, as the students began moving, the teacher also reacted to their motions, creating a more equal footing as the group acted in coordination, and began to recognize underlying patterns in particle movement.

Taken together, these different forms of interaction show how it is impossible to separate the social role of movement within embodied modeling practice from the knowledge building role of that same movement. The continuous movement of participants has cascading effects on their collective embodiment and social positioning. Thus, it is important for educators and designers who aim to leverage whole-body embodied learning to think about the unique way that physical positioning contributes to social positioning that in turn promotes or constrains embodied agency within these contexts.

Revisiting positioning: How a teachers' physical movements amplify socio-epistemic messages in the classroom

Susan Kelly and Christina Krist

This paper uses both physical and epistemic positioning to track how a teacher's talk and physical movement support students in knowledge building. Students come to understand expectations relative to knowledge building and their role in the process through the interactional routines that occur in the classroom. They pick up how they are expected to respond based on how a teacher frames the environment and the kind of ideas the teacher gives space to in the classroom (e.g., Scherr & Hammer, 2009; Russ & Luna, 2013). A teacher conveys these ideas through the *epistemic messages* they send that emphasize what kind of knowledge counts and how students are expected to participate (Russ, 2018). Because these messages are continuously communicated through teacher and student interactions and are dynamically negotiated moment-to-moment, they work as *socio-epistemic messages* that guide how students interact with each other and with the ideas they are constructing in their work together (Kelly, 2020). In this paper, we explore how Mr. M, an experienced teacher who enacted reform-aligned science instruction, used his physical positioning to amplify and emphasize the discursive socio-epistemic messages he communicated during an eighth-grade science class.

Focusing on one socio-epistemic message, we describe how Mr. M uses his physical movements to amplify the message *Everyone's Ideas are Valued* he communicated (Kelly, 2020). This message conveyed to students that their ideas were important and that their contributions were taken seriously. To do this, Mr. M often used metadiscursive affirmations like "Great idea" or "That's cool" in response to their ideas. He also encouraged students to go public with their ideas by asking students to speak loudly so their ideas would be heard by the classroom community. He also emphasized making ideas public by revoicing their thoughts or by asking students to revoice their peers' ideas.

This video case was drawn from a larger project that investigated middle school students' participation in science knowledge building practices. In our analysis, we examined 15 video recordings of lessons taken from the beginning, middle, and end of a multi-day Earth science unit that investigated the movement of the Earth's plates. The students, who were ethnically and economically diverse, were initially reticent to engage collectively in the intellectual work at the start of the unit, so Mr. M was actively working to develop a classroom community that would encourage their participation as agents in their own learning.

Using a grounded approach, we conducted video analysis to characterize how Mr. M positioned students to do the knowledge building work by tracking his talk and physical movement. To do this, we completed a line-by-line analysis of whole group discussion to identify the epistemic messages Mr. M conveyed (see Kelly, 2020 for additional detail). Concurrent with this analysis, we created a multimodal transcript describing Mr. M's physical movements during each class. Within this transcript, we identified moments with an obvious or dramatic shift in physical position. We then compared whether particular physical movements coincided with the coded epistemic messages and documented these patterns and relationships in analytic memos.\We identified three distinct patterns of physical movement that Mr. M used in conjunction with the message *Everyone's Ideas are Valued.* Each of these movements served to amplify the message, albeit in different ways. We provide a brief example of each. First, one pattern of physical positioning involved Mr. M *moving away from the speaker* while verbally positioning them with intellectual authority. For example, during a discussion in which students were sharing initial ideas, Mr. M acknowledged a student, Vanessa's, idea was interesting and then moved to the opposite side of the room while asking her to repeat her idea in a louder voice. A second pattern involved Mr. M *moving toward the speaker* to emphasize their ideas. In this case, Mr. M moved toward speaker while simultaneously revoicing that speaker's idea to emphasize or clarify it. For example, after Jason shared his idea about how tectonic plates converged, Mr. M moved toward Jason to make sure he was imitating Jason's hand gesture for convection correctly and if he was revoicing his idea accurately. Finally, while Mr. M rarely stood at the front of the room during class activities and instead moved around the room, he would often *move to the side of the speaker(s*), effectively positioning students to take on the intellectual work by physically and discursively giving them the floor. Sometimes Mr. M would sit at or on a table with the rest of the class while students drew and discussed their ideas at the board. In these instances, he physically positioned himself to as member of the community, rather than an authority.

Taken together, Mr. M's physical positioning, moving *away from*, *toward*, or *to the side* of the student(s) speaking served to amplify the socio-epistemic message, *Everyone's Ideas are Valued,* he was communicating discursively. He encouraged students to "go public" with their ideas and act with agency. He reinforced this notion by using physical movements to increase the "airtime" for student's ideas, so their ideas could be examined, critiqued, and modified by the classroom in their knowledge building endeavors. Showing how discursive and physical positioning work together to laminate the socio-epistemic messages conveyed in the classroom is an important consideration for educators who are, knowingly or unknowingly, continuously sending messages about learning to their students.

Making space for joint exploration: The embodiment of social and epistemic positioning in student-teacher interaction

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Across reform efforts in mathematics education is an emphasis on involving students productively in the intellectual work of the discipline. Often, this involves re-negotiating the roles and authority structures typical in school contexts in order to position students and teachers as partners who are jointly exploring disciplinary questions (Scardamalia, 2002). This re-negotiation is both social and epistemic: it is a marked shift from classroom structures in which a teacher holds the majority of intellectual and social authority.

In order to better understand how joint exploration of ideas between students and teachers as partners is established and maintained through interaction (Keifert & Stevens, 2019), we analyzed an episode in a secondary mathematics classroom in which a teacher responded to a student's wondering. We adopt the theoretical framing of positioning (Davies & Harré, 1990) to consider social and epistemic authority, while also foregrounding physical positioning in our analysis. The focal episode comes from a dataset of classroom video of teachers who were developing responsive teaching practices in secondary mathematics. We view responsive teaching practices as pedagogical tools that build on students' ideas, wonderings, and sensemaking; accordingly, the use of such practices requires that teachers establish and maintain moments of joint exploration with students. We selected one teacher, Rachel, as prior analyses demonstrated that she consistently used responsive teaching practices (Dyer & Sherin, 2016). Using "joint exploration" as a sensitizing concept (Blumer, 1954), the research team reviewed Rachel's videos from 10 100-minute class periods to identify potential episodes for close microanalysis.

Figure 2. Four physical positions of the teacher (from left): Position 1- standing upright, Position 2- leaning back, Position 3- standing, leaning over table and Position 4-standing leaning over table with head down

In this paper, we present our microanalysis of one identified episode of "joint exploration" in order to begin to elucidate social, epistemic, and physical patterns around how such explorations are established and maintained. In this episode, Rachel, interacts with two students who are seated next to each other, James and Steven. We analyzed Rachel's physical positions throughout the episode and found that Rachel assumed one of four positions, shown in Figure 2. To analyze social positioning, we considered a person to assume social authority when giving a social directive that was followed by others in the group. Similarly, we analyzed epistemic (intellectual) authority by considering whose mathematical ideas were proposed and taken up by the group.

From this analysis, we identified a strong relationship among physical, social, and epistemic positioning in establishing and maintaining joint exploration of a mathematical idea. Of the 10 shifts in Rachel's physical position in the interaction, 9 were associated with a shift in her social and/or epistemic authority. Conversely, no shifts in Rachel's social or epistemic authority were observed without a shift in physical position. Further, we found that shifting between certain positions often coincided with certain epistemic or social moves.

To illustrate this phenomenon, we focus on one shift in physical positioning (from position 1 to 2; see Figure 2) and describe the change in epistemic positioning that served to ***establish*** joint exploration. We argue that this shift involved a concurrent release of epistemic authority by Rachel and an uptake of epistemic authority by James and Steven. As James asked the teacher a question about whether there is "a natural log that is equivalent to e" while "messing around with [his] calculator" and looking up at her, Rachel restated James' question, paused, stepped back, and shifted from physical position 1 to position 2. The question appeared to catch Rachel off guard, as she did not provide an immediate response. Rachel then remained in position 2, leaning back, as she tried to understand James's question by asking clarifying questions. Steven then intervened to affirm Justin with "I mean yeah, cuz it'd be a power" to which Justin replied "of e, right?" leading to a discussion between Steven and James with little feedback from Rachel. Notably, Steven and James arrive at a solution to James' question that they were both satisfied with, without any affirmation from Rachel.

During this episode, Rachel's shift backward created space, both physically and metaphorically, for James and Steven to take up the intellectual authority within the conversation. Through our analysis of an episode that contained joint exploration, we found that shifts in the teacher's physical positioning were highly correlated with shifts in social or epistemic positioning within the group. Furthermore, patterns have begun to emerge among certain positions and their associated shifts in authority and interactional dynamics. We illustrated one such shift here, demonstrating how a particular shift in the teacher's physical positioning, coupled with verbal and other interactional dynamics, served to create space for students to take up intellectual authority. These findings suggest that shifts in a teacher's physical positioning may be a strong indication of changes in social or epistemic positioning and/or are an important part of conveying social and epistemic messages. We offer the suggestion of triangulating physical, social, and epistemic positioning to develop in-depth analysis of how authority is negotiated to establish and maintain moments of joint exploration in mathematics classrooms.

References

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E. R., Soto, H., & Alibali, M. W. (2020). The future of embodied design for mathematics teaching and learning. *Frontiers in Ed., 5,* 147.

Anderson, K. (2009). Applying positioning theory to the analysis of classroom interactions: Mediating micro-identities, macro-kinds, and ideologies of knowing . *Linguistics and Education, 20*(4), 291–310.

Bergin, C. C., & Bergin, D. A. (2018). *Child and Adolescent Development in Your Classroom: Chronological Approach*. Boston, MA: Cengage Learning.

Bishop, J. P. (2012). "She's always been the smart one. I've always been the dumb one": Identities in the mathematics classroom. *J. for Res. In Math. Ed*, *43*(1), 34-74.

Blumer, H. (1954). What is wrong with social theory? *American Sociological Review*, *19*, 3–10.

Bohart, A. C., & Stipek, D. J. (2001). What have we learned?. In *Constructive & destructive behavior: Implications for family, school, & society.* (pp. 367-397). American Psychological Association.

Cobb, P. (2007). Putting philosophy to work: Coping with multiple theoretical perspectives. In F. K. Lester (Ed.) *Second handbook of research on mathematics teaching and learning* (pp. 3-38). Charlottle, NC: Information Age Publishing.

Cobb, P. & Bowers, J. (1999). Cognitive and situated learning perspectives in theory and practice. *Ed. Res., 28*(2) 4-15.

Cohen, E. G., & Lotan, R. A. (1997). *Working for equity in heterogeneous classrooms: Sociological theory in practice*. New York, NY: Teachers College Press.

Danish, J. A., Enyedy, N., Saleh, A., & Humburg, M. (2020). Learning in embodied activity framework: A sociocultural framework for embodied cognition. *Int. J. of Comp.-Supported Coll. Learning*, *15*(1), 49–87.

Davies, B., & Harré, R. (1990). Positioning: The discursive production of selves. *J. for the Theory of Soc. Behav.*, *20*(1), 43–63.

Dyer, E. B., & Sherin, M. G. (2016). Instructional reasoning about interpretations of student thinking that supports responsive teaching in secondary mathematics. *ZDM, 48*, 69-82.

Engeström, Y. (2018). Expansive learning: Toward an activity-theoretical reconceptualization. In K. Illeris (Ed.), *Contemporary theories of learning: Learning theorists...in their own words* (2nd ed., pp. 53–73). Routledge.

Engle, R. A., Langer-Osuna, J. M., & McKinney de Royston, M. (2014). Toward a model of influence in persuasive discussions: Negotiating quality, authority, privilege, and access within a student-led argument. *JLS, 23*(2), 245-268.

Esmonde, I., & Langer-Osuna, J. M. (2013). Power in numbers: Student participation in mathematical discussions in heterogeneous spaces. *J. for Res. in Math. Ed., 44*(1), 288–315.

Flood, V. J., Amar, F. G., Nemirovsky, R., Harrer, B. W., Bruce, M. R., & Wittmann, M. C. (2015). Paying attention to gesture when students talk chemistry: Interactional resources for responsive teaching. *J. of Chem. Ed.*, *92*(1), 11-22.

Fosnot, C. (2007). *Contexts for learning mathematics*. Portsmouth, NH: Heinemann.
Fosnot, C. (2007). *Contexts for learning mathematics: The Double Decker Bus*. Portsmouth, NH: Heinemann.
Fosnot, C. (2007). *Contexts for learning mathematics: Bunk Beds and Apple Boxes*. Portsmouth, NH: Heinemann.
Franke, M. L., & Kazemi, E. (2001). Learning to teach mathematics: Focus on student thinking. *Theory into practice*, *40*(2), 102-109.
Hall, R., & Nemirovsky, R. (2012). Introduction to the special issue: Modalities of body engagement in mathematical activity and learning. *JLS*, *21*(2), 207-215.
Hawley, P. H. (2002). Social dominance and prosocial and coercive strategies of resource control in preschoolers. *Int. J. of Behav. Dev., 26*(2), 167-176.
Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *JLS, 4*(1), 39-103.
Keifert, D., & Stevens, R. (2019). Inquiry as a members' phenomenon: Young children as competent inquirers. *JLS*, *28*(2), 240-278.
Kelly, S. (2020) Characterizing Epistemic Messages in the Classroom. [Unpub. doctoral dissertation]. Univ. of Illinois.
Ko, M. M., & Krist, C. (2019). Opening up curricula to redistribute epistemic agency: A framework for supporting science teaching. *Science Education*, *103*(4), 979–1010.
Kotsopoulos, D. (2014). The case of Mitchell's cube: Interactive and reflexive positioning during collaborative learning in mathematics. *Mind, Culture, and Activity, 21*(1), 34 –52.
Langer-Osuna, J. M. (2011). How Brianna became bossy and Kofi came out smart: Understanding the trajectories of identity and engagement for two group leaders in a project-based mathematics classroom. *Canadian J. of Sci., Math. and Tech. Ed.*, *11*(3), 207-225.
Langer-Osuna, J. M. (2016). The social construction of authority among peers and its implications for collaborative mathematics problem solving. *Mathematical Thinking and Learning, 18*(2), 107–124.
Langer-Osuna, J. M., Gargroetzi, E., Munson, J., & Chavez, R. (2020). Exploring the role of off-task activity on students' collaborative dynamics. *J. of Ed. Psych.*, *112*(3), 514-532.
Lindgren, R., Tscholl, M., Wang, S., & Johnson, E. (2016). Enhancing learning and engagement through embodied interaction within a mixed reality simulation. *Computers & Education*, *95*, 174–187.
Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *J. of Res. in Sci. Teaching*, *55*(7), 1–23.
Ostrov, J. M., & Guzzo, J. L. (2015). Prospective associations between prosocial behavior and social dominance in early childhood: are sharers the best leaders?. *J. of Genetic Psych*., 176(2), 130-138.
Pellegrini, A. D., Roseth, C. J., Mliner, S., Bohn, C. M., Van Ryzin, M., Vance, N., ... & Tarullo, A. (2007). Social dominance in preschool classrooms. *J. of Comparative Psych., 121*(1), 54-64.
Robertson, A. D., Scherr, R., & Hammer, D. (Eds.). (2015). *Responsive teaching in science and mathematics*. Routledge.
Roth, W. M., & Thom, J. S. (2009). Bodily experience and mathematical conceptions: From classical views to a phenomenological reconceptualization. *Ed. Studies in Math., 70*(2), 175-189.
Russ, R. S. (2018). Characterizing teacher attention to student thinking: A role for epistemological messages. *J. of Res. in Sci. Teaching*, 55(1), 94–120.
Russ, R. S., & Luna, M. J. (2013). Inferring teacher epistemological framing from local patterns in teacher noticing. *J. of Res. in Sci. Teaching*, 50(3), 284–314.
Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. *Liberal education in a knowledge society*, *97*, 67-98.
Scherr, R. E., & Hammer, D. (2009). Student behavior and epistemological framing: Examples from collaborative active-learning activities in physics. *Cognition and Instruction*, *27*(2), 147–174.
Sherin, M., Jacobs, V., & Philipp, R. (Eds.). (2011). *Mathematics teacher noticing: Seeing through teachers' eyes*. NY: Routledge.
Tu, X., Georgen, C., Danish, J., & Enyedy, N. (2020). Extended embodiment: Physical and conceptual tools in a Mixed-Reality learning environment as supports for young learners' exploration of science concepts. In M. Gresalfi & I. S. Horn (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS)* (Vol. 3, pp. 1269–1276). ISLS.
van Es, E. A., & Sherin, M. G. (2008). Mathematics teachers "learning to notice" in the context of a video club. *Teaching and Teacher Education*, *24*(2), 244-276.
Walkoe, J., (2015). Exploring teacher noticing of student algebraic thinking in a video club. *J. of Math. Teacher Ed., 18*(6), 523-550.
Walkoe, Williams-Pierce, Flood, & Walton, in progress.
Wood, M. B. (2013). Mathematical micro-identities: Moment-to-moment positioning and learning in a fourth-grade classroom. *J. for Res. In Math. Ed., 44*(5), 775–808.

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Learning to Center Relational Ontologies: Desettling Interaction Analysis Methods

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Abstract: In this symposium we work toward our responsibility in learning how to be human through a deep reciprocal relationship to and with the more than human, by interrogating an influential method in the learning sciences, interaction analysis. As settler scholars learning to "set aside the ways of the colonist" (Kimmerer, 2013, p. 207) we aim to think with Indigenous Ways of Knowing (IWOK) to reinterpret the methodological commitments of interaction analysis. In acknowledgment of the continual learning required for this goal, we propose a symposium where authors and audience members learn together, engaging in two iterations of a video analysis session around the same piece of data: one using more traditional interaction analysis methods, and one engaging with our emerging understandings of a relational ontology. Our two discussants, leading scholars of both IWOK and interaction analysis in the learning sciences will support analysis sessions and subsequent discussion.

> "*Indigenous* is a birth-right word. No amount of time or caring changes history or substitutes for soul-deep fusion with the land. Following Nanabozho's footsteps doesn't guarantee transformation of Second Man to First. But if people do not feel 'Indigenous', can they nevertheless enter into the deep reciprocity that renews the world? Is this something that can be learned?" (Kimmerer, 2013, p. 213)

In this symposium, we propose to work toward desettling and expanding a commonly used (and settled) method in the Learning Sciences, interaction analysis (Jordan & Henderson, 1995), by thinking with Indigenous Ways of Knowing (IWOK; Bang & Marin, 2015). Rather than adopting and decontextualizing IWOK to fit into what the method already is (Afonso Nhalevilo, 2013), we take what we see as a settler responsibility to interrogate how conventional interaction analysis is rooted in settler colonial logics and surface what needs to be reimagined. As scholars who do interaction analysis, we believe that starts by interrogating the settler-colonial logics of research, and truthmaking, that undergird the rooted ontologies from which it has sprung. In acknowledgement of the complex and necessarily ongoing nature of desettling work, this symposium is structured as an alternative to the traditional symposium structure of a collection of paper presentations. Instead, we invite members of the learning sciences community to participate in a data session with us to first interrogate the settled assumptions embedded in interaction analysis methodology, and then to explore alternative ways to take up interaction analysis commitments that at the same time position us to be in ethical relation with our human and More Than Human (MTH) research partners. To this end, we will, with gratitude, be joined by two scholars, Megan Bang and Ananda Marin, who have transformed our own and the learning sciences' understandings of IWOK and the possibilities of interaction analysis to incorporate a relational ontology. They will serve as "discussants" in the data session symposium, participating in data analysis with the group, stewarding our efforts to take up IWOK in interaction analysis, and providing discussion points along the way.

Learning from Indigenous Ways of Knowing

In her book Braiding Sweetgrass, Robin Kimmerer shares the story of Nanabozho - part man, part manido, immigrant on Turtle Island (known to colonizers/settlers as North America) populated with worlds of animals, plants, winds and waters. When placed here by the creators, Nanabozho was assigned the responsibility of learning how to be human from the many MTH beings that already inhabited the world. Their advice to not "control or change the world as a human, but to learn from the world how to be human" (Kimmerer, 2013, p. 208) formed the beginnings of the original instructions passed down through generations of Indigenous peoples on Turtle Islands - the First Man. Since the time (2) of Nanabozho, the many waves of colonizers, settlers and immigrants - the Second Men - brought with them an approach to being human informed by an ontology that views humans as separate from and higher in a material hierarchy than the MTH. Unlike Nanabozho who was made responsible for learning *from* and *in relationship with* the MTH, 'Western' or 'Eurocentric' ontologies lay claims to objective truths informed by Francis Bacon's call to "bind nature and reduce her to a slave" (Semali, 2002, p. 30). Rooted in living in and with the MTH, IWOK prioritize a relational ontology and value taking care of the land through an understanding of the nuanced relationships between and within humans and the MTH from a holistic framework. This way, neither humans nor the MTH are higher in a material hierarchy since the MTH world is deeply embedded in how reality emerges. In stark contrast to this, settlers have had little interest in the responsibility embedded in living with the land. Over the last few centuries, they have enacted oppressive extractionist frameworks through residential schooling systems, claiming and stealing land by displacing Indigenous peoples from their homes and the ongoing pollution of unceded Indigenous territories to mine and extract nutrients from the Earth (amongst many other acts of violence). In this symposium, we seek to shift away from this colonial ontology by learning from IWOK to decolonize our ways of understanding reality. In discussing the role of colonizers who want to decolonize their ways of being on Turtle Island, Kimmerer asks what it might mean for us to live on this land "as if we were staying [...] with both feet on the shore" (Kimmerer, 2013, p. 207). Her question pushes non-Indigenous people to consider how we might learn to be human as though our "ancestors lie in this ground [...] to take care of the land as if our lives and the lives of all our relatives depend on it. Because they do" (Kimmerer, 2013, p. 215). Embedded in Kimmerer's question is a call for the Second Man to consider our responsibility in learning how to be human through a deep reciprocal relationship to and with the MTH. In this symposium, we take up this call to "set aside the ways of the colonist" (Kimmerer, 2013, p. 207) by deeply engaging with a relational ontology towards decolonizing how we understand learning.

In this work, we understand Indigenous knowledge systems as "a product of the cognition of the people that predate westerners and have operated independently of the western paradigm for thousands of years" (Hewson, 2015b, p. 41). While disparate in their particulars, IWOK across the world do share commonalities in their worldviews such that reality comes into being in, with, and through nature and human beings (Smith, 1999) be it Indian tribal communities' use of plants for medicine (Ignacimuthu, Ayyanar, & Sivaraman, 2006), the science of *titen* developed by the Java community in present day Indonesia (Wilujeng & Prasetyo, 2018), or the Indigenous knowledge for artisan fishing in Mozambique (Afonso Nhalevilo, 2013). Framed as 'relational epistemologies' (Bang, Marin & Medin, 2018), IWOK center relationality, emphasizing the responsibility required in human-MTH relationships so that we not only "honor the knowledge in the land" but also engage in "caring for its keepers" (Kimmerer, 2013, p. 210). We draw on Bang, Marin & Medin (2018) to inform how we frame relational epistemologies by recognizing that we need to:

1. view humans as a part of the natural world, rather than apart from it;
2. attend to and value the interdependencies that compose the natural world;
3. attend to the roles actors play in expanded notions of ecosystems from assumptions of contribution and purpose, rather than assumptions of competition;
4. focus on whole organisms and systems at the macroscopic level of human perception (also a signature of complex-systems theory);
5. see all life forms as agentic, having personhood and communicative capacity (as distinct from anthropocentrism);
6. adopt multiple perspectives, including interspecies perspectives, in thought and action; and
7. weigh the impacts and responsibilities of knowledge toward action." (p. 151)

Learning from Indigenous scholars in the field, we seek to engage in recognizing <u>relations</u> as our unit of analysis. This speaks not only to our attempts at learning from (rather than about; Jones and Jenkins, 2008) IWOK but also to the ethical dimensions of what we analyze (who, and for whom/towards what ends) (Philip, Bang & Jackson, 2018). We recognize this work as part of our learning *how* to be relation in and with this land and engaging with the need for our "commitment to transform processes that uphold and assert Western epistemic supremacy" (Bang, Marin, & Medin, 2018, p. 156).

Within the Learning Sciences, we look to Indigenous scholars (and their collaborators) who have shared decolonial understandings of human-MTH relations towards more expansive conceptions of learning both in and out of formalized education settings. Building on much of Gregory Cajete (e.g., 1994 and 2000) and Douglas Medin's (e.g., 2006) work in illustrating different cultural conceptions of human-nature relations (Medin, 2006) that highlight Indigenous knowledge systems as rooted in a relational ontology (Cajete, 2000), Megan Bang and Ananda Marin have brought to the fore *how* we can understand learning from a decolonial perspective. "Settled expectations" (p. 303) in schooled science education impose colonial human-nature divides, restricting both the "content and form" of knowledge systems valued within education spaces that then "devalue(s) and dismiss(es) boundary-expanding forms of knowledge, experience and meaning-making" (Bang, Warren, Rosebery & Medin, 2012, p. 303). In addition, focusing on formalized school spaces as the primary sites for learning further marginalizes Indigenous youth by positioning them in "untenable epistemological positions that work against engagement in meaningful learning" (p. 303). Formalized schools on Turtle Island were built through colonial frameworks to dominate and eradicate Indigenous communities and IWOK, and continue to marginalize Indigenous youth through purporting a colonial ontology. Looking to non-formalized learning spaces, Bang, Marin and other colleagues show how we might understand a decolonial approach to learning that values MTH entities as part of knowledge creation (Bang, 2012, 2020). For example, Bang & Marin (2015), Pugh, McGinty & Bang (2019), and Marin (2019) explain how walking, reading and storying the land as methodology provides a space for intergenerational interactions and relationship building with the MTH that liberates youth towards engaging in decolonial scientific practices. This approach to analyzing 'learning on the move' (Bang, 2020) is rooted in Interaction Analysis methods that focus on "assemblages of micro-practices" (Marin, 2018, p. 96) and 'ambulatory sequences' as the unit of analysis to desettle our focus from shifting speakers, towards "configurations of movement" (p. 96) that prioritize human-MTH relations.

Authors' positionality

To "live with both feet on shore" (Kimmerer, 2013, p. 210), for each author, requires that we not only deeply engage with and learn from Indigenous scholars such as Gregory Cajete, Megan Bang and Ananda Marin amongst others, but that we also recognize and are accountable to the many relations that brought us to this shore. While all three authors identify as non-Indigenous, each one of us brings relations with ancestors connected with and through different lands and communities of MTH beings. Doing the work of honoring the knowledge in the land does not begin and end with decolonizing our approach to research but is *one* way for us to continue to learn how to live with responsibility in relation with the human and MTH worlds.

I (Rishi) am a settler on Turtle Island, living on the traditional territory of the Mississaugas of the Credit, the Anishnabeg, the Chippewa, the Haudenosaunee and the Wendat peoples. Part of the South Asian diaspora, I am connected with South Indian and queer ancestry. In my (biological) family spaces, understandings of learning were rooted in pre-colonial (South Indian) relational ontologies, and I was formally educated through Krishnamurti and Steiner schools that prioritized learning in and with the MTH. However, my parents were also deeply embedded in and committed to reproducing Brahmin supremacy (i.e., why they prioritized private, 'alternative' schools). Thereafter, much of my formalized learning engaged with colonial disciplined science. It was through my relationships with the marshy wetlands and the queer, trans, Black, Indigenous and people of colour communities in Tkaronto that I began to desettle my own commitment to colonial ways of knowing.

I (Colin) am a settler on the lands of the Lenape. I carry with my Elliott name paternal ancestors who were early perpetrators and beneficiaries of settler colonial violence, some having reached the shores of the US as early as the 18th century. My Hennessy name tells a familiar European immigrant story, with little known about how my ancestors two generations before me fled a famine-ravished Ireland to the United States. My relationship to knowing comes from my family, raised by queer moms who continually challenged me to see privilege and showed me what struggling for collective change can look like and my father who knows the value of a good story. As a physics teacher I was confronted by how the colonial science – which I was so steeped in from my own formal schooling – is an ontological source of injustice and violence. I continue to learn from scholars, and youth, who challenge me to do to work to recognize my own colonized perspectives and imagine differently.

Beneficiaries of the Hart-Celler Act of 1965, my (Jasmine's) parents immigrated from Taiwan to the US, both seeking advanced graduate degrees in technical fields. I was subsequently educated almost exclusively in White-dominated private school settings, with the understanding that this kind of (settler) education was the key to liberation from poverty. My graduate preparation was steeped in the traditional learning sciences discourses of cognitive science and ethnomethodology, but also oriented me to being open to interdisciplinary (and therefore epistemological) surprise and wonder, and to operate in the service of positive change for the collective.

Interaction analysis in the learning sciences

Given our commitment in the learning sciences to study and design for learning in situ (Hoadley, 2018), interaction analysis has been taken up by many in the field – including the authors and discussants of this symposium – as a useful tool that situates cognition in social life and privileges participants' perspectives and meaning making in the course of dynamically unfolding activity (Jordan & Henderson, 1995). This has proven invaluable for understanding the breadth of human practice and what can and should count as knowledge and learning, beyond narrowly defined notions of, for example, "mathematics" (Hall & Stevens, 2016). Additionally, it has proven powerful for bridging between structural and individual explanations for human behavior and cognition (Erickson, 2004), providing analysts with tools to look across social and developmental scales. However, while even early uses of the method in the learning sciences incorporated ethnographic analysis (Jordan & Henderson, 1995), interaction analysis has roots in ethnomethodology and conversation analysis, where a deep commitment to analysis held accountable to data of naturally occurring talk and interaction as primary. Therefore, inferences not grounded in empirical evidence in audio or video records are not permissible. To an extent, this has constrained scholarship that uses this method from engaging with broader sociohistorical and sociopolitical issues relevant to learning. In other words, while interaction analysis has been used to illuminate and describe foundational phenomena in the learning sciences--professional vision (Goodwin, 1994) and disciplined perception (Stevens & Hall, 1998), what counts as a context (McDermott, Gospodinoff & Aron, 1978), and talk moves like initiation-response-evaluation sequences (Mehan, 1978) and revoicing (O'Connor & Michaels, 1993) – it is rare that it is deployed to grapple explicitly with issues of power or broader cultural contexts that are not explicitly referenced, or "demonstrably relevant" in the data (Garfinkel, 1967). This is not to say it cannot be done. Gutiérrez, Rymes, and Larson (1995) demonstrated how attending to the joint accomplishment of social order and sense making in dynamically unfolding activity allows researchers to bring together the role of human action and interaction with how social structures may operate – but be variably taken up, resisted, or remixed. Their analysis revealed how official and unofficial scripts may come into contact in classroom spaces, producing the possibility of a third space where transformation and disruption of sedimented power structures may occur. This kind of work is rare but inspiring for the future of interaction analysis.

As the field of learning sciences continues to develop, scholars are taking up interaction analysis in increasingly expansive, yet still rigorous ways. These expansive methodological developments are not just in line with the increasing ease of recording and capturing data that cheaper and smaller digital technological tools have brought, but in fact challenge fundamental assumptions about what learning is and how to analyze learning activity from video data. For example, recent scholarship on "learning on the move" (Marin, 2020; Bang, 2020) has introduced theoretical arguments and methodological tools for looking beyond sedentary, classroom-like settings for where and how learning happens. Vossoughi and colleagues (2020), as another example, relied on interaction analysis to trace in-the-moment phenomena and longer scale trajectories of participation as a way to make the history of unfolding relationships part of what is available in the data.

Introducing the data for analysis

In the tradition of Koschmann's (2011) edited volume - the outcome of a group of learning scientists gathering to analyze the same set of video data with different theoretical lenses - we seek to interrogate our methodological (and therefore theoretical) commitments, and the consequences they entail. Our data were generated as part of a four-year ethnographic study of a youth robotics team, Turing Robotics, that relied on video recording methods and microethnographic analysis (Erickson, 2004). The vast majority of the data were recorded in the teams' basement shop at Turing High School (THS), where members of the team spent, on average, over 15 hours a week each competitive season (January through April) working with machines and materials to design a robot, build the robot, program the robot, operate the robot, strategize for competitions, and organize as a team. Almost all the youth who participate on the team are students at THS and identify as Black and/or Latinx in some way. The large machines that populate their workspace, particularly one evident in the selected episode, are vestiges of the past when the basement space was once part of a vocational school in the 1980s, and not the engineering focused high school that THS was at the time of the study.

I (Colin) partnered with the team to explore how youth learned as they participated. Over the multiple seasons, I began to take on more of a mentor role, in addition to being a researcher. I chose what to record as team action unfolded in an emergent way (Goldman-Segall, 2002); I selected particular important moments to explore further because they stood out in reviewing the corpus (Erickson, 2004; Jordan & Henderson, 1995); and I transcribed the data in multiple ways recognizing it as an act of theory itself (Ochs, 1979). Each of these actions shaped the data as it is presented in the selected episode. The particular clip we selected for this symposium shares two different angles on unfolding action as multiple youth engage with a large machine that bores holes and cuts metal parts as designed. We see this symposium as a space to not only recognize the settler logic that encompasses the larger research project, but to learn how an IWOK framework might decolonize analysis of such video-data based research. Working backwards from data generated we aim to collectively explore how we might desettle the methods (and in turn methodological assumptions) towards reimagining our understandings of learning.

Mill relationships

The focal episode was generated in the fourth year of the research project as youth worked with a central machine in their shop called a CNC three-axis mill press, or just "the mill". In this particular instance, the machine and youth collaborated on lining up and boring a hole in a metal part that would later be used to bolt it onto the robot and act as a part of the robot's "arm" (see Figure 1). The unfolding action of these 90 seconds were selected because they depicted the ongoing relationships between the mill and youth as they worked towards making the robot. The actions depicted are ripe for a traditional interaction analysis because it shares various embodied motions, speech, and human-machine interactions. Finally, the episode also shares some of the typical practices that youth engage in as they learn to participate in particular team tasks including; observing a more expert perform, and step in to engage with some parts of the task. Table 1 describes the actors that emerge in the episode.

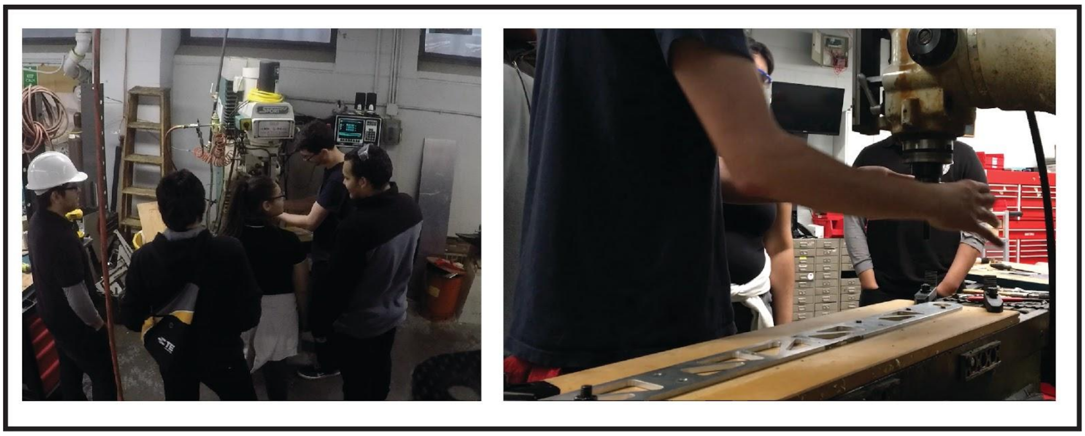

Figure 1. Two different perspectives of the actors in focal episode as they change the end bit on the mill

Table 1: Actor descriptions

Actors	Description and Notes
CNC three-axis Mill Press	Originally installed when the school was a vocational school as part of a classroom of large machines in the 1980s. Uses floppy disks for data transfer. Now the only one of its kind in the teams' shop. Called "the mill."
Metal robot part	This flat aluminum piece on the mill's table was possibly part of a previous robot (indicated by the various triangles that have been cut out of it "to save weight" without compromising structural integrity). This part will eventually become a stable part of the robot's arm that is attached to the base of the robot and to the other, moving, part of the arm.
Leia	A first-year newcomer to the team who identifies as a young woman of Cuban descent. She is particularly interested in working on the machines and learning to design robot parts. This episode is early on in her relationship with the mill, which she later becomes one of the experts at the mill, working with Santiago in future seasons.
Jav	The 4th year captain of the team who identifies as a young man of Portuguese and Brazilian descent. He began his relationship working with the mill three years before. He is now considered by the team the expert at using the mill. He recognizes that he is about to graduate and needs to help younger students learn how to operate with the mill so they can continue the tradition of cutting parts with it in future seasons. After graduating high school, he took on a job as a machinist at a local company.
Santiago	A first-year newcomer to the team who identifies as a young man of Dominican descent. He immediately began following Jav around when he started participating on the team, hoping to be his apprentice. His relationship with the mill is emerging through Jav's ongoing work at it. He later becomes an expert at the mill, working with Leia in future seasons.
Nick	A fourth-year member of the team who identifies as a young man. He consistently floats between various tasks on the team, often supporting new members in learning how to do various tasks. He has not developed a relationship with the mill much at all besides observing work, as he does in this episode. He later goes to the local college studying to be an engineer.

Jav, Leia, Santiago (and a few other onlookers) moved around and with the mill as the group prepared to bore a hole in the metal piece that sat on the table (see Figure 1 for two different angles generated at the same point in time). Over the course of the episode, depicted in Figure 2, Jav brought a new bit to the Mill, Leia stepped in to tighten it with a specialty wrench, Santiago came back to hold the mill's break so the end did not spin as Leia tightened, Leia tightened the chuck around the bit and stepped away, and Jav stepped in while flipping the switch to make the bit spin.

Jav: ((places bit into the end of the mill)) Ok, now
Sanitago: Now you -- now you do it one handed.
Jav: ((spinning chuck around bit to hold in place)) can't reach
Nick: Technically you did it with two hands.
Santiago: ((chases Nick away; laughs))

Jav: Tighten that back up
Leia: ((grabs the wrench and leans in to the chuck))
Leia: ((spins the chuch with the wrench))
Jav: If you're moving the chuck it's not gonna do nothin. One of yous gotta hit the break.

Leia: ((points towards the break))
Santiago: ((grabs the break lever))
Nick: Push it forward (12s)
Santiago: Ut uhh fat boy strennngth.
Leia: ((pushes then stops, removes wrench, and steps back))
Santiago: That was pathetic. ((Leia places wrench and keeps pushing again)) You have no um type of strength whatsoever.

Jav: Lean into it. You gotta put your body in it.
Leia: ((wrench starts to move))
Santiago: THERE we GO:::
Jav: The only way I can do it. (1s) That's good enough. Alright let me try it ((flips switch on mill; it spins))
Leia: You heard what I said. ((pokes Santiago's stomach with wrench)) you lose some fat.

Santiago: Yeah I did. THE MORE BLOOD I LOOSE THE MORE WEIGHT I LOSE.
Leia: That's not how it works.
Santiago: I know.
Leia: ((looks to onlooking student as she places down the wrench on the mill)) Not good enough.

Figure 2. The mill actors' episode (90s); underlined represents the frame pictured

Organization of the data session

We propose collectively analyzing the data shared above in two different ways to surface the tensions between interaction analysis rooted in a colonial ontology, and analysis emergent through a relational ontology rooted in IWOK. The symposium will begin with the authors and discussants situating the symposium aims within the responsibilities of settlers/colonizers in learning from IWOK. The remainder of the symposium time will be split into three sections. The first and second for interaction analysis, then relational ontology microanalysis of the data, and the third for summarizing discussions around disrupting our settled, human centered ways of seeing. We conclude by sharing our protocol and guiding questions for the two rounds of data analysis. In both versions of the data analysis, we will follow a protocol adapted from that described by Jordan and Henderson (1995):

1) Watch the whole 90s clip without stopping.
2) Watch the whole 90s clip with the 'stop protocol'. This protocol encourages audience members to ask the authors to stop the video anytime someone asks, so that we may collectively discuss what they see/notice.
3) Audience members will be invited to share what they would like to trace/notice in the next viewing, to ensure we encourage different perspectives on what to follow.
4) Watch the 90s clip again with stop protocol. We will encourage audience members to include or add to the traces shared before.

5) Round of reflection and wondering, where we will ask audience members to comment on:
   (a) What can you say is happening here?
   (b) What do you wonder about?
   (c) What role might other data (ethnographic, or different video data) help with?

Additionally, we will use the following norms and assumptions (many borrowed from comments by Ananda Marin and Shirin Vossoughi at a workshop at Northwestern University in 2019 convened by Marcelo Worsley):

- We treat the data as a gift, and remember the real people who are sharing with us
- Participants are sensible, capable, and act with intelligence and ingenuity
- Conditions for interaction are always being shaped, and interaction forms its own context
- We are looking at the details of moment-to-moment coordination of joint action
- We ground our noticings in what is available in the data

We propose performing the data viewing sessions with the guidance provided in Table 2, each contending with the protocol from above (1-5) and the norms and assumptions shared above.

Table 2: Two different Data Viewing guidelines

First Data Viewing	Second Data Viewing
Collective analysis of the video clip through traditional interaction analysis methods that center human participants in the unfolding interaction will use these guiding questions:	The authors and the audience, learning from and with the discussants, will engage in group analysis of the same video data, recognizing relations as the unit of analysis guided by the following questions:
● To what are human actors orienting across the material landscape? ● What sense are human actors making of their worlds? ● What resources support joint activity? ● How do previous actions provide contexts for subsequent action?	● What kinds of human-MTH relations emerge in the data? ● How does the metal piece contribute to the ongoing unfolding interaction? ● How does the mill-human relation form part of a local ecosystem? ● Where does the mill end and the human actor begin?

Endnotes

(1) The two first authors contributed equally to this work.
(2) In the telling of this story, Kimmerer explains that Indigenous recognize circular (and not linear) time. Therefore the time of Nanabozho is both a past and a telling of the future that is to come.

References

Afonso Nhalevilo, E. Z. (2013). Rethinking the history of inclusion of IKS in school curricula: Endeavoring to legitimate the subject. *International Journal of Science and Mathematics Education*, *11*, 23–42.

Bang, M. (2016). Towards an ethic of decolonial trans-ontologies in sociocultural theories of learning and development. *Power and privilege in the learning sciences: Critical and sociocultural theories of learning*, 115-138.

Bang, M. (2020). Learning on the Move Toward Just, Sustainable, and Culturally Thriving Futures. *Cognition and Instruction*, *38*(3), 434-444.

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*(4), 530-544.

Bang, M., Marin, A., & Medin, D. (2018). If Indigenous peoples stand with the sciences, will scientists stand with us?. *Daedalus*, *147*, 148-159.

Bang, M., Warren, B., Rosebery, A., Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*, 302-318.

Cajete, G. (1994). *Look to the mountain: An ecology of indigenous education*. Kivaki Press, 585 E. 31st St., Durango, CO 81301.

Cajete, G. (2000). *Native science: Natural laws of interdependence*. Clear Light Publishers.

Cammarota, J., & Fine, M. (2008). Youth participatory action research. *Revolutionizing education: Youth participatory action research in motion*, 1-12.

Erickson, F. (2004). *Talk and social theory*. Cambridge: Polity Press.

Charles, G. (1994). Professional vision. *American Anthropologist*, *96*(3), 606-633.

Garfinkel, H. (1967). Studies in Ethnomethodology. Englewood Cliffs, N.J.: Prentice-Hall.

Goldman-Segall, R. (1998). Points of viewing children’s thinking: A digital ethnographer’s journey. L. Erlbaum.

Gutierrez, K., Rymes, B., & Larson, J. (1995). Script, counterscript, and underlife in the classroom: James Brown versus Brown v. Board of Education. *Harvard educational review*, *65*(3), 445-472.

Hall, R., & Stevens, R. (2016). Interaction Analysis Approaches to Knowledge in Use. In diSessa, AA, Levin, M., & Brown, NJS (Eds.), Knowledge and interaction: A synthetic agenda for the learning sciences.

Hewson, M. G. (2015b). Teaching Science in Southern Africa. In *Embracing Indigenous Knowledge in Science and Medical Teaching* (pp. 37–50). Springer Netherlands.

Hoadley, C. (2018). A short history of the learning sciences. In *International handbook of the learning sciences* (pp. 11-23). Taylor and Francis.

Ignacimuthu, S., Ayyanar, M., & Sivaraman K, S. (2006). Ethnobotanical investigations among tribes in Madurai District of Tamil Nadu (India). *Journal of Ethnobiology and Ethnomedicine*, *2*, 25.

Jones, A., & Jenkins, K. (2008). Rethinking collaboration: Working the indigene-colonizer hyphen. *Handbook of critical and indigenous methodologies*, 471-486.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The journal of the learning sciences*, *4*(1), 39-103.

Kimmerer, R. W. (2013). *Braiding sweetgrass: Indigenous wisdom, scientific knowledge and the teachings of plants*. Milkweed Editions.

Koschmann, T. (Ed.) (2011). *Theories of learning and studies of instructional practice*. Springer.

Marin, A. (2019). Seeing together: The ecological knowledge of indigenous families in Chicago Urban forest walks. *Everyday learning: Leveraging non-dominant youth language and culture in schools*, 41-58.

Marin, A. (2020). Ambulatory Sequences: Ecologies of Learning by Attending and Observing on the Move. *Cognition and Instruction*, 1-37.

Marin, A., & Bang, M. (2018). “Look it, this is how you know:” Family forest walks as a context for knowledge-building about the natural world. *Cognition and Instruction*, *36*(2), 89-118.

McDermott, R. P., Gospodinoff, K., & Aron, J. (1978). Criteria for an ethnographically adequate description of concerted activities and their contexts. *Semiotica*, *24*(3-4), 245-276.

Medin, D. L., Ross, N. O., Atran, S., Cox, D., Coley, J., Proffitt, J. B., & Blok, S. (2006). Folkbiology of freshwater fish. *Cognition*, *99*(3), 237-273.

Mehan, H. (1978). Structuring school structure. *Harvard educational review*, *48*(1), 32-64.

O’Connor, M. C., & Michaels, S. (1996). Shifting participant frameworks: Orchestrating thinking practices in group discussion. *Discourse, learning, and schooling*, *63*, 103.

Philip, T., Bang, M., Jackson, K. (2018). Articulating the "how," the "for what," the "for whom," and the "with whom" in concert: A call to broaden the benchmarks of our scholarship. *Cognition and Instruction*, *36*, 83 - 88.

Pugh, P., McGinty, M., & Bang, M. (2019). Relational epistemologies in land-based learning environments: reasoning about ecological systems and spatial indexing in motion. *Cultural Studies of Science Education*, *14*(2), 425-448.

Tuck, E., & Guishard, M. (2013). Uncollapsing ethics: Racialized sciencism, settler coloniality, and an ethical framework of decolonial participatory action research. *Challenging status quo retrenchment: New directions in critical qualitative research*, *3*, 27.

Smith, L. T. (1999). *Decolonizing methodologies: Research and Indigenous peoples*. Zed Books.

Stevens, R., & Hall, R. (1998). Disciplined perception: Learning to see in technoscience. *Talking mathematics in school: Studies of teaching and learning*, 107-149.

Vossoughi, S., Jackson, A., Chen, S., Roldan, W., & Escudé, M. (2020). Embodied pathways and ethical trails: Studying learning in and through relational histories. *Journal of the Learning Sciences*, *29*(2), 183-223.

Wilujeng, I., & Prasetyo, Z. K. (2018). Elaborating indigenous knowledge in the science curriculum. *Journal of Teacher Education for Sustainability*, *20*(2), 74-88.

Worsley, M. (PI). (2019). Catalyzing Research in Multimodal Learning Analytics. Northwestern University, Evanston, IL.

International Society of the Learning Sciences

Towards Bringing Human-Centered Design to K-12 and Post-Secondary Education

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Abstract: Human-Centered Design (HCD) is a growing field that has the potential to positively impact students' learning. A general consensus on the terms, practices, scaffolds, and assessments of HCD can foster its effective implementation in K-12 and post-secondary education. This session brings together researchers whose work is focused on implementing HCD across K-16 classrooms. It aims to develop a coherent definition of HCD, its methods, practices, and assessments, to help frame the field and reduce ambiguity at a critical time in its broader adoption.

Introduction

Engaging students in problem solving experiences during project or problem-based learning has long been shown as a particularly effective means for students to learn both content and thinking strategies (e.g. Hmelo-Silver, 2004). While effective, many of the problems that students are tasked with in these curricula do not have a direct connection to their lives and experiences outside of the classroom. This disconnect between the content and their lived lives has been shown to cause students, particularly those underrepresented in STEM, to self-deselect from many career pathways, because they cannot envision how what they learn will have an impact on them and those they care about (Valla & Williams, 2012). In response, Human-Centered Design (HCD) is an approach that focuses problem-solving on the real needs of real people (Brown, 2008). In many ways, HCD has been shown to help students develop human-centered, experimental, collaborative, metacognitive, communicative, and creative mindsets (Goldman et al., 2012; Razzouk & Shute, 2012). With these mindsets, students become better prepared to effectively engage in future learning endeavors and actively participate in today's globally competitive world.

While, there has been increasing research into how we can best engage students in HCD in K-16 classrooms (Caroll et al., 2010; Zoltowski, Oaks, & Cardella, 2012), we still lack a general consensus on the terms, practices, scaffolds, and assessments that are needed for us to effectively implement and scale HCD integration. This lack of consensus makes it difficult for researchers, teachers, and policy makers to understand the best practices for implementing HCD in their classrooms, to assess the efficacy of an implementation, or to dive deeply into an implementation for iterative refinement. Given the increased interest in HCD as an approach across the educational spectrum, there is a need to develop a more unified consensus around the terms, practices, scaffolds, and assessments, or we risk a fragmented landscape.

Objectives
The symposium features researchers whose work on implementing HCD across K-16 classrooms focus on: 1) defining the design thinking processes and practices that are associated with HCD; and 2) providing exemplar approaches to integrate and support the teaching and learning of HCD. Lawrence and her colleagues introduce an HCD taxonomy that defines the HCD processes and practices and can inform the design and implementation of HCD curricula. Shehab and his colleagues present a case of integrating HCD in an undergraduate food science capstone course that positively impacted students' knowledge of implementing the HCD processes and using the HCD skills. Dhvani and her colleagues propose an instructional model that integrates the practice of (human-computer interaction) HCI education that takes an HCD approach in K-12 education by outlining the roles and responsibilities of learners and facilitators, prioritizing learner's agency in the process of learning. Lewis and his colleagues present a design and researcher assessment approach for coupled iteration in design that can help students learn to better create designs to meet human needs. Spencer and his colleagues present a researcher assessment approach that assists students in identifying risks in the domains in which they will practice HCD to reduce uncertainty and improve their designs. Royalty and his colleagues propose a reflective tool that can be used to assess and capture how students develop HCD practices. Finally, Goldman and her colleagues show how HCD can also be used by teachers to conduct their own educational design projects to better understand and support their students. Together, these contributions aim to provide a single venue to synthesize the current terms, practices, methods, and assessment of HCD. The symposium aims to develop a coherent and robust understanding of HCD, and its uses in curriculum and instruction, to help frame the field and reduce ambiguity at a critical time in its broader adoption. The symposium also offers methods and assessments that researchers can use to understand the efficacy of their HCD instructional designs.

Session format
The symposium will start with each researcher giving a six-minute talk to introduce the participants and attendees to their work across the symposium's two themes. Next, the discussant will facilitate conversations between researchers on critical issues emerging out of our shared approaches to HCD such as: What are the challenges of integrating HCD in non-design focused curricula, and how can we address them? How do we effectively scale implementation of HCD in K-16 classrooms? How as researchers, do we know if our designs are having the impact we want? Finally, the symposium will close with an open discussion with attendees to identify areas of further research and collaborations that can help us better bring HCD to K-16 education.

Implications
We believe that this session will provide a foundation in a new and growing field. It will solidify the meaning of HCD in order to avoid ambiguity. It will also facilitate the work of researchers and practitioners around the design and implementation of HCD instruction and activities in K-16 classrooms.

Implementation of a Human-Centered Design taxonomy with a novice, multidisciplinary design team
LuEttaMae Lawrence, Saadeddine Shehab, and Mike Tissenbaum

HCD is a problem-solving approach that identifies the unmet need of a population in order to collaboratively and iteratively develop solutions (Brown, 2008). Researchers have studied important components situated in this approach, including iteration (Lewis et al., 2018), sketching (Härkki et al., 2018), and design failure (Yan & Borge, 2020), leaving unexamined how students navigate the overarching approach. While there are well known models that theorize the processes of HCD (Brown, 2008), they do not provide pedagogical guidance that articulates what this learning looks like and how to support it. Therefore, we have developed an HCD Taxonomy that outlines five design spaces (understand, synthesize, ideate, prototype, and implement) (See Figure 1) and practices that describe how students operationalize specific spaces. This taxonomy was designed iteratively with designers, researchers, and teachers from multiple disciplines to develop a flexible tool that can be used across contexts. The goal of this taxonomy is for teachers and designers to develop curricula, learning objectives, and assessments based on what space they are teaching and the practices they want their students to implement. In this case study, we present findings on how the taxonomy emerged during a novice team's HCD approach. Toward this end, we aim to understand how this novice team used HCD practices during their design project.

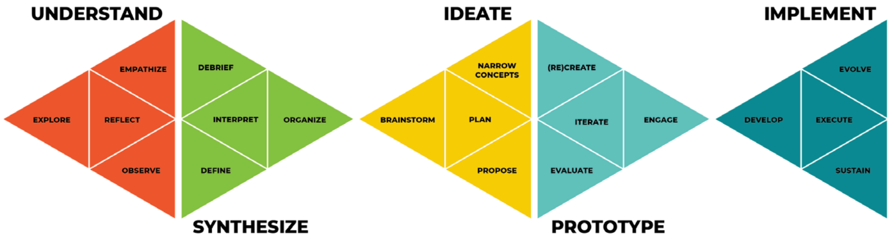

Figure 1. The HCD Taxonomy

We report on a five-week design project from an Introduction to Design Thinking course that teaches students from non-design disciplines about HCD. Three members comprised the design team, a first-year graduate student in education, a senior in civil engineering, and a first-year graduate student in architecture. The instructor assigned a project to select a subculture of which they did not belong and develop three frameworks to address a problem for this subculture. We collected instructional materials, audio recordings of the team's meetings, video recordings of their in-class presentations, and a reflection and post-survey from each team member. We leveraged knowledge integration theory (Linn, Clark, & Slotta, 2002) to analyze the design process and understand how HCD practices can be interconnected to achieve higher levels of integration and can be built over time.

Using our taxonomy and knowledge integration theory (Linn, Eylon, & Davis, 2013), we sought to understand how HCD practices were used by a novice design team and to what extent they made connections across spaces and practices. While this team iteratively used the taxonomy spaces, our findings highlight the challenges of teaching HCD to beginners and the differences among students. Within this group, only one student was able to achieve high levels of integration more than a single instance. We also found that while the group went through the motions of HCD, their process and final results did not always align to the overarching goals. Our paper highlights the complexity and challenges of teaching with the HCD taxonomy, and we share learning considerations to scaffold this process for beginners so that they may achieve higher levels of integration.

Integrating Human-Centered Design in a food science capstone course: A case study

Saadeddine Shehab, LuEttaMae Lawrence, and Mike Tissenbaum

The integration of HCD in post-secondary education can help undergraduate students come up with innovative solutions to authentic and complex problems that are relevant to their field of study (Withell & Haigh, 2013). Lately, there has been some work around the implementation of HCD in undergraduate classrooms (Puente, van Eijck, & Jochems, 2013); nevertheless, much of this work has been mainly reported from a theoretical or design-focused lens, rather than empirical evaluation, especially in STEM disciplines. This case study describes the integration of HCD into a food science capstone course through a) defining HCD and food science learning goals, b) providing scaffolding tools that support students' engagement and learning of HCD, c) creating opportunities for formative assessment and revisions, and d) promoting students' participation and collaboration (Barron et al., 1998). The study explores the students' experiences in this course to provide evidence-informed insights of instructional models that effectively integrate HCD in post-secondary STEM courses.

This study is part of a broader design-based implementation research initiative led by the Siebel Center for Design at the University of Illinois at Urbana-Champaign, which collaborates with faculty members to integrate HCD in their courses. The study took place in an undergraduate food science capstone course in which students solve authentic food science problems while developing novel food products. In Fall 2019, the 42 students who took this course worked in small groups to develop a food product using HCD. Each week, students attended two 50-minute lectures and one 4-hour lab section. The lectures were focused on introducing the students to the different processes and practices of HCD and the principles of food product development. The laboratory sessions were focused on engaging the groups in activities to implement HCD and using the principles of food product development in refining and prototyping their concepts and thinking about the actual implementation of their design in the food science industry.

Pre- and post-surveys were collected from the students to measure the impact of the course on their knowledge of implementing the HCD processes and using the HCD skills, and to assess if the students accomplished the food science learning goals. Classroom observations were collected during the lectures and the laboratory sessions. The video and audio recordings of the students' presentations of their final concepts and their final products were collected from the six consented groups. Interaction analysis of the presentations indicated that integrating HCD in the course helped the groups to systematically approach the development of their food products through empathizing with the users, synthesizing design opportunities, and applying principles of food product development in ideation and prototyping. A paired sample t-test was conducted using students' responses to the pre- and post-survey items and results indicated significant differences suggesting a positive impact of the course on students' knowledge of implementing the HCD processes and using the HCD skills, and that students accomplished the food science learning goals. These findings support the use of an instructional model that can help teachers teach about and through HCD in STEM post-secondary classrooms, including scaffolding and assessment tools.

Embedded design: An approach to support learning of Human-Centered Design practices

Dhvani Toprani, Mona AlQahtani, Yu Xia, and Marcela Borge

Creating learning environments for human-computer interaction (HCI) education for children requires taking a broader perspective towards learning that goes beyond focusing on teaching domain knowledge to include higher-order metacognitive, socio-emotional, and socio-metacognitive skills. However, formal education's emphasis on domain knowledge deprioritizes engaging learners in learning about and practicing these higher-order skills, making it challenging to integrate HCI education into K-12 (Collins & Halverson, 2018; Duschl & Bismark, 2016). Within an increasingly connected world, HCI designers require to not only know but also practice sophisticated thinking processes (Carroll, 2013). Building upon previous work on instructional support for children to iterate and solve ill-structured, real-world design problems (Collins et al., 1991, 1989; Jonassen 2000), and integrating HCD approaches we propose an instructional model, i.e., embedded design framework, for designing learning environments that foster higher-order skills to integrate HCI education into K-12 (Borge et al., 2020). The goal of embedded design is to create human-centered learning environments that focus on teaching through practice where learners have the agency to craft their learning experiences.

This framework is developed from an ongoing research project with eight to twelve years old children in an afterschool club, where children engage with playful design challenges within an HCI context. Children worked in groups of three, using different technologies like Lego, Minecraft, and Makey-Makey. Each session was structured to give children forty-five minutes to do hands-on designing with their group members, and the instructors used ten to fifteen minutes at the beginning and end of the session for whole-class discussion to introduce the design challenge and reflect on groups' design and collaborative processes.

As an instructional tool, embedded design framework proposes six core principles for facilitators and learners (See Table 1). These principles emerge from case studies drawn from one year of the afterschool club data. It embraces learners' agency by allowing their experiences and needs to be the main driving force of community rules, future discussions, and activities. As needed, facilitators observe learners and create perspective shifting opportunities to help learners discern complex concepts. They provide learners with activities where they can take over different roles within an HCI design context as both users and designers. Facilitators take over the role of orchestrators as they engage learners in reflective discussions where they help them recognize their needs as well as the needs of others in their community. As a community and across time, facilitators work as connectors of experiences as they help learners make sense of previous events in relation to current and future ones. In doing so, community experiences become objects to reflect on, making abstract concepts accessible and attainable by learners.

Table 1: Principles of Embedded Design and the Roles and Responsibilities of Learners and Facilitators.

Principles	Roles and responsibilities
Learners as Agents, Actively Participating in Domain Thinking Processes	
Learners as primary learning agents	Learners spend the majority of the time in control of their own learning experiences. They work on self-directed projects with peers, making collective decisions about what they will design and how they will spend club time.
Learners as central participants	Learners are taking an active role in different aspects of design, even during expert modeling, by playing an important complementary role that the expert must interact with, i.e., user for the designer, builder for the planner, etc.
Learners as anchors of the sense-making & solution process	Learners' perspectives/feelings during the process of design anchor collective sense-making during reflection. These concrete experiences are used as objects of thought to understand problems and devise solutions.

Principles	Roles and responsibilities
Facilitators as Learning Designers, Orchestrating Co-Construction of Knowledge	
Facilitators as creators of perspective shifting events	Facilitators create opportunities for learners to experience a design event from different perspectives, i.e., the learner takes on the role of designer receiving feedback from potential users and then takes on the role of a potential user providing feedback to the designer.
Facilitators as orchestrators of ongoing reflection	Facilitators lead reflective activities where the facilitator prompts learners to share their thoughts, feelings, and concrete experiences; learners' contributions are used as a means to connect the situated practice to expert practice, help learners identify important expert practices and existing problems in their own practices, and to understand why these problems occur. Facilitators also help learners to understand and develop shared goals and concrete plans for improving existing practices.
Facilitators as connectors of experiences	Facilitators observe learner activity, taking notes on important topics to discuss and analyze during community reflections. Individual and team experiences are shared with the community to develop shared understanding of important processes, dispositions, and values embodied by different experiences. These shared experiences can then be used as shared references to make sense of future events.

Embedded design contributes to the practice of HCI education that takes an HCD approach by outlining the roles and responsibilities of learners and facilitators, prioritizing learner's agency in the process of learning. By prioritizing agency, the higher-order skills required for HCI education are learned around the authentic experiences of the learner, giving them the opportunity to practice these abstract skills rather than learning it as technical knowledge. The six principles outlined within embedded design are developed with the aim of helping educators redesign their learning environments of HCI education by giving agency to children and broadening our perspective of learning.

Planning to Iterate: Designing to support and assess iteration in design

Daniel Rees Lewis, Spencer Carlson, and Matthew Easterday

To meet the needs of the stakeholders they are designing for, HCD students must learn how to iterate effectively. Iteration is a vital practice because real-world design problems are highly ill-structured, with "ambiguous specifications of goals, no determined solution path, and the need to integrate multiple knowledge domains" (Jonassen 2000, p. 80). To create solutions that support stakeholder needs, expert designers conduct *coupled iterations* in which they simultaneously (a) learn more about the nature of the problem, including stakeholder needs, (b) learn more about the extent to which their design is effective in addressing the problem, and (c) change the design in accordance with what is learned (Adams, Turns, & Atman, 2003). In short, we argue that if we are not supporting students to continually apply what they have learned about their problem, stakeholders and current design to their future design, we are not teaching them the core skill in HCD.

We present Planning-to-Iterate (Rees Lewis et al., 2018), a design and researcher assessment approach for coupled iteration in design. Planning to Iterate supports iteration by (a) facilitating discussions and prompting teams to conduct a planning process of representing the problem, prioritizing unknowns, and making iteration plans; (b) using two templates, the design canvas and iteration plan; (c) providing and prompting use of guiding questions that drive students to consider common pitfalls, and examples.

We created the assessment in Planning to Iterate for researchers to understand the extent teams are conducting coupled iteration—that is, to what extent are teams gathering information on problems and solutions to inform revisions to their design. Assessment involves videoing and analyzing weekly student Planning to Iterate sessions. We analyze weekly student planning through applying three codes in video analysis: (a) *problem learning* which to capture team reports of learning about aspects of the problem, (b) *solution learning* which captures reports of learning about the design, and (c) *solution revision* to capture reports of plans to change the solution based on reported learning. We code for teams conducting coupled iterations when problem learning (code a) and solution learning (code b), informed solution revisions (code c).

Our goal with Planning to Iterate has been to create scaffolds and assessments for supporting coupled iteration. Initial work in Planning to Iterate shows that compared to a far more intensive face-to-face coaching, student design teams supported by Planning to Iterate conducted more coupled iterations and created more effective designs (Rees Lewis et al., 2018). In doing so, we can help students learn to better create designs to meet human needs.

The Design Risks Framework: *Risks* as a key learning goal in Human-Centered Design

Spencer Carlson, Daniel Rees Lewis, and Matthew Easterday

Iteration is the strategic management of the design process to refine one's understanding of the problem and advance a solution (Adams et al., 2003). As such, iteration is a defining characteristic of effective design processes (Adams et al., 2003; Crismond & Adams, 2012). Design practitioners recognize that effective iteration requires designers to identify *risks*—gaps in their knowledge of the problem stakeholders, and the current design that could lead them to design something that does not support stakeholders' needs—so that they can plan iterations in which they learn more about those unknowns and update their design solution if necessary (Bland & Osterwalder, 2019). While this skill is of general importance across design domains, the underlying knowledge varies by domain. For example, toy designers must learn to identify the risk that their toy might be a choking hazard while social media designers must learn to identify the risk that their platform might radicalize users.

We must teach students to identify risks in the domains in which they will practice HCD. This requires assessment methods to measure students' ability to identify risks in a given design domain. We present the Design Risks Framework (Carlson et al., 2018), a researcher assessment approach for identifying risks in HCD. In this approach, students construct an external representation of their knowledge about the problem, stakeholders, and their current design. Then, students attempt to identify risks by reflecting on the gaps in their knowledge that could lead them to design the wrong thing. Next, a researcher with design expertise (or a design instructor) reviews the students' problem representation to identify risks. Last, the researcher compares the risks they (or the instructor) identified, with those the students identified. This allows researchers to measure students' ability to identify risks in their projects relative to that of an expert. Over time, this method also enables researchers to develop a list of the key risks that students must learn to identify in a given design domain—thereby defining in detail a critical learning goal for HCD learning environments in that domain. This list could be used to create rubrics or checklists that instructors might use for formative assessment of students' ability to identify risks.

Our goal with the Design Risks Framework has been to assess students' ability to identify risks in specific design domains. In initial work assessing novice designers completing service design projects, researchers used the Design Risks Framework approach to assess a large number of domain-specific risks that students struggled to recognize in their projects (Carlson et al., 2018). By focusing on risks as a key learning goal in HCD, we can help students learn to plan iterations to reduce uncertainty and improve their designs.

Reflective Design Practice: A novel tool that captures how students develop Human-Centered Design practices

Adam Royalty, Helen Chen, and Sheppard Sheri

Learning HCD in a university setting can be "messy." Students often work in project teams on ambiguous problems (Goldman et al., 2012). In short order each project unfolds in a unique way, making understanding student growth difficult. This work utilized a tool for capturing students' design work. Furthermore, we analyzed this design work and found three ways in which students internalize the methods and mindsets of HCD.

The results come from a study of 33 students from five schools within a large U.S. research university who took a 10-week introduction to HCD course. The data were gathered using a novel digital reflection tool called Reflective Design Practice (RDP) which allows students to capture authentic work and reflect upon it longitudinally (Royalty, Chen, & Sheppard 2018). RDP prompted participants to photograph an artifact they created in their HCD course each week. The artifact could be tangible (e.g. a physical prototype) or it could be intangible (e.g. an interview protocol). For each artifact, participants were given questions to help them reflect on their creation. Participants uploaded the artifact and the associated reflections to an online folder—forming a multi-page portfolio of design work. After seven weeks, researchers conducted a semi-structured interview with each participant based on their weekly reflections. We used a grounded theory approach to analyze the weekly reflections and the interviews. The aim was to distill how students linked their own perceived growth to the academic environment in which they learned design.

The data suggest three general categories for student sense making. Supports for Learning Design are specific details of the academic environment students identified as supporting how they learn design and transfer that situated learning (Greeno Moore & Smith 1993). Self-Differentiation of Design are aspects of the academic environment that shape students' perspective of what design is and what design is not. Many of these realizations come from contrasting design work with work performed in other courses. Student Responses are the cognitive and emotional responses to design instruction that shape how students develop their own design practice.

Although Student Responses are internal, they develop through working repeatedly within the academic environment. Each general category has between five and eleven sub-categories. These initial findings can help researchers and practitioners better understand how students construct their own HCD practice. It may be the case that students learn HCD in ways that instructors do not perceive or account for.

Empathy development in design thinking for improving access and equity for students designated as English learners

Shelley Goldman, Annie Camey Kuo, Kimiko Lange, Melissa Mesinas and Rose K. Pozos

Design thinking during HCD begins with understanding a problem holistically and from the eyes of the people for whom one is designing and iterates with cycles of prototyping and feedback (Goldman & Kabayadondo, 2016). We report on a three-year, four school district research practice partnership (RPP) (Coburn, Penuel, & Giel, 2013) to use design thinking with K-8 teachers and administrators to design solutions for supporting students designated as English learners (DELs). As of 2018, DELs comprise approximately 19.3% of public school students in California (McFarland et al., 2019). DELs are present in nearly every district, yet not all schools serving DELs have specialized teachers or resource programs. The districts in our study lacked specialized supports for DELs and had low numbers of DELs (10% or less), a situation not yet addressed by research or policy.

Our RPP employed design thinking in conjunction with hybrid professional development workshops (Rutherford-Quach, Kuo, & Hsieh, 2018) to help teachers and administrators build capacity for understanding and supporting DELs. The goal was to raise collective awareness of, and attention to, systematic educational inequities surrounding DELs such as social isolation and lack of specialized language learning services, and to support teachers and administrators in designing change to many aspects of their DELs' experiences.

Empathy development was a key component of the training and the design thinking approach. The educators generated 18-24 solutions for students each year. We relied on empathy exercises with teachers throughout the design thinking process. HCD work stretched throughout the design process and was especially evident during prototyping, feedback, and iteration cycles. Resulting designs ranged from new classroom languaging strategies, to relationship building, to reorganizing specialized staff, to focused professional development. The designs were responsive to individual students and small groups, whole classes, and district and structural systems.

Data were gathered using an ethnographic approach, with documentation of the participants' design processes, with a goal of capturing small changes in practice and mindsets over time. We administered pre- and post-year surveys, collected field notes, written artifacts from participants, video and audio recordings of meetings, and focus group reflections. The role of empathy and the attention to students' needs in the designs turned out to be a key factor in effective design projects. We present an analysis of survey results and resulting educator design project analyses to show how the empathy orientations impacted educators' work on behalf of students. We identify connections between the empathy work educators completed and their perceptions of their DEL students' abilities (e.g. exhibiting asset-based rather than deficit-based views) and achievements (being situated in the system rather than in the children). Findings show robust changes in classroom instructional practices, a few examples of systems change, and uneven awareness of and attention to inequitable social and educational access for DELs. Empathy was essential to the progress that was made.

References

Adams, R. S., Turns, J., & Atman, C. J. (2003). Educating effective engineering designers: The role of reflective practice. *Design Studies*, *24*(3), 275–294. https://doi.org/10.1016/S0142-694X(02)00056-X

Bland, D. J., & Osterwalder, A. (2019). *Testing business ideas*. Hoboken, New Jersey: John Wiley & Sons, Inc.

Borge, M., Toprani, D., Yan, S., & Xia, Y. (2020). Embedded design: engaging students as active participants in the learning of human-centered design practices. *Computer Science Education*, *30*(1), 47-71.

Carlson, S. E., Maliakal, L. V., Rees Lewis, D. G., Gorson, J. S., Gerber, E. M., & Easterday, M. W. (2018). Defining and assessing risk analysis. *Rethinking Learning in the Digital Age: Making the Learning Sciences Count*, *1*, 352–359. London, UK: International Society of the Learning Sciences.

Carroll, J. M. (2013). Human computer interaction-brief intro. The Interaction Design Foundation.

Carroll, M., Goldman, S., Britos, L., Koh, J., Royalty, A., & Hornstein, M. (2010). Destination, imagination and the fires within: Design thinking in a middle school classroom. *International Journal of Art & Design Education*, *29*(1), 37–53.

Coburn, C. E., Penuel, W. R., & Geil, K. E. (2013). Practice Partnerships: A Strategy for Leveraging Research for Educational Improvement in School Districts. *William T. Grant Foundation*.

Collins, A., Brown, J. S., & Holum, A. (1991). Cognitive apprenticeship: Making thinking visible. *American Educator, 15*(3), 6–11.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive apprenticeship: Teaching the crafts of reading, writing, and mathematics. *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser, 18*, 32–42.

Collins, A., & Halverson, R. (2018). Rethinking education in the age of technology: The digital revolution and schooling in America. New York: Teachers College Press.

Crismond, D. P., & Adams, R. S. (2012). The informed design teaching and learning matrix. *Journal of Engineering Education*, *101*(4), 738–797. https://doi.org/10.1002/j.2168-9830.2012.tb01127.x

Duschl, R. A., & Bismack, A. S. (Eds.). (2016). *Reconceptualizing STEM education: The central role of practices*. Routledge.

Goldman, S., Carroll, M. P., Kabayadondo, Z., Cavagnaro, L. B., Royalty, A. W., Roth, B., et al. (2012). Assessing d.learning: Capturing the journey of becoming a design thinker. In H. Plattner, C. Meinel, & L. Leifer (Eds.), *Design thinking research: Measuring performance in context* (pp. 13–33). Berlin: Springer

Goldman, S., & Kabayadondo, Z. (2016). Taking design thinking to school: How the technology of design can transform teachers, learners, and classrooms. In *Taking Design Thinking to School* (pp. 21–37). Routledge.

Härkki, T., Seitamaa-Hakkarainen, P., & Hakkarainen, K. (2018). Hands on design: comparing the use of sketching and gesturing in collaborative designing. *Journal of Design Research*, *16*(1), 24-46.

Hmelo-Silver, C. E. (2004). Problem-based learning: What and how do students learn?. *Educational Psychology Review*, *16*(3), 235-266.

Jonassen, D. H. (2000). Toward a design theory of problem solving. *Educational Technology Research and Development*, *48*(4), 63–85.

Lewis, D. G. R., Gorson, J., Maliakal, L. V., Carlson, S. E., Gerber, E. M., Riesbeck, C. K., & Easterday, M. W. (2018). Planning to Iterate: Supporting iterative practices for real-world ill-structured problem-solving. *Rethinking Learning in the Digital Age. Making the Learning Sciences Count*, *2018*, 9.

Linn, M. C., Davis, E. A., & Eylon, B. S. (2013). The scaffolded knowledge integration framework for instruction. *Internet Environments for Science Education*, 47.

McFarland, J., Hussar, B., Zhang, J., Wang, X., Wang, K., Hein, S., Diliberti, M., Forrest Cataldi, E., Bullock Mann, F., & Barmer, A. (2019). The Condition of Education 2019. NCES 2019–144. *National Center for Education Statistics*.

Puente, S. M. G., van Eijck, M., & Jochems, W. (2013). A sampled literature review of design-based learning approaches: A search for key characteristics. *International Journal of Technology and Design Education*, *23*(3), 717–732.

Razzouk, R., & Shute, V. (2012). What is design thinking and why is it important? *Review of Educational Research*, *82*(3), 330–348.

Rees Lewis, D.G., Gorson, J., Maliakal, L.V., Carlson, S.E., Riesbeck, C.K., Gerber, E.M., & Easterday, M.W. (2018). Planning to Iterate: Supporting iterative practices for real-world ill-structured problem-solving. In *Proceedings of the international conference of the learning sciences (ICLS)*. London, UK: ICLS.

Royalty, A., Chen, H., & Sheppard, S. (2018, October). Reflective design practice: A novel assessment of the impact of design-based courses on students. *In 2018 IEEE Frontiers in Education Conference (FIE)* (pp. 1–4). IEEE.

Rutherford-Quach, S., Kuo, A. C., & Hsieh, H. (2018). Understanding their Language: Online professional development for teachers of ELLs. *American Educator*, *42*(3), 27.

Valla, J. M., & Williams, W. (2012). Increasing achievement and higher-education representation of under-represented groups in science, technology, engineering, and mathematics fields: A review of current K-12 intervention programs. *Journal of women and minorities in science and engineering*, *18*(1).

Withell, A. & Haigh, N. (2013). Developing design thinking expertise in higher education. CUMULUS 2013. 2nd International Conference for Design Education Researchers Oslo, 14–17 May 2013. Retrieved from https://openrepository.aut.ac.nz/ handle/10292/6326

Yan, S., & Borge, M. (2020). Learning from design failure, collaboratively. *International Society of the Learning Sciences.*

Zoltowski, C. B., Oakes, W. C., & Cardella, M. E. (2012). Students' ways of experiencing human-centered design. *Journal of Engineering Education*, *101*(1), 28–59.

Posters

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Creation of an Inventory Assessing Epistemic Beliefs about the Co-Construction of Knowledge in Team Science Contexts

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Abstract: Scientific collaboration is necessary as research grows increasingly more complex. Research focusing on the Science of Team Science (SciTS) seeks to better understand and facilitate collaborative research in science. The current work provided new empirical understandings on epistemic beliefs about group knowledge or how a group collectively comes to know something by developing the Epistemic Beliefs about the Co-Construction of Knowledge (EB-CCK) inventory. Using exploratory and confirmatory factor analyses, the present study established an 18-item inventory composed of two factors: one capturing a more collaborative mindset and one capturing a more individual mindset about the co-construction of knowledge. Limitations and future directions are discussed.

Introduction

Science is inherently a collaborative affair. During every stage of the research process, scientific research involves working together with others, both within and across respective fields of study (Jonassen, et al., 2006). As issues in empirical research grow more complex and sophisticated, so does the need for collaborative teams of researchers that are fundamental to the future of scientific understandings, and in ensuring the use of rigorous, yet diverse methodologies (Falk-Kresinski, et al., 2010). Although interdisciplinary scientific collaboration appears to undergird many important research findings over the past several decades, scientists do not always employ the best practices for collaborate one another, which can undermine success. To compound these potentially problematic issues, scientists are mostly trained extensively within their respective disciplines, and not on the most effective and efficient ways to collaborate with scientists in other disciplines (Jonassen et al., 2006). Thus, there is a need for educators to promote interdisciplinary collaborative problem-solving skills in the classroom, due to the assumed benefits of training students to work in a collaborative manner with colleagues in other disciplines (Graesser, et al., 2018).

Current research

To measure Epistemic Beliefs about the Co-Construction of Knowledge (EB-CCK). we 1) developed initial scale items and used exploratory factor analyses on two samples to investigate factor structure; 2) confirmed our anticipated factor structure using two additional samples; and 3) examined the validity of the EB-CCK. Across two studies with 1373 participants, an 18-item inventory composed of two factors, one reflecting that team science should be more collaborative and a second that it should be more individualistic, were identified.

Discussion

The current study sought to create a measure that assesses an individual's epistemic beliefs about the co-construction of new knowledge in team science contexts via exploratory and confirmatory factor analytic techniques. Given no studies to date have attempted to create a measure regarding epistemic beliefs about the co-construction of new knowledge in team science contexts, the present work hopes to inform current policies that seek to train students and scientists on the best practices for group collaboration in scientific research.

Personal epistemology or personal epistemic beliefs have been studied and found to guide how individuals interact with knowledge and information (Hofer, 2000; Kardash & Scholes, 1996; Pieschl et al., 2008; Strømsø et al., 2008). While extant epistemic beliefs inventories focus on the individual's acquisition of new knowledge and ways of knowing, we hope the EB-CCK can provide a nuanced understanding of how an individual's beliefs about the co-construction of knowledge can influence their behaviors related to group collaboration. When an individual answers questions about their own personal ideas related to knowledge and knowing, responses do not necessarily reflect their views about knowledge and knowing in a group setting. For example, an individual may believe that knowledge is ever-changing and can be increased with learning and effort. However, this same individual may not feel that knowledge or coming to know something in a group setting is productive, perhaps instead endorsing that an individual can achieve more knowledge than a group. This element of epistemic beliefs may be more predictive of collaborative efforts in scientific research, thus supporting the utility of questionnaires like the EB-CCK.

Factor 1: Collaboration

Obviously, when looking at how groups collaborate, their beliefs about and approaches towards collaboratively creating knowledge is imperative. The first of the two factors identified in the current work consisted of items that reflect a more collaborative view on the construction of knowledge in groups. Examples of items that reflect the collaborative factor include: *"When scientists find conflicting results, the differences can help to further refine theories"*, and *"The production of knowledge in a scientific domain requires the help of multiple scientists"*. These items all reflect an individual who may work in a more collaborative manner with others to provide better empirical understandings of scientific findings.

An individual who scores highly on the collaboration factor of the EB-CCK may be better suited for working efficiently and effectively in collaborative group science contexts. For example, these individuals may value new methods of research that reflect a combination of techniques from multiple disciplines, thus creating approaches that may function above and beyond the sum of the parts. Additionally, researchers are often faced with conflicts or contradictory findings in science, and an individual who is open to exploring these areas of conflicting information may come to better understand the topic as a whole. Personal beliefs that scientific research is best conducted under the umbrella of collaboration are not only beneficial for the individual's understanding of how a group comes to know something but also for the entire scientific community as we move towards more transdisciplinary approaches to conducting research. As Fiore et al. (2018) explain, some areas of research require collaboration as core research questions become more and more complex. In order to progress towards more sophisticated research practices, teams of individuals with more collaborative mindsets could produce more innovative, successful outcomes. Stokols et al (2006) suggest that strong leaders, especially those with a "collaborative orientation" could not only facilitate group research efforts but may also demonstrate management skills within the group when necessary. Perhaps the EB-CCK can help to identify individuals that endorse collaborative orientations and, by doing so, aid in the construction of groups of scientists who not only collaborate but collaborate *well* together.

Factor 2: Individual

Although individualist mindsets may be beneficial in some learning situations, they may undermine efficient and effective group collaboration. The second of the two factors identified in the current work is composed of items that reflect a more individualistic view on the construction of knowledge in a group setting. Example items include: "*Science works best if each scientist sticks to the methods he/she knows"*, and *"The production of knowledge in a scientific domain is best done by a solitary researcher working independently of others"*. These items reflect that an individual may find group collaboration to be ineffective or unnecessary when constructing knowledge or coming to know something, not valuing the potential synergy that could arise from more collaborative approaches.

An individual who scores highly on the individual factor of the EB-CK may struggle to accept or help create new knowledge in team science collaborative settings. For example, if someone in the team believes that scientific research is best conducted by an individual using the techniques in which they are familiar, their contributions in a collaborative setting may be ineffective or absent altogether. Graesser et al. (2018) explain that collaborative research may be threatened by an individual group member that is disengaged and/or unskilled when collaborating with others. Identifying those individuals who could potentially undermine successful collaborative research could help streamline scientific collaboration altogether, while also serving as a point of belief remediation for graduate student mentors, employers, and the like.

The emerging field of SciTS has assisted in the progression of our scientific understandings of collaborative research by acting as a catalyst for collaborative research itself. It is the hope of the current research that a measure of Epistemic Beliefs about the Co-Construction of Knowledge will provide additional insight into the promotion of collaborative research across and within various fields of research.

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Investigating Perseverance Improvement in Secondary Mathematics Students

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Abstract: I examined the perseverance in problem-solving of 30 secondary students as they engaged with challenging mathematical tasks over six weeks. Their perseverance improved, primarily due to consistent opportunities to record their conceptual thinking at the outset of their engagement. These artifacts of their thinking often helped prolong their productive efforts upon impasse and improved their selection of problem-solving strategies and affect regulation.

Supporting and improving perseverance in problem-solving

Perseverance with challenging ideas is an essential process for learning with understanding. In the context of problem-solving, perseverance is initiating and sustaining in-the-moment productive struggle in the face of mathematical obstacles, setbacks, or discouragements (DiNapoli & Miller, 2020). Supporting in-the-moment student perseverance has been made explicit as a way of improving mathematics education, with the expectation that such support will nurture students' perseverance to improve over time. This demand has widened the assumptions about what can constitute mathematical learning. The process of perseverance, long viewed as solely an affective or supporting component to mathematical learning, can now be simultaneously viewed as an outcome measure capable of development and improvement, alongside more standard summative achievement.

Many research studies have sought to detail classroom activity that supports student perseverance with challenging mathematics, yet little is known about how such practices can help improve student perseverance in specific ways over time. In general, research shows that providing consistent opportunities for students to engage with unfamiliar yet complex tasks encouraged more variability in problem-solving strategies and greater learning gains, compared to providing consistent opportunities to engage with more routine mathematics (e.g., Warshauer, 2015). Students need support and feedback, however, to help facilitate metacognition and creative problem-solving during times of frustration (e.g., Bass & Ball, 2015). A recent study found that when secondary students created artifacts of their personal conceptualization of a mathematical task prior to problem-solving, they could better self-regulate their efforts at times of impasse and continue to persevere (DiNapoli & Miller, 2020). Without recording their conceptual thinking at the outset, these students felt frustrated after a setback and often gave up without making an additional attempt at solving.

Despite the recent research to uncover ways to support student perseverance at moments of struggle, questions remain about whether these practices help foster student perseverance to improve over time. Research on perseverance in problem-solving can produce insights into effective practices by which to learn mathematics with understanding, yet much of the empirical evidence of student perseverance have been situated in single points of time with little or no exploration of how those perseverance experiences may be related or demonstrate signs of specific improvement. Therefore, the purpose of this study was to address these lingering concerns about whether and how student perseverance, when supported properly, can improve over time.

Methodology

The participants of this study were 30 ninth-grade students from two algebra classes with the same teacher in a Mid-Atlantic state. These participants were purposely chosen to have demonstrated, via pretest, the prerequisite knowledge necessary to initially engage with each task included in the study.

To collect data, each participant was observed engaging with five low-floor/high-ceiling mathematical tasks, one per week. For each participant, three tasks were randomly chosen to be scaffolded (i.e., prompting participants to record an artifact of their conceptual thinking at the outset), and two tasks were randomly chosen to be non-scaffolded (i.e., no such prompt). Each participant worked on these set of five tasks in a random order. I conducted problem-solving interviews, video reflection-interviews, and an exit interview with each participant.

To analyze data, I used the Three-Phase Perseverance Framework (3PP) (DiNapoli & Miller, 2020) to capture if the task at hand warranted perseverance for a participant (the Entrance Phase), the ways in which a participant initiated and sustained productive struggle (the Initial Attempt Phase), and the ways in which a participants re-initiated and re-sustained productive struggle, if they reached an impasse as a result of their initial attempt (the Additional Attempt Phase). All coding decisions (or whether or not certain engagement constituted evidence of perseverance) depended on student cues from all interviews. I also calculated 3PP scores based on demonstrated perseverance per task; 3PP scores ranged from 0 to 12, depicting minimal to optimal demonstrated perseverance in this context, respectively.

Results and conclusions

Overall, participants' perseverance across mathematical tasks improved over time, more so on their scaffolded tasks than on their non-scaffolded tasks. Participants' demonstrated perseverance on their three scaffolded tasks improved in quality over time as evidenced by increasing mean 3PP scores (see Figure 1). Participants' demonstrated perseverance on their two non-scaffolded tasks also improved in quality over time (see Figure 1). However, the average rate at which participants' scores on their non-scaffolded tasks improved was over two times less than the rate of improvement of scores on their scaffolded tasks. All 30 participants affirmed in the Entrance Phase of the 3PP that they understood the objectives, but did not know how to solve each task. Also, all 30 participants reported a perceived impasse as a result of their engagement with each task.

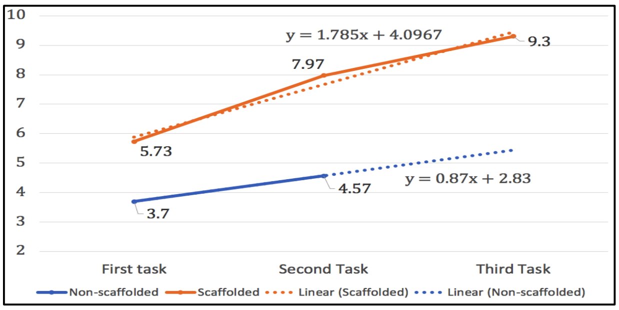

Figure 1. Mean perseverance scores over time and by scaffold condition.

There is also qualitative evidence to suggest that the task scaffolds were helping participants improve their perseverance over time. Considering all interview data, participants reported personal improvements they noticed, over time, about their engagement with the tasks in the study. Most participants (83%) mentioned they thought they were getting better as they had more practice with these types of problems. Several participants (63%) mentioned their improved work on tasks specifically prompting them to conceptualize the situation prior to starting (i.e., their scaffolded tasks). Arguably the most noticeable improvement, from the participants' point of view, was affective in nature. Many participants (73%) explained in their exit interview that they felt like they were getting better at handling the stress of the situation as they reached impasses within their work on mathematical tasks they did not know how to solve. Some participants (40%) reported cognitive gains: the ways they were thinking about the mathematics and their problem-solving abilities were improving.

These results suggest that developing students' perseverance for solving challenging mathematics tasks may be possible through the process of deliberate practice, a systematic effort to improve performance in a specific domain (Ericsson et al., 1993). Through this study's design, participants essentially deliberately practiced to improve their perseverance. They worked toward specific objectives of challenge, demonstrated appropriate prior knowledge, invested their full effort and attention to make progress on these tasks (relying heavily on self-control to not give up at moments of impasse and continue to persevere), were a self-source of feedback when recognizing a setback and modified their efforts accordingly, and had opportunities to repeat and practice working through these processes every week. With their scaffolded tasks, this repeated opportunity helped students refine their strategies over that time to learn to persevere in more effective ways. Although students also had a chance to repeat the processes of deliberate practice with their non-scaffolded tasks, the data showed that they did not refine their strategies in the same high-quality ways as they did with their scaffolded tasks. This lack of transfer should motivate future research to investigate conditions that may support students to incorporate these conceptualization practices into their normative problem-solving repertoire.

References

Bass, H. & Ball, D. L. (2015). Beyond "you can do it!": Developing mathematical perseverance in elementary school. In N. Alpert (Ed.), *The Collected Papers*. Chicago, IL: Spencer Foundation.

DiNapoli, J., & Miller, E. K. (2020). Recognizing and supporting perseverance in mathematical problem-solving via conceptual thinking scaffolds. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 1* (pp. 11-18). Nashville, Tennessee: International Society of the Learning Sciences.

Ericsson, K. A., Krampe, R. T., & Tesch-Romer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*(3), 363-406.

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms. *Journal of Mathematics Teacher Education*, *18*(4), 375-400.

Cognitive Load Measurement Using Two Kinesthetic-Based Methods: Rhythmic Tapping Method and Tactile Detection Response Task

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Abstract: Cognitive load theory has struggled to develop a modality-unspecific method of measurement, that being a secondary task which measures overall cognitive load rather than only auditory or visuospatial processing. The current study compares two kinesthetic-based methods, the rhythmic tapping method (RTM) and the tactile detection response task (TDRT) in relation to their modality specificity. The methods were examined in relation to the degree of modality specificity they had with auditory and visuospatial working memory processing, via separate n-backs in each modality. The findings indicated the RTM may be modality specific. The RTM was found to have greater interference with auditory working memory processing compared to visuospatial processing. There was evidence the TDRT may be modality-unspecific, as the method had parallel interference with auditory and visuospatial working memory processing.

Introduction and background

Cognitive load theory (CLT) is one of the most used frameworks in learning sciences (Park & Brünken, 2015; Sweller, 2018). A goal of the theory is to provide practical implications for instructional design to facilitate learning by promoting schema acquisition through efficient use of limited working memory resources (Baddeley, 2012). However, CLT has struggled in developing a method to measure cognitive load. John Sweller, who formulated CLT, states "Attempts to find a sufficiently sensitive measure are ongoing" (2018, p. 4), with sensitivity referring to the measures capacity to validly detect changes in overall cognitive load. A promising course is the use of secondary task, which have been used in psychology to study a variety of cognitive capacities, such as working memory (Baddeley, 2012) attention during driving (Stojmenova, Jakus, & Sodnik, 2017), and cognitive load in the field of educational psychology (Park & Brünken, 2015).

In educational psychology, the use of secondary tasks for cognitive load measurement has been less than optimal as most methods are modality specific. The term modality specific refers to a measurement method that can only provide a measure of cognitive load for processing in one modality, rather than total cognitive load (Baddeley, 2012; Park & Brünken, 2015). The current work will study two kinesthetic-based measurement methods to examine the modality specificity of each secondary task in relation to auditory and visuospatial working memory processing. The is aim to empirically examine if the two kinesthetic-based methods of measurement are modality unspecific. The two tasks are the rhythmic tapping method (RTM) is a recently developed secondary task that requires participants to respond by tapping their foot to a specific, internally-driven rhythm. The other task is the tactical detection response task (TDRT) is a secondary task, developed by the International Organization for Standardization (ISO) (ISO, 2016). However, the methods have yet to be systematically compared in relation their modality specificity. The goal of the present work is to examine the degree of modality specificity the RTM and TDRT have with auditory and visuospatial processing.

Methodology

Participants

Participants were recruited from undergraduate courses at a large research university in Western United States. The preliminary analysis consisted of 41 participants (M = 22.56, SD = 7.18).

Instruments

Modality specific working memory tasks

The working memory tasks were the auditory n-back and visuospatial n-back, each being a 2-back. Participants completed three blocks for each condition (approximately three minutes). The tasks were administered using the software PsychoPy3.

Secondary tasks

The TDRT used the ISO 17488 system and software. The vibrating buzzer was placed on the participants collarbone and responses were recorded via a foot tapping device. Performance was measured by accuracy and RT. The procedure from the RTM was the same method used in the study that developed the instrument (Park & Brünken, 2015). Performance on the RTM consists of an intra-individual analysis that computed the mean rhythm for the baseline condition that was compared to the mean rhythm in the n-back + RTM conditions. The tapping was recorded by the software, Audacity version 2.3.2.0.

Procedure

After participants voluntarily consented to the research, they filled out a demographic questionnaire followed by a practice of the auditory n-back and visuospatial n-back. The experimental trials consisted of each n-back (order-counter balanced by modality) accompanied with each secondary task or no secondary task (order counter-balanced). For instance, one participant could do the n-backs with no secondary task, then the n-backs with the TDRT, lastly, the n-backs with the RTM. For the n-back conditions with the secondary tasks, the participants received training and completed the baseline for each secondary task immediately prior to performing the concurrent n-backs. The study took approximately 45 minutes. Participants received 1 credit for course research hours for their participation.

Results and conclusion

There was a main effect of the RTM on n-back accuracy, $F(3, 119) = 8.01$, $p < .001$. The auditory n-back + RTM had a significantly lower accuracy compared to both the baseline auditory ($z = 4.39$, $p < .001$) and the baseline visuospatial n-back ($z = 3.80$, $p < .001$) accuracies.

There TDRT had a main effect on n-back accuracy, $F(3, 120) = 7.50$, $p < .001$. Visuospatial n-back + TDRT had a significantly lower accuracy compared to both the baseline visuospatial n-back ($z = 3.68$, $p < .001$) and the baseline auditory n-back ($z = -4.10$, $p < .001$) accuracies. Also, auditory n-back + TDRT had significantly lower accuracy compared to the auditory n-back baseline accuracy ($z = 2.70$, $p < .001$).

The RTM had a determinantal effect on auditory working memory processing, but not visuospatial processing, meaning the RTM may be modality specific for auditory processing. The findings could reflect the RTM requires more auditory processing in order to tap to the internally-driven rhythm. The TDRT had equal interference with both auditory and visuospatial processing, which suggests this method may be modality unspecific. The modality-unspecific nature of the TDRT may be due to the minimal attentional resources needed to monitor the TDRT stimulus. The findings are important for measurement of cognitive load as the TDRT may be a new, modality-unspecific method to measure the construct.

References

(ISO), I. O. for S. (2016). Road Vehicles: Transport information and control systems: Detection Response Task (DRT) for assessing selective attention in driving (ISO/DIS Standard No. 17488). Retrieved from https://www.iso.org/standard/59887%0D%0A.html%0D%0A

Baddeley, A. (2012). Working memory: Theories, models, and controversies. *Annual Review of Psychology*, *63*, 1–29. https://doi.org/10.4324/9781315111261

Park, B., & Brünken, R. (2015). The Rhythm Method: A New Method for Measuring Cognitive Load-An Experimental Dual-Task Study. *Applied Cognitive Psychology*, *29*(2), 232–243. https://doi.org/10.1002/acp.3100

Stojmenova, K., Jakus, G., & Sodnik, J. (2017). Sensitivity evaluation of the visual, tactile, and auditory detection response task method while driving. *Traffic Injury Prevention*, *18*(4), 431–436. https://doi.org/10.1080/15389588.2016.1214868

Strayer, D. L., Turrill, J., Cooper, J. M., Coleman, J. R., Medeiros-Ward, N., & Biondi, F. (2015). Assessing Cognitive Distraction in the Automobile. *Human Factors*, *57*(8), 1300–1324. https://doi.org/10.1177/0018720815575149

Sweller, J. (2018). The role of independent measures of load in cognitive load theory. In R. Zheng (Ed.), *Cognitive Load Measurement and Application: A Theoretical Framework for Meaningful Research and Practice* (pp. 3–8). New York: Routledge.

Identifying and Responding to Process Failures in Problem-solving

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Abstract: Learning from failure is a vital skill. One aspect of failure that has received little empirical attention, however, is its process-focused nature and how technology interventions might benefit from this understanding. I present a conceptual framework for (a) identifying process failures via thin-slice methodology, and (b) responding to process failures by building on the idea of regulative loop systems, but with additional emphasis on psychological mechanisms describing causes (and remedial pathways) of process failures.

Introduction

Failure in empirical research in educational psychology is typically defined in relation to a desired goal (e.g., scores on a posttest) and reflects an *outcome-focused* viewpoint of designing for learning. In tasks with high failure-likelihood, terminal failures are but naturally contingent on individual *problem-solving actions* en route to developing a solution. These actions can comprise, for instance, selecting and executing appropriate problem-solving operators that allow making tractable and meaningful progress through a problem, as well as monitoring and reflecting on intermediate outcomes to revise solutions. I conceptualize among such actions, those that might constrain the affordances available for task progress and block, disrupt or alter routes to immediate recovery (progress towards the canonical solution), as *process failures*.

Study context

I use as study context the learning design of problem-solving followed by instruction (PS-I), where students are given opportunities for the generation of multiple representations and solution methods before being formally exposed to the targeted concepts (Loibl, Roll, & Rummel, 2017). To illustrate the conceptual framework for identifying and responding to process failures in the current article, I will use video (face and screen) recordings of a convenience sample of $N = 4$ participants (60 minutes of problem-solving data). This convenience sample is randomly chosen from a controlled lab study reported in Sinha & Kapur (2021), where $N = 132$ university students (59% male, $n = 78$; 41% female, $n = 54$) participated in a PS-I intervention in the domain of introductory data science. The learning objective was to help students understand the complementary importance of numerical and graphical representations when reasoning with data.

Identifying process failures

Person perception research has demonstrated that thin-slices, or judgments of others based on *brief exposure* to their behaviors (Ambady, 2010) give an accurate assessment of several ecologically valid outcomes. I adopted such a *thin-slice* approach for coding process failures, defined as moments of struggle during the problem-solving process that cause a delay or a pause in learning (Warshauer, 2015). Two video streams, including the frontal view of the face (and upper body) and the screen recording of students' problem-solving actions in the learning environment, were juxtaposed to allow for rating of the level of struggle for each 60-second video segment (thin-slice). The first, middle and last five minutes of the problem-solving phase from the convenience sample was used as the coding stimulus (totaling 15 X 4, or 60 one-minute thin-slices). Two raters were used to allow computation of reliability metrics. The presentation order of these thin-slices was randomized within as well as across all five-minute segments. Raters chosen for the coding of process failures were well-versed with conceptual tasks associated with the problem-solving environment, and went through a brief training session in recognizing prototypical facial expressions of affect. The presented prompt asked raters to rely on gut instinct to make judgments – "how struggling does the participant appear to be?". Post-hoc (that is, after completing all ratings), raters were asked to summarize what led them to rate an episode with a certain intensity of struggle. The quality of results obtained during the iterative coding process were used to adjust the rating scale and time-window. After resolving disagreements and achieving high enough inter-rater reliability ($\kappa = 0.76$), the ratio of thin-slices where students were adjudged to be struggling ($n = 21$) versus where they were merely on-task (low levels of struggle, $n = 39$) was roughly in the ratio of 1:2. *High struggle problem-solving episodes* involved observable behaviors such as writing programming code that led to error messages followed by episodes of debugging, re-running same code several times, scrolling up and down the learning environment without necessarily focusing on a particular comparison and contrast, confused facial expression (brows furrowed, eyelids narrowed), confused smile, leaning back and/or shaking head, etc. *Low-struggle problem-solving episodes* mainly involved on-task behavior where students appeared to be engaged with a neutral facial expression and performed required operations like writing programming code, seeking syntax-specific help as needed, etc. To argue for the *meaningfulness* of the coded episodes of struggle, I also looked at empirical data (see Sinha & Kapur, 2021for details) for the $N = 4$ participants with thin-slice coding. These case studies can be found at https://www.tinyurl.com/SMSinhaISLS2021.

Responding to process failures

Having demonstrated a plausible coding approach for identifying process failures, it is imperative to work towards designing appropriate response strategies for educational technology interventions, in the service of facilitating positive effects and mitigating the negative effects of process failures (Figure 1). Here, I draw on ideas of *regulative loop systems* (VanLehn, 2016), in particular focusing on a particular genre of regulative tasks (that is, *coaching*) that uses the comparison between observed and desired student *behaviors* to generate remedial scaffolding. What is conceptually novel with respect to these previous strands of work is the explicit addition of a theoretically-grounded layer of *functions*, or psychological mechanisms underlying process failures, which are intended to serve as a basis for scaffolding via an educational technology (rather than basing scaffolding directly on the observed behavior). This addition presupposes that design-based researchers choose intervention strategies tightly coupled to the causes of particular kinds of process failures (drawing on theoretical research), and consequently monitor a specific corresponding set of observed behaviors to decide when to intervene. More generally, the plea is to embrace a more holistic view to understanding *why* specific instantiations of process failures arise and *what can be done* about them in interventional terms. Further details and example walk-throughs are present at https://www.tinyurl.com/SMSinhaISLS2021. Note that there exists a many-to-many mapping between different layers of the framework and although I focus on educational technologies, this framework is applicable for teachers too. The ideas presented in this brief article are part of a larger research effort to understand the scaffolding of failure-driven learning, and to use that understanding to implement a technology-supported learning environment that can (ideally) assist students in (a) reducing floundering before, during, and after process failures, (b) anticipating future process failures better, and finally (c) maximizing learning after process failures.

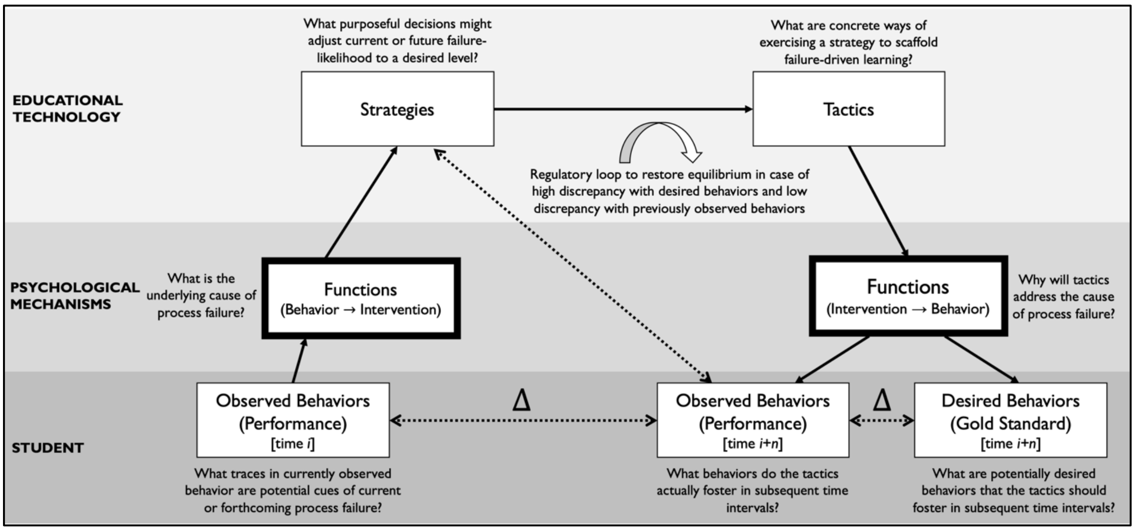

Figure 1. Proposed Conceptual Framework for Responding to Process Failures (Episodes of Struggle).

References

Ambady, N. (2010). The perils of pondering: Intuition and thin slice judgments. *Psychological Inquiry*, 21(4), 271-278.

Loibl, K., Roll, I., & Rummel, N. (2017). Towards a theory of when and how problem solving followed by instruction supports learning. *Educational Psychology Review*, *29*(4), 693–715.

Sinha, T., & Kapur, M. (2021). Robust Effects of the Efficacy of Explicit Failure-driven Scaffolding in Problem-Solving Prior to Instruction: A Replication and Extension. *Manuscript under Revision*

VanLehn, K. (2016). Regulative loops, step loops and task loops. *International Journal of Artificial Intelligence in Education*, 26(1), 107-112.

Warshauer, H. K. (2015). Productive struggle in middle school mathematics classrooms. *Journal of Mathematics Teacher Education*, 18(4), 375-400.

Kitchen Science at Home: Engaging Pre-School Children through Distance Education during Covid-19 Quarantine

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Abstract: This is a case study describing the ways I engaged a group of 20 5-6,5-year-old children in an afternoon, distance, science education unit investigating snails. The study took place during the Covid-19 quarantine time in Spring 2020. The paper demonstrates the transferability of pedagogical ideas usually implemented in the face-to-face classroom. It also illustrates pedagogical ideas that were more productive to use during the online unit. Lastly, it describes the development of an online learning community that included children and parents.

Keywords: distance education, pre-school science education, emergency response teaching

Introduction

In Spring of 2020, COVID-19 pandemic confronted educators worldwide with a series of unprecedented challenges (e.g., Whittle et al., 2020). Educators were "forced" to use distance education (DE) approaches as a response to wide-scale educational shutdowns. Despite their wide use, many educators were reluctant to use DE approaches with young children, due to the fact that this age group may not be accustomed of using DE tools fluently, productively and independently, since they usually need their parents' input to participate in technology-mediated learning from home.

Methods, data sources and analyses

This is a descriptive case study (Yin, 2017) presenting a 3-week DE science unit investigating snails with a group of 20 5-6,5 year-old children voluntarily participating at a STEM education, afternoon on-line club. In response to covid-19 quarantine in Spring 2020, this is a paper describing DE approaches in science education specifically addressing the challenge of meaningfully engage young learners using a mixture of synchronous and asynchronous learning in science.

In an effort to provide young children continued educational opportunities while schools in Cyprus suspended their operation in March 2020, I have developed and taught a program of DE in science for young children that included highly interactive, weekly activities for a series of topics under the theme of "Kitchen Science," following different teaching approaches (investigative-based learning, problem solving and modeling-based learning) Children met synchronously once a week for 60 minutes from April - June 2020, while asynchronous communication mediated through their parents continued throughout the week.

Using a simple, timeline-based Learning Management System (LMS), all communication, instructions, materials, children work submission were organized. These included materials that children used, preparation instructions for each meeting, links for the online meetings, instructions and links for submission of children work after a particular meeting. Synchronous meetings were carried out in the afternoon, during a time at which at least one parent was in position to facilitate the technicalities. During the meetings, children developed (new) habits of working through on-line tasks, including how to take turns for speaking, how to agree or disagree with others and how to ask permission to talk.

For this study, I focus on the investigation of snails (three 60-mintes lessons), their body parts, habits, behaviors and their role in the ecosystem, engaging children in a series of authentic activities. Part of the unit involved the engagement of children in Model-based Learning in science (Louca, 2020). Data consists of field notes prior to and after each synchronous meeting and children-generated work. Following methodological approaches of science classroom discourse (e.g., Gallas, 1995; van Zee et al., 2001; Edwards & Mercer, 1995), I used fieldnotes reflections as a gateway to children's thinking and experience. Data analysis includes the representation of phenomena studied (Louca et al, 2011) and the levels of student participation in the DE activities.

Findings and Discussion

A main challenge during DE during Covid-19 was to increase children learning engagement (e.g., Whittle et al, 2020) especially during the loss of teacher social face-to-face presence (which usually provides guidance), as well as the loss of children social presence (which facilitates formative assessment). Children in the study were actively engaged from home throughout the synchronous meetings as well as the asynchronous tasks.

A factor that contributed to the successful implementation of this unit was engaging children in the collaborative participation in the process of meaning-making (Donaldson, 2020) and knowledge construction.

This was evident by the creation of an on-line community of learners (Itow, 2020) that shared a common purpose for learning and had a mutual contribution to the process of learning. The parents' engagement was also important in this (Whittle et al, 2020), supporting their children with the use of the digital tools, sending their children work/models, and helping children submit their opinions and evaluations of each-other's models.

Despite working from distance, children throughout this unit followed a scientific stance in their work making predictions, collecting observations, confirming ideas, and collaboratively building new knowledge through the development of representations. Two areas of pedagogical ideas may have contributed to this. The first area is related to pedagogical ideas normally used in the face-to-face classroom settings, which were easy to transfer and apply in the DE activities. In order to keep all 20 children engaged during the 60 minutes of the synchronous online tasks, it was important that: (1) The unit included a variety of different tasks, seeking to meaningfully engage children with different learning styles and preferences. This also resulted in a shorter duration of the tasks and more frequent alteration between the activities. (2) The tasks had a highly playful nature. The investigation through an activity designed around a "snail-sprint" is an example of such as task, during which children followed an authentic investigation of snail dietary habits through a playful activity. (3) The tasks included high interaction between children, materials and the instructor. The design of the meetings, activities and task included a number of different interactions, with parents' participation much more active than classroom based face-to-face instruction. In many cases, parents were sitting next to their child participating in the task, or opposite of them (to avoid being present on camera – but their reflection on a window behind their child indicated their presence). This, along with the facilitation on behalf of the parents for the asynchronous tasks created a learning community (Donaldson, 2020; Flynn, 2020) that, in addition to children presence, included the parent presence and interaction with specific characteristics. (4) The tasks followed an authentic inquiry-oriented approach that included both hands-on & minds-on properties (NRC, 2000).

The second area is related to pedagogical ideas that were more productive to use during the DE activities (both synchronous and asynchronous) than in face-to-face activities. (1) Children-friendly digital tools made it easier and more meaningful for children to work, communicate, and build knowledge collaboratively from their homes. (2) Social distancing (quarantine) was used in favor of the learning process. Evaluating peer's work by voting was a necessary task due to the social distancing. When carried out in the regular classroom, this is usually time consuming, and children often vote for their friend's work and not necessarily applying scientific criteria. Social distancing helped to overcome this difficulty. (3) The synchronous and asynchronous communication used, facilitated the formative assessment processes (Whittle et al, 2020). Monitoring children progress through e.g., their work submission and their peer feedback (voting), was a dynamic process that enabled me to appropriately respond to children work, ideas, and reasoning in some cases in better ways than classroom-based teaching.

References

Louca, T. L., Zacharia, C. Z., & Constantinou, P. C. (2011). In Quest of Productive Modeling-Based Learning Discourse in Elementary School Science. Journal of Research in Science Teaching, 48(8), 919-951.

Louca, T.L. & Zacharia, C. Z. (2015). Learning through Modeling in K-6 Science Education: Re-Visiting the Modeling-Based Learning Cycle. Journal of Science Education and Technology, 24(2), 192-215.

Donaldson, J. P. (2020). Building a digitally enhanced community of practice. In Information and Learning Science. https://doi.org/10.1108/ILS-04-2020-0066.

Edwards, D. & Mercer, N. (1995). Common knowledge: The development of understanding in the classroom. NY: Routtedge.

Flynn, P. (2020). DESIGN-ED: a pedagogical toolkit to support K-12 teachers' emergency transition to remote online education. Information and Learning Science. https://doi.org/10.1108/ILS-04-2020-0103

Gallas, K. (1995). Talking their way into science: hearing children's questions and theories, responding with curricula. NY: Teachers College Press.

Itow, R. C. (2020). Fostering valuable learning experiences by transforming current teaching practices: practical pedagogical approaches from online practitioners. *Information and Learning Sciences*.

NRC [National Research Council]. (2000). Inquiry and the national science education standards: A guide for teaching and learning. Washington, DC: The National Academies Press.

van Zee, E., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. Journal of research in science teaching, 38 (2), 159-109.

Whittle, C., Tiwari, S., Yan, S., & Williams, J. (2020). Emergency remote teaching environment: a conceptual framework for responsive online teaching in crises. Information and Learning Science.

Yin, R. K. (2017). Case study research and applications: Design and methods. Sage publications.

Worked Examples: Do Learning and Perceived Helpfulness Align?

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Abstract: Worked examples are effective instructional support but limited research has examined the impacts of different worked example designs in online settings. We measured algebra students' learning gains and perceived helpfulness of worked example designs in an online problem set to identify how *extensive* and *dynamic* worked examples should be in online settings. Students were randomly assigned to view worked examples in: 1) *concise static*, 2) *extended static*, 3) *concise sequential*, 4) *extended sequential*, 5) *dynamic no history*, or 6) *dynamic history* formats. The findings provide recommendations to design worked examples for online settings.

Keywords: worked examples, algebra learning, online learning, perception

Introduction

Worked examples display a step-by-step solution for students to study how to solve a problem. Extensive research has demonstrated the worked example effect showing that studying worked examples is effective for learning beyond problem solving (Sweller, 2006). However, worked examples are typically presented as static images that could be displayed in textbooks. As we look ahead to the future of K-12 education and the increasingly central role of online tools, worked examples should be intentionally designed from theory to support learning in online settings. We reason that there are two primary competing theories: cognitive load theory and perceptual learning.

On the one hand, cognitive load theory posits that studying worked examples frees up students' working memory and cognitive resources for learning, reducing cognitive load (Sweller, 2006). From this perspective, the presentation of worked examples in multimedia should minimize extraneous complexity, avoiding features that would split students' attention, and drawing attention to the problem subgoals (Schwartz et al., 2016). On the other hand, perceptual learning researchers suggest that providing more details in materials to direct students' attention to relevant information can help adapt their perceptual experiences to support high-level cognition. Reasoning about mathematics is inherently perceptual, as ample evidence shows that algebraic learning is influenced by the visual presentation of notation (Goldstone et al., 2017). Therefore, studying worked examples which direct attention to each term, operation, and resulting transformation may increase learning through perceptual processes.

From these theories, we aim to identify how *extensive* (details in derivations) and *dynamic* (static images or looping videos) worked examples should be to optimally support students online. We ask: 1) *Which worked example design is most effective for student learning?*, 2) *Which worked example design do students perceive to be the most helpful?*, and 3) *Do students' learning gains align with their perceived helpfulness of worked example designs?*

Methods

A total of 25 teachers assigned the study to 530 middle-school students from North and Central America as an online problem set to complete individually in class or as homework. Of those students, 259 were assigned an experimental condition and finished the posttest to be included in data analysis. Within the problem set, students first completed an eight-item pretest on algebraic equation solving. Next, students were randomly assigned to a condition, where they completed six problem pairs that each consist of one worked example and one practice problem to solve. Students then completed a posttest mirroring the pretest. Finally, students rated the helpfulness of the worked example design they saw on a 6-point scale and explained their rating.

All of the problem set materials used in the intervention were identical across conditions. We adapted the equations and derivations used for the worked examples from Rittle-Johnson and Star (2007). We created each practice problem to intentionally mirror the structure of its paired worked example. We adapted open-source curricula algebra problems to create the pretest then substituted numbers of similar magnitude to create the posttest.

The study included six experimental conditions. First, the ***concise static*** condition mirrored a commonly used worked example design (Rittle-Johnson & Star, 2007). Students (n=50) viewed each worked example as a static image which displayed the major derivations of each problem. Students in the ***extended static*** condition (n=54) viewed worked examples as static images that showed every step in the derivations. Students in the ***concise sequential*** condition (n=38) viewed looping GIF videos that presented the *concise static* examples line-by-line in 2-3 second intervals to create a step-by-step history of the derivation. Students in the ***extended sequential*** condition (n=42) viewed *extended static* worked examples that were presented in the same way as concise sequential examples. Students in the ***dynamic history*** condition (n=35) viewed looping worked example videos that demonstrated the transformation process through a screen recording. For example, to transform $2(x-3)=8$ to $2x-6=8$, students watched as the 2 was dragged over the parentheses to create the next line, $2x-6=8$, recording the result of the action (Figure 1). Each step of the problem was shown on the following line and a history of the steps taken was displayed sequentially. Last, students in the ***dynamic no history*** condition (n=40) viewed identical transformations to those in the *dynamic history* condition but all occurred on one line of equation without a derivation history.

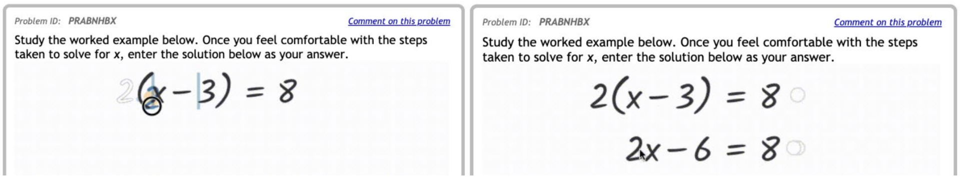

Figure 1. The *dynamic history* design for worked examples shows each transformation.

Results and conclusions

First, a 6(condition) × 2(time: pretest, posttest) repeated measures ANOVA revealed a main effect of time. Students improved from pre- (M= .43, SD=.34) to post-test (M=.48, SD=.37), $F(1,253)=10.02$, p=.002. There was no main effect of condition or an interaction effect. Second, a one-way ANOVA showed no significant differences between conditions on the *perceived helpfulness* of the worked example format (M=3.96, SD=1.43). Third, to detect whether students' learning gains align with how helpful they think the worked example designs are, we qualitatively compared students' learning gains and perceived helpfulness of the designs. The ANOVA findings suggest that, on average, students in all conditions experienced learning gains and perceived the worked examples to be somewhat helpful.

This research provides theoretical and practical contributions by showing that multiple worked example designs are effective for learning in online settings. Similarities across conditions may explain why there were no differences in learning gains; however, we conclude that the worked example effect is robust. Students' perceptions of the worked examples seem broadly aligned with learning outcomes. Moving forward, we will identify themes in free responses (e.g., the videos were too fast or too slow) to guide future research and modifications to the designs.

References

Goldstone, R. L., Marghetis, T., Weitnauer, E., Ottmar, E. R., & Landy, D. (2017). Adapting perception, action, and
technology for mathematical reasoning. *Current Directions in Psychological Science, 26*(5), 434-441.

Rittle-Johnson, B., & Star, J. R. (2007). Does comparing solution methods facilitate conceptual and procedural knowledge? An experimental study on learning to solve equations. *Journal of Educational Psychology, 99*(3), 561.

Schwartz, D. L., Tsang, J. M., & Blair, K. P. (2016). *The ABCs of how we learn: 26 scientifically proven approaches, how they work, and when to use them.* W W Norton & Co.

Sweller, J. (2006). The worked example effect and human cognition. *Learning and Instruction, 16*(2), 165–169.

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Design of Multi-Dimensional Science Labs for Future Teachers for Online Learning

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Abstract: Providing authentic and engaging science labs for pre-service elementary teachers is important because incomplete science knowledge affects their future teaching. We describe our design project that focused on providing quality physics and earth science labs for pre-elementary education majors within the constraints of online learning. Our design principals draw from the Next Generation Science Standards and the Modeling Instruction methodology (Hestenes, 1996). We present our design process, design principles, and initial findings.

Introduction

Empowering future educators with strong science knowledge is important, and requirements for physical distancing required us to adapt in an engaging and equitable manner. When elementary science teachers have incomplete science knowledge, they compensate in ways that limit student science learning including avoiding hands-on experiences and minimizing subject coverage (Akerson, 2005). As the Covid-19 pandemic forced classes online, we needed to provide engaging and authentic laboratory experiences for future teachers. Authentic lab and field experiences are possible in emergency remote learning (Pennisi, 2020), and university instructors triaged lab experiences during the initial shut down with many different approaches (Fox, Werth, Hoehn, Lewandowski, 2020). Additionally, it is important to design labs to be multi-dimensional, explicitly engaging students with both content and authentic science practices through phenomena, to enhance student learning and help future teachers understand how the Next Generation Science Standards (NGSS) conceptualize science (NGSS Lead States, 2013). Supporting future-teacher learning within the constraints of an online format while maintaining multi-dimensional, collaborative labs requires thoughtful adaptation of lab activities. We engaged in our design work both before and during the semester of our course.

Through our design process and implementation of collaborative labs for future teachers, we have developed design principles that can inform future work and research. We report on our efforts to re-design physics and earth science lab activities for a science content course for pre-elementary education majors including our design principles, our cyclical process for development, examples of resulting labs, and initial findings about strengths and constraints.

Design process

Our lab design process was purposefully iterative, while still fitting within the constraints of designing materials during the semester. Each lab was developed by a course instructor or teaching assistant (TA), using the design principles described below. Design began with the development of learning objectives and guiding questions based on the unit topic. Subsequently, activities, conclusion questions, and reflection prompts were developed for each lab. Once each lab was drafted, the undergraduate peer leaders, who previously took the course, tested the labs with the TAs in a digital environment (Zoom) and provided detailed feedback. Our team of instructors and TAs then reviewed each lab together. The author of each lab then revised it and created supplementary materials such as technology introduction videos and clarifying images. A pre-lab activity was also created to prepare students for the lab. Teaching assistants then implemented labs across three sections of about twenty students each. Afterwards, TAs provided feedback to help other lab sections run smoothly and to make notes for future revisions. Our design cycle benefited student learning through reviewed and revised labs, provided invaluable instructional design experience for our TAs and peer leaders, and created notes for future lab revisions.

Design principles

The goal of our design principles is to guide the creation of multi-dimensional labs that facilitate the students through the learning process of each lab while meaningfully connecting the content and practices to students' future classroom teaching.

Center student talk and engagement in science practices

This design principle is grounded in having students learn science by engaging in authentic, situated learning (Lave & Wenger, 1991). To do this, we included multiple NGSS science practices in each lab, for example asking questions, constructing explanations, and developing models. Inspired by Modeling Instruction (Hestenes, 1996), the participation structures of our labs included individual, small group, and whole group time. TAs presented a phenomenon and discussed how data could be collected, then students worked in small groups and reported out to the whole group to discuss their findings. A majority of the time was spent in small groups to foster student-student talk and place the intellectual work on the students.

Connect to real-world phenomena and students' future classrooms

Connection to the real world helps students contextualize and connect to the science content they are learning. We built our labs around observable phenomena and observations students were likely to have personally experienced. As the course was for future teachers, we wanted to help them think about the science material within the context of their future classrooms. Each lab included reflection prompts that asked students to write about how they saw the material relating to their own lives or being used with their future students.

Include hands-on activities when possible

One major constraint of moving labs from in the classroom to online is the restrictions on lab equipment. For each lab, we tried to incorporate some kind of physical observation or experimentation by providing a lab kit. The lab kits included thing such as: a rock identification kit for geology, a slinky for waves, a mini air puck for motion and forces, and earth and moon balls to create solar system models. The items were specifically selected to be useful in our students' future classrooms as well as in the labs. After the hands-on introductions, online tools were used to engage students in quantitative data analysis in activities that built off the hands-on activities.

Organize shared documents for clarity and to foster online participation

In order to set students up for success and keep them engaged in lab activities, we created a template structure for the lab documents and Google Slides for presentation and group work that we carried throughout the lab. We used icons to indicate participation expectations for each section of the lab and to prompt students to insert screenshots of their work. The Google Slides used for group work allowed the teaching assistants to monitor progress in the digital breakout rooms and help groups as needed. A single grading rubric was developed for all the labs and provided consistency in expectations. We also provided rotating lab roles for the members of each group.

Initial findings

Our preliminary findings are that the online environment exacerbated time constraints and made facilitation of whole group discussion between students more difficult. We found success in engagement within small group work and presenting to the whole group. On our poster, we present examples of student work from the labs and report in more detail about student actions, including how they were able to draw connections between labs and their future teaching. We share our experience, process, and design principles to contribute to the discussions around adapting labs to be online and engaging in real-time course development.

References

Akerson, V. L. (2005). How do Elementary Teachers Compensate for Incomplete Science Content Knowledge? *Research in Science Education*, *35*(2-3), 245–268. https://doi.org/10.1007/s11165-005-3176-8

Fox, M. F. J., Werth, A., Hoehn, J. R., & Lewandowski, H. J. (2020, July 2). *Teaching labs during a pandemic: Lessons from Spring 2020 and an outlook for the future.* Retrieved from https://arxiv.org/pdf/2007.01271

Hestenes, D. (1996). Modeling Methodology for Education for Physics Teachers. *International Conference on Undergraduate Physics Education*.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation.* Cambridge: Cambridge Univ. Pr.

NGSS Lead States (2013). *Next Generation Science Standards*. Washington, D.C.: National Academies Press.

Pennisi, E. (2020). During the pandemic, students do field and lab work without leaving home. *Science*. Advance online publication. https://doi.org/10.1126/science.abd8385

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Striving for Adaptivity - Enabling Complex Problem-Solving Processes in a Computer-Based Learning Environment

Striving for Adaptivity - Enabling Complex Problem-Solving Processes in a Computer-Based Learning Environment

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Abstract: In multi-phase learning designs with initial problem solving (PS-I) the fit of the subsequent instruction seems crucial for learning. Research shows that individual solution attempts need to be addressed when comparing incorrect and correct solutions in the subsequent instruction phase. A computer-based implementation of a PS-I learning environment offers the possibility of adaptively addressing each individual's solution type but also poses a double challenge: It requires an implementation that allows valid problem-solving processes *and* an accurate diagnosis of problem-solving results. We address these two challenges by investigating two learning environments with different extents of openness.

Keywords: problem solving, learning from errors, computer-based learning environment

Introduction and theoretical background

In multiphase learning scenarios with an initial problem-solving phase followed by an instructional phase (PS-I), those students show the greatest learning effects who compared in the instruction phase the correct solution to a typical student solution that corresponded to their own solution type from the problem-solving phase (Loibl & Leuders, 2019). These findings call for adaptively taking students' solution attempts into account. This adaptivity could be implemented with a computer-based learning environment. The computer-based learning environment should enable valid problem-solving processes. At the same time, the problem solving products must be diagnosable in a computer-based manner to enable automated adaptive instruction. These two challenges influence each other in opposite directions. In their assistance dilemma, Koedinger and Aleven (2007) describe the challenge of balancing giving and withholding information during the learning process (Figure 1). In assessment, there is a validity-reliability dilemma (Figure 2), that is, a discrepancy between the complexity of the assessed knowledge and the diagnosticity (Seifried et al., 2020). In our study, we combine both dilemmas as a trade-off between complexity and accuracy (Figure 3), which needs to be addressed when a learning scenario with an initial problem-solving phase followed by an adaptive instruction phase is to be implemented computer-based.

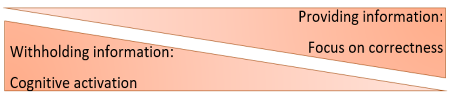

Figure 1. Assistance dilemma

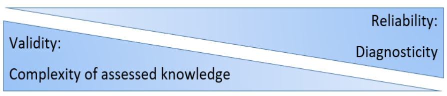

Figure 2. Validity-reliability-dilemma

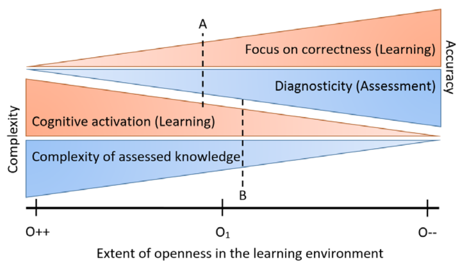

Figure 3. Synthesis of both dilemmas

Schematically, on the left side of the B-mark (higher extent of openness in the learning environment) valid problem-solving processes are possible (complexity), whereas an accurate computer-based diagnosis is difficult. In environments on the right side of the A-mark (lower extent of openness), processes can be diagnosed accurately but these do not represent valid problem solving. A valid problem-solving process and at the same time an accurate diagnosis of the problem-solving result is feasible in the overlap area between A and B, if it exists at all. Our overall ambition is to develop and test a learning environment O_1 in this hypothetical area that allows valid problem-solving processes *and* an accurate diagnosis.

Research question

The analyses of the current paper focus on one challenge of the trade-off, namely the complexity of the problem-solving processes. Our research question is: What influence does the extent of openness of the computer-based learning environment have on the types and frequencies of the solution types?

Methods

63 fifth-graders participated in the present study. The learning unit covered comparing fractions with graphical representations. All students were asked to decide which group win a scoring contest where each kid attempts to score a goal once: a team of 5 girls who scored 3 goals or a team of 10 boys who scored a total of 5 goals.

To investigate this research question, we developed two learning environments O+ and O- in Cinderella. Both variants ask for a graphical solution in the form of fraction bars and a short written answer. The two learning environments differ in their extent of openness: The learning environment O+ (Figure 4) represents the more open learning environment. It is strongly oriented towards the paper-based version (cf. Loibl & Leuders, 2018). Starting from this rather open learning environment O+, we derived the more structured (i.e., less open) learning environment O- (Figure 5) to enable an accurate diagnosis. It can be assumed that the affordances and constraints of the more structured learning environment O- allow a computer-based diagnosis of the conceptual understanding of the learners, but are valid problem-solving processes still feasible despite the pre-structuring?

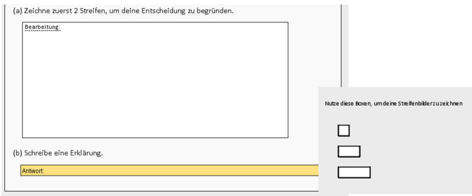

Figure 4. More open learning environment O+.

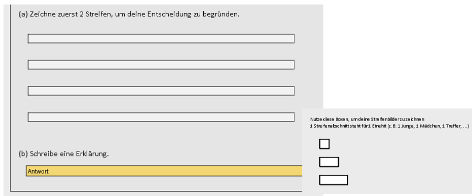

Figure 5. More structured learning environment O-.

The study focused on the problem-solving phase. The students worked in one of the learning environments, followed by a stimulated recall interview. The graphical student solutions and the verbal explanations from the interview were categorized using the coding scheme from Loibl and Leuders (2018).

Findings

Table 1 shows the relative frequencies of the categories in the two learning environments, O+ and O-, and for both levels of diagnosis (graphical and verbal solution). Interrater reliability was very high, $\kappa = .97$.

Table 1: Frequency distribution of categories in the learning environment O+ ($N = 20$) and O- ($N = 43$).

Solution types	Graphical solution		Verbal solution	
	O+	O-	O+	O-
0	25%	37%	15%	23%
1a	55%	37%	50%	42%
1b	10%	7%	15%	9%
1c	10%	7%	5%	14%
2	0%	12%	15%	12%
	χ^2 (4, $N = 63$) = 4.259, $p = 0.372$		χ^2 (4, $N = 63$) = 2.160, $p = 0.706$	

Discussion

The results show that the problem-solving products and their frequencies in the more structured environment O- are similar to the once in the more open environment O+. We interpret this finding as an indicator that valid problem-solving processes are also possible in this more structured learning environment. The next step is to investigate the second part of the trade-off, namely the accuracy. If the graphical solution proves to be a good predictor for conceptual understanding, we can implement an algorithm in the learning environment O- that allows to automatically initiate an adaptive instruction phase after the problems-solving phase.

References

Koedinger, K. R., & Aleven, V. (2007). Exploring the assistance dilemma in experiments with cognitive tutors. *Educational Psychology Review, 19*(3), 239-264.

Loibl, K., & Leuders, T. (2018). Errors during exploration and consolidation – The effectiveness of productive failure as sequentially guided discovery learning. *Journal für Mathematik-Didaktik, 39* (1), 69-96.

Loibl, K., & Leuders, T. (2019). How to make failure productive: Fostering learning from errors through elaboration prompts. *Learning and Instruction, 62*, 1-10.

Seifried, J., Brandt, S., Kögler, K., & Rausch, A. (2020). The computer-based assessment of domain-specific problem-solving competence—A three-step scoring procedure. *Cogent Education*, 7(1), 1719571.

Integrating Computational Thinking into Elementary Science Online

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Abstract: As a result of the COVID-19 pandemic, teachers were forced to consider how their integration of computational thinking (CT) within elementary science would shift during Emergency Remote Teaching (ERT). We present preliminary analysis of interviews with teachers about their experiences and expectations for integrating CT in online teaching and how these expectations mirror and shift integration in-person. We offer principles for designing professional development to support online integration of CT in elementary science.

Introduction

Researchers argue that computational thinking (CT), defined as "the thought process involved in formulating problems such that their solutions can be expressed as computational steps or algorithms to be carried out by a computer" (Lee et al., 2020, p. 1), is a skill every student should learn (Wing, 2006). The value of CT is highlighted in science education, where professional careers are increasingly computational (Weintrop et al., 2016). To introduce CT into the classroom, some professional development (PD) opportunities focus on CT integration within disciplinary contexts, particularly science (Delyser et al., 2018). This type of PD and the focus on CT integration have given CT a stronger foothold within classroom practice.

But this integration has been affected by the COVID-19 pandemic, requiring teachers to reconsider if, how, and when they integrate CT into science lessons. In March 2020, teachers in the U.S. transitioned to Emergency Remote Teaching (ERT; Hodges et al., 2020) and while some schools reopened in-person in the Fall, most adopted either a fully remote or hybrid (part remote, part in-person) model. These transitions required teachers to abruptly transform their teaching, often navigating a redistribution of pedagogical priorities and responsibilities. In this study, we set out to understand how the transition to ERT impacted CT integration and how this transition can inform CT integration in online environments.

Previously, we provided CT PD to pre-service and in-service teachers (Coenraad et al., 2021) with a focus on in-person instruction. In the PD, teachers wrote CT-integrated science lesson plans that included using computational devices for data collection and analysis, using simulations to illustrate scientific phenomena, and extending science learning with programming activities (Cabrera, in preparation). Following up with participants from that PD, we answer the research questions: *How did ERT impact teachers' integration of CT into elementary science?* and *How do teachers expect to integrate CT into elementary science if they continue to teach online?*

Data collection and analysis

We interviewed five elementary teachers (all White women, one Hispanic; 1-15 years of teaching experience) who previously participated in our Spring 2019 PD about their experiences integrating CT during the 2019-2020 school year. All five teachers began the school year teaching in-person but shifted to ERT in March of 2020. We conducted semi-structured audio-recorded interviews during the summer of 2020 focusing on teachers' experiences integrating CT, transitioning to ERT, and their ideas integrating CT in online environments. Interviews lasted 45-80 minutes and were professionally transcribed. The interview transcripts were coded using descriptive coding (Saldaña, 2015) to identify CT integration in-person and online, potential CT-integration online, and barriers to CT integration.

Findings

Although most of the participating teachers had demonstrated the ability to write and enact CT-integrated science lesson plans during the Spring 2019 PD, our interviews showed that no teacher was able to successfully integrate CT into science during ERT. One common barrier to integration was a shift on how and by whom science was taught at schools. As one teacher explained, *"There was only math and reading… then, as online learning went on, they started rolling out science and social studies, but it wasn't taught by the [main] teacher, it was taught by one teacher for the whole school."* Another teacher also shared a shift in priorities and how CT had fallen to the bottom of those: *"just the lack of time that's allocated for Science. I found myself a lot of times having to find ways to integrate science and social studies into math and reading, just to make sure I exposed students to that* *content. So, on top of that, trying to integrate computational thinking is kind of challenging."* Teachers also explained that ERT had also made it difficult to integrate CT by changing the instructional dynamic between teachers and students. A participant described this obstacle as a change in teaching style from *"cooperative learning where the kids learn together…[to] online [where] it is more of a lecture-based type."*

While teachers had difficulty integrating CT during ERT, they were able to identify future means for CT integration online. They specifically identified the potential to integrate programming through online environments, such as Scratch, and computational simulations, such as those available through PhET. One teacher noted both saying, *"What comes to mind is definitely coding, Scratch, things like that, where students can kind of independently explore and work with the technologies…more of those online simulations, things like that."* Teachers identified these technologies *"especially because the students are already on their technology,"* highlighting the online nature of these CT activities and the ability of students to complete them on individual computers without additional resources.

Discussion

From previous work, we know that integrating CT into elementary science is difficult for elementary teachers but moving science instruction online exacerbated the existing barriers they faced. The lack of science instruction time and agency to integrate a new skill like CT became worse during ERT. Advocates of science education should continue to encourage schools and districts to allot significant instructional time to science education. Nevertheless, it is hopeful that teachers recognize ways to integrate CT within the existing context, particularly using simulations and programming. We see pathways that could support teachers to continue the momentum of CT integration as they move forward with ERT and online teaching.

While the teachers who participated in our PD had previously integrated CT through a variety of activities and practices, they saw CT online as limited to easily accessible programming and simulations. However, this conceptualization of CT can be reframed as an opportunity to expand the role of computational tools in science learning—particularly given that districts have now expanded technology access for students learning from home. In our previous work, we observed teachers integrate simulations mostly as a way to visualize a scientific phenomenon, but less often as a tool to test scenarios, answer inquiry questions, and discuss how computational simulations model the real world. Similarly, teachers in our PD often integrated programming only as an extension activity that followed a typical science lesson. Therefore, we suggest that PD designers and teacher educators support instructors in leveraging the affordances of simulations and programming to integrate CT more deeply and making them core practices of science learning. Moreover, it is important that we provide teachers with tools to foster collaborative and active learning online, as they identify that CT is often incompatible with the lecture-based teaching that emerged during ERT.

References

Cabrera, L. (In Preparation). Elementary Teachers' Integration of Computational Thinking into Science.

Coenraad, M., Byrne, V., Ketelhut, D. J., Plane, J., Cabrera, L., Killen, H., & Mills, K. M. (2021). Designing the Science Teaching Computational Thinking Inquiry Group: Professional Development for CT-Integrated Elementary Science. To be presented at the AERA Conference 2021.

Delyser, L. A., Goode, J., Guzdial, M., Kafai, Y., & Yadav, A. (2018). Priming the computer science teacher pump: Integrating computer science education into schools of education.

Hodges, C., Moore, S., Lockee, B., Trust, T., & Bond, A. (2020, March 27). The difference between emergency remote teaching and online learning. Educause Review.

Lee, I., Grover, S., Martin, F., Pillai, S., & Malyn-Smith, J. (2020). Computational thinking from a disciplinary perspective: Integrating computational thinking in K-12 science, technology, engineering, and mathematics education. Journal of Science Education and Technology, 29(1), 1–8.

Saldaña, J. (2015). The coding manual for qualitative researchers (3rd Edition). Sage.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. Journal of Science Education and Technology, 25(1), 127–147.

Wing, J. (2006). Computational thinking. Communications of the ACM, 49(3), 33–35.

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Show the Flow: Visualizing Students' Problem-Solving Processes in a Dynamic Algebraic Notation Tool

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Abstract: We apply an advanced data visualization technique, *Sankey diagram*, to explore how middle-school students ($N = 343$) solved problems in a game-based algebraic notation tool. The results indicate that there is a large variation in the types of students' strategies to solve the problems, with some approaches being more efficient than others. The findings suggest that Sankey diagrams can be used both in research and practice to unpack our understanding of variability in mathematical problem-solving.

Keywords: math learning, problem-solving strategies, data visualization, Sankey diagram

Introduction

Teachers' knowledge of their students' learning is one of the important factors contributing to classroom practices, and ultimately, what students learn in mathematics (Asquith et al., 2007). However, teachers often have difficulties in monitoring students' learning progress or identifying their misconceptions. In response to these issues, advances in data analytics and visualizations have enabled teachers and researchers to identify complex data on student learning in an easier and faster way. However, there has been little research that has employed advanced data visualization techniques on students' mathematical learning processes (Vieira et al., 2018). Over the past several years, our team has designed and developed a dynamic algebraic notation tool, *Graspable Math* (GM), which helps develop students' conceptual and procedural learning in algebra. The tool allows students to dynamically manipulate and transform numbers and mathematical expressions using various touch or mouse-based gesture-actions. Using the data collected in GM, students' problem-solving processes can be represented as a series of time-based steps that form the mathematical derivation as they transform mathematical expressions and equations. Thus, the purposes of this study are to 1) present visualizations of students' algebraic problem-solving processes in GM using an advanced and novel data visualization technique, called *Sankey diagram*, and 2) investigate how we can use these visualizations to provide meaningful and comprehensive information to researchers and teachers.

Methods

Our sample ($N = 343$) was drawn from a randomized controlled study conducted in 2019. Of the 343 students (54% male, 43% female, 3% not reported), most students (96%) were in sixth grade, and the remaining students (4%) were in seventh grade. *From Here to There!* (FH2T, https://graspablemath.com/projects/fh2t), is a gamified version of the GM that was developed to help students' algebra learning. It allows students to dynamically manipulate and transform numbers/mathematical expressions using various gestures. The problems in the game consist of two mathematically equivalent mathematical expressions, a start state and a goal state. Students must transform the starting expression into the target goal state using algebraically permissible actions. Among the 252 problems that cover a variety of mathematical concepts, this study focuses on two multiplication problems.

Results

Figure 1 presents the students' problem-solving processes for the square numbers problem (turning "9×4" into "3×6×2"). Each node in the diagram represents a different mathematical expression made by students, and the thickness of each path represents the number of students who made that expression. Colors in the diagram represent the productivity of students' first steps (blue: productive, red: non-productive). As shown in Figure 1, more than half of the students made productive first steps for this problem (e.g., 3×3×4, 9×2×2), and most of them solved the problem with the fewest possible steps to reach the goal state. On the contrary, the students who made non-productive first steps (e.g., 36, (3+6)×4) did not solve the problem in the most efficient way. Thus, noticing the underlying structure of the problem equation and how to transform it played a critical role in students' subsequent transformations as well as their overall efficiency of algebraic problem-solving.

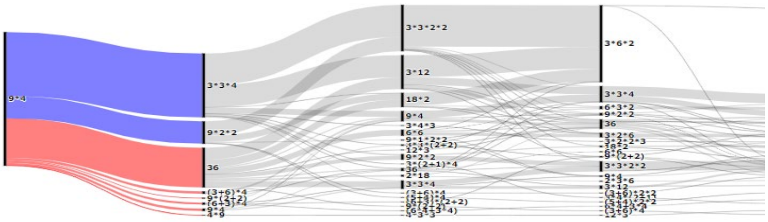

Figure 1. Section of the Sankey diagram showing productivity of initial solution strategies for the square numbers problem (for full image: http://tiny.cc/pd51tz)

Figure 2 presents the students' problem-solving processes for the non-square numbers problem (turning "6×10" into "2×15×2"). Most students who made the numbers in the goal state (e.g., 2) or the factors (e.g., 3, 5) of the numbers in the goal state on their first steps solved the problem in the most efficient way. However, the students who did not attend to the structure of the problem and simply combined two numbers failed to solve the problem in the most efficient way. Specifically, many of the students who made 60 on their first step did not solve the problem in the most efficient way, indicating that factoring 60 into small numbers was an obstacle point to the students. Thus, as demonstrated by the Sankey diagram, students' first mathematical transformation played a significant role in students' subsequent and overall efficiency of problem-solving.

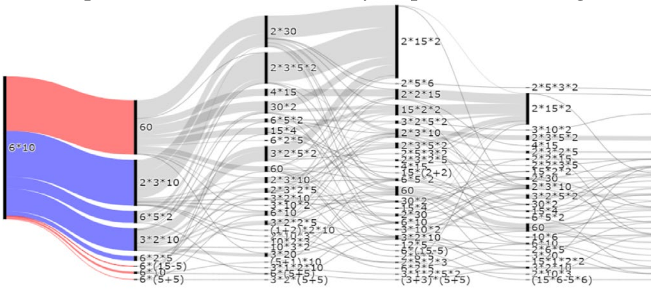

Figure 2. Section of the Sankey diagram showing students' problem-solving processes for the non-square numbers problem (for full image: http://tiny.cc/wd51tz)

Discussion

This work presents a new way to visualize students' problem-solving processes in a dynamic algebraic notation tool. The results showed that Sankey diagrams could provide a lot of information to help teachers and researchers efficiently understand students' algebraic problem-solving processes. They presented the variability of problem-solving processes, the most common pathways used, the obstacle points of problem-solving, and the efficiency of different solution strategies. In particular, the diagrams revealed that noticing the underlying structure of the problem equation and how to transform it on their first step played a critical role in students' subsequent transformations as well as their overall efficiency of problem-solving (Stephens et al., 2013). Visualizing students' problem-solving processes for a given mathematical task would help teachers and researchers perceive students' individual differences and their mathematical thinking processes. This work has clear implications for practice as students' strategies are often invisible to teachers. In combination with the GM, teachers could use these visualizations in several ways to inform their instruction.

References

Asquith, P., Stephens, A. C., Knuth, E. J., & Alibali, M. W. (2007). Middle school mathematics teachers' knowledge of students' understanding of core algebraic concepts: Equal sign and variable. *Mathematical Thinking and Learning*, *9*(3), 249-272.

Stephens, A. C., Knuth, E. J., Blanton, M. L., Isler, I., Gardiner, A. M., & Marum, T. (2013). Equation structure and the meaning of the equal sign: The impact of task selection in eliciting elementary students' understandings. *The Journal of Mathematical Behavior*, *32*(2), 173-182.

Vieira, C., Parsons, P., & Byrd, V. (2018). Visual learning analytics of educational data: A systematic literature review and research agenda. *Computers & Education, 122*, 119-135.

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A Multimodal Discourse Analysis of Textbooks: A Case Study of *Oxford Junior Middle School English (Shanghai Edition)*

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Abstract: This research chooses *Oxford Junior Middle School English (Shanghai Edition)* for a multimodal discourse analysis. Applying Kress and van Leeuwen's Visual Grammar and Royce's Ideational Intersemiotic Complementarity as the theoretical framework, the research investigates how visual images construct three meta-functional meanings and explores the relations between texts and images. It is found that the frequency of using repetition, synonymy and hyponymy is the highest. Such design facilitates students to understand textbooks more comprehensively.

Background

With the fast development of multimedia and the arrival of the information age, multimodal means of communication are flourishing and influencing the traditional way of thinking. The expression of information has changed from relying on a single mode to combining multiple channels. In the field of education, textbooks convey information to readers with the help of multiple modes. Texts, illustrations, tables, tapes, videos, PPT and so on all together help teachers and students better understand textbooks. They are an important medium that directly connects teachers, students and knowledge.

However, second language learners usually pay more attention to vocabulary and grammar which are embodied in the texts than other modes. In China, students who learn English often recite words and sentences, thinking little of pictures. After all, examinations are usually presented in the form of texts. In fact, this kind of study is not beneficial to develop multiliteracies of learners that are so important in such a modern society filled with multiple modes. Therefore, it is necessary for researchers to explore how multiple modes in textbooks convey knowledge together. By investigating how visual images construct three meta-functional meanings and exploring the relations between texts and images, this research is aimed at assisting both teachers and students. Teachers can further understand multimodal discourse in textbooks by expanding their focus on texts to both texts and other modes. Moreover, when teachers pay attention to those modes, students who are under the guidance of teachers learn to attach importance to them, helping to improve their development of multiliteracies and adapt to modern society better.

Research design

Research object

This research chooses the reading part of *Oxford Junior Middle School English (Shanghai Edition)* to do a multimodal discourse analysis. Six books are analyzed, including 7A published in 2008, 7B in 2009, 8A in 2009, 8B in 2010, 9A in 2010 and 9B in 2011. There are 52 articles and 135 pictures in total (see Table 1).

Table 1: A table for articles and pictures in textbooks

	7A	7B	8A	8B	9A	9B	Total
Articles	12	13	7	8	7	5	52
Pictures	45	35	18	13	12	12	135

Research method

This research analyzes textbooks from the perspective of multimodal discourse analysis, which focuses on multiple semiotic resources like texts and images. The main research method is case analysis. There are two reasons to choose English textbooks used in Shanghai as a case. Shanghai is a pioneer in curriculum reform and Shanghai students performed very well in PISA, and in English learning as well. It is helpful to demystify educational ideas from the perspective of analyzing textbooks. There is no denying the fact that this series of textbooks contribute to some extent. Therefore, it is necessary to analyze this series so as to better understand textbooks and get some enlightenment.

Theoretical framework
Based on Visual Grammar's three dimensions, namely representational, interactive and compositional meaning proposed in Kress and van Leeuwen's (2006) book, *Reading Images, the Grammar of Visual Design*, this research classifies and analyzes pictures in the textbooks to interpret the meaning and function of images. It also explores relations between images and texts based on Royce's (2007) Ideational Intersemiotic Complementarity theory. By combining such two theories, this study analyzes the multimodal characteristics of textbooks, provides new theoretical perspectives for textbook analysis and interpretation, and promotes English teaching and learning.

Coding
This research classifies each picture and relations between pictures and texts according to the definition of theories and then records results in the Excel. For example, according to Visual Grammar, the action process has vectors formed by oblique lines which are composed of represented participants' tools or limbs. Figure 1 shows that three cleaners are cleaning streets (see Figure 1). The represented participants are cleaners. The two obvious vectors are the lines formed by cleaners' action, holding the broom and the water pipe. This picture depicts the action that the text embodies, that is, the cleaners sweep the streets and collect rubbish. Therefore, it belongs to action process.

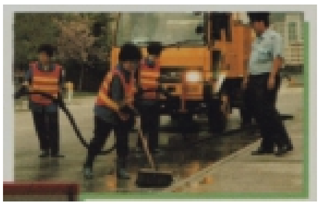

Figure 1. The action process.

Findings
First of all, as to the representational meaning, the total amount of narrative process exceeds the totality of conceptual process to a prominent extent for the reason that narrative process makes students less demanding to join in the reading through vectors of actions and eyes. In regard to the interactive meaning, the main relationship in the contact presented in pictures is "offer", because the role of textbooks is to provide readers with information, not to ask readers for something. In addition, the frontal angle and the head-up angle are in the majority, more than half of the total number. With respect to the compositional meaning, the information on the right section which offers new information to arouse readers' interest in reading contributes most. Apart from that, it is found that pictures with lines are decreasing with junior school students' age increasing because when they grow older and own a higher cognitive level, pictures without lines are not likely to distract them.

Secondly, in the aspect of figuring out the relations between texts and images in making the meaning coherent based on the Ideational Intersemiotic Complementarity, the frequency of using repetition, synonymy and hyponymy is the highest because an image which conveys the same denotation as the text expresses can facilitate students to understand textbooks more thoroughly.

Conclusion and discussion
The findings show that every picture constructs its own meta-functional meaning and most pictures have a good consistency with texts, except some pictures which mismatch texts, causing learners' misunderstanding. It is better for textbook writers to be more careful when they choose pictures. The significance of this research is that it not only expands the application scope of two theories mentioned above, but also provides a new perspective and some enlightenment for understanding textbooks. To better understand and use them, it is necessary for teachers and students to pay attention to those multiple modes first instead of focusing on texts only. In addition, teachers can invite students together to analyze the function of different modes and explore how they cooperate with each other to successfully convey meaning. The function may be interpreted from different perspectives. It is the awareness to analyze and interpret that matters a lot. This research's perspective is just an example and there is broader space to explore for educators and learners who have a creative thinking.

References
Kress, G., & Van Leeuwen, T. (2006). *Reading images: The grammar of visual design*. New York: Routledge.

Royce, T. (2007). Intersemiotic complementarity: A framework for multimodal discourse analysis. In T. Royce & W. Bowcher (Eds.), New directions in the analysis of multimodal discourse (pp. 63-109). New York: Lawrence Erlbaum.

Supporting Children's Spatial Representation Practices through Playful and Embodied Experiences

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Abstract: This poster examines how embodied and playful STEM learning supports young children's visualization and representation of space. We present two case studies where participants engaged in playful experiences with movement in space and later used these dynamic experiences to create and interpret spatial representations. As part of the conference theme, we aim to examine and reflect on how these playful and embodied experiences can extend current approaches to spatial reasoning and visualization in STEM education.

Theoretical framework

Generating and interpreting spatial representations play critical roles across STEM domains (National Research Council, 2006). However, current early STEM instruction largely neglects cultivating children's considerations of what about space is worth representing and how to go about symbolizing or inscribing this spatial content. We draw and build from research on the embodied nature of reasoning and creating spatial representations to examine how childhood activities (like object play and dramatic role play) can support disciplinary spatial understanding in different ways (Keifert, et al., 2020; Ng & Sinclair 2015; Thom & McGarvey, 2015). Our current aim is to further understand how forms of embodied learning rooted in playful experiences moving in space can support children's representations of space in other mediums, including collage making, notation, and pattern design. Specifically, this paper addresses the following question: How do different playful embodied learning experiences support children's development of spatial representation practices?

Methods

To address our research question, we present two cases of early STEM learning in 1st and 2nd grade classrooms that examine how children's playful encounters with movement can promote embodied learning of dynamic spatial relations and serve as resources for representing these relations in 2-D, static representations. Although both cases focus on playful movement and spatial representations, we also selected these cases because of their differences. Case 1 presents an analysis of children playing with an object while case 2 presents an analysis of children engaged in dramatic role play. Case 1 looks at small scale, discrete movements in the context of pattern design; Case 2 looks at large scale, multi-party movements in the context of collage making. Our current and developing analysis looks to understand how these scales of movement and space relate to children's emergent representational practices.

Findings

Case 1: Movement in space represented in pattern making

This case took place in a 1st grade (ages 6-7) classroom (n = 27) in a public elementary school in the U.S. Data comes from a larger project aimed at connecting movement, design, and spatial mathematics in grades K-5. Here, our case study focuses on a whole class discussion from day 4 of a 5-day instructional sequence on the use of geometric motions (slides, flips, and turns) to create and analyze symmetrical frieze (1-dimensional) patterns. Analysis of this case focuses on how children interpreted frieze patterns using the motions they previously explored in their playful encounters with a fictional 2-D dinosaur, Mr. Dino. These initial playful experiences of moving Mr. Dino encouraged children to create categories of similar motions by distinguishing between the direction of movement (e.g., slide left or right). Teacher then helped further these distinctions in motions by introducing points of rotation and lines of reflection to further extend children's conceptions of ways to move Mr. Dino.

In order to communicate distinctions of movements in space that children experienced while playing with Mr. Dino, the class invented a notational system that included ways to symbolize direction and center of motion. After children played with different ways of moving Mr. Dino, they then analyzed and created frieze patterns by moving and tracing asymmetric figures. To preserve how children made their patterns or how they visualized others' patterns, children used the classroom invented notational system to create a record of their enacted or imagined movements. These records allowed the class to compare the movements used by pattern makers and the different ways of visualizing these patterns. In sum, children's initial playful explorations of motions and the symbolization of these motions supported children in visualizing static 2-D patterns through a lens of dynamic transformations— a critical aspect of mathematical visualization.

Case 2: Movement in space represented in children's collage making

Our second case is from a larger study (n=26) that took place in a mixed-age dual language classroom (English and Spanish) of 1st and 2nd grade students at a progressive elementary school in the U.S. (ages 6-8). The case study follows four children learning both science and math concepts by role-playing as various marine animals, algae, and plants living together in a kelp forest ecosystem (i.e. sea otters, sea urchins, kelp, fish, plankton). With the guidance of their teacher, children moved and organized themselves in ways that represented how these marine creatures would interact with one another in the ocean. For example, children role-playing as smaller creatures (fish or sea urchins) would often "swim away" from children playing as predators and rely on children who played as kelp as sources of shelter or food. Thus, while the movements individual children performed in space (e.g. swimming away, hiding, etc.) were determined by which marine creatures they were assigned, the resulting emergent and collective movement of the class embodied and represented the interdependent relationships in the kelp forest ecosystem.

Following each role-play activity, children documented, represented, and shared what they learned about the kelp forest ecosystem in group collage making activities. Over time, two of the most salient changes of the collage making activities were how the playful experiences of movement in space were documented in ways that (1) showed how each piece of the ecosystem moves within the kelp forest and (2) showed the relational movement within a living, moving, and dynamic ecosystem. We also saw children connect the movement of each sea creature to others by using arrows—the arrows represent the larger food web where specific characters rely on others for survival. In sum, children's role-playing experience of embodying the ecosystem supported their visualization and illustration of the kelp forest that communicated the moving, interconnected, and relational thinking that is central to STEM practices.

Conclusions

Findings from our two cases demonstrate how playful embodied experiences are activities where children utilize movement in space to make sense of disciplinary spatial relationships. Children's embodied and playful experiences are then further reflected on, and ultimately serve as resources in children's spatial representational practices as they work to communicate previously embodied spatial relations in new mediums (e.g. notational systems, patterns, and collages). Findings have the potential to contribute to the growing research on developing spatial understanding in early elementary years by presenting two cases of learning that place playful movement at the center of early disciplinary spatial learning and representational practices. Additionally, although pattern and collage making are not often found in STEM classrooms, these artistic representational practices served as productive entry points for children to consider how dynamic spatial relations, first experienced in playful embodied experiences, can be inscribed in static representations. Thus, these findings also highlight the potential role that playful movement and artistic representations can have in developing children's spatial reasoning within STEM learning.

References

Keifert, D., Lee, C., Enyedy, N., Dahn, M., Lindberg, L., & Danish, J. (2020). Tracing bodies through liminal blends in a mixed reality learning environment. International Journal of Science Education, 42(18), DOI: 10.1080/09500693.2020.1851423.

National Research Council. (2006). Learning to think spatially: GIS as a support system in the K-12 curriculum. Washington, DC: National Academies Press.

Ng, O. L., & Sinclair, N. (2015). Young children reasoning about symmetry in a dynamic geometry environment. *ZDM Mathematics Education*, *47*(3), 421–434. https://doi.org/10.1007/s11858-014-0660-5

Thom, J. S., & McGarvey, L. M. (2015). The act and artifact of drawing(s): observing geometric thinking with, in, and through children's drawings. *ZDM Mathematics Education*, *47*(3), 465–481. https://doi.org/10.1007/s11858-015-0697-0

Supporting Youth Environmental Interest and Identity Development through Program Infrastructures Connecting People and Place

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Abstract: This case study of an informal science program in an urban park explores adolescent environmental interest and identity development. Using participant observations, interviews, and artifact analysis, I identified three program infrastructures that rely on relational processes between youth, educators, and more-than-human nature to support this development. They are: 1) encouraging physical interaction between human/more-than-human nature; 2) providing youth opportunities to be caretakers of land and waters; 3) exposing youth to visions of their future selves.

Introduction

Science interest and identity are important components for civic engagement (Rudolph & Horibe, 2016). Civic science identity that builds on knowledge of and direct experience with the natural world is essential given the global climate crisis and local environmental issues, such as water quality degradation (Tewksbury et al., 2014). Informal science programs can play an important role in supporting youth environmental interest development (Carlone et al., 2015). However, informal programs often only spark interest (Hecht, Knutson, & Crowley, 2019), even though this is just a first step in developing persistent individual interest (Hidi & Renninger, 2006).

In this program case study, I examine program elements designed to support the deepening of environmental interest for a group of adolescent learners as they transition from initial interest to individual interest and identity development. This case study is of an urban environmental education program designed for teens who had expressed initial interest in the environment and wanted to learn more. The program drew on naturalist practices to deepen youth interest and skills. The park organization that led the program paid youth a stipend and provided youth gear for outdoor activities (e.g., work boots). The stipend and gear facilitated equitable access to program participation but did not alter the informal tenor of the program activities. Therefore, I characterize this as an informal science program because of the emphasis on choice based, interest-driven learning and participation in scientific practices in the informal learning setting of a park (Sacco, Falk, & Bell, 2014).

This project was part of a research-practice partnership which aimed to support the needs of the entire project team including university-based researchers and environmental educators with the park organization. We maintained structured opportunities for collaboration, including six months of planning meetings before data collection began in order to understand practitioner problems of practice, co-develop research questions and program activities to support both learning objectives and data collection needs, and analyze data during meetings that extended more than six months after data collection was completed. This consistent process allowed our team to authentically co-construct the unfolding knowledge described here. Our research questions were:

- What program infrastructures facilitate relational processes between youth, educators, and more-than-human nature?
- How do these program infrastructures support youth development of environmental interest and identity?

Methods

After the co-design of research questions and program activities with practitioner partners, I conducted observations, interviews, and artifact analysis as a participant observer in the program. The data include 89 hours of observations (i.e., handwritten jottings expanded into typed fieldnotes); artifacts from program activities (e.g., youth field journals); and audio recorded and transcribed interviews of youth and educators (n=16), youth large group discussions (n=3), and educator debriefing sessions (n=10). To center the materiality of the park, each interviewee selected an outdoor walking route or place to sit for our interview. This was inspired by work that explores the significance of walking for embodied learning in informal learning settings (Marin & Bang, 2018).

My observational practice focused on robust episodes of interest expressed through interactions between educators, youth, and more-than-human nature. Episodes lasted from 15 minutes to an hour or more and were defined as observable youth expression of environmental interest such as auditory cues (e.g., question asking, concentrated silence) or physical actions (e.g., leaning in, facial expressions). Episodes included human-human interactions (e.g., youth asking questions about environmental phenomena), human-tool interaction (e.g., use of field guides), and human-more-than-human interactions (e.g., tasting a wild edible plant). Data analysis included thematic coding of observational notes, followed by collaborative code review and modification with practitioner partners. I then created structured case summaries that triangulated observational data with other data sources.

Findings

Using these structured case summaries, I worked with practitioner partners to identify key program infrastructures that contributed to deepening environmental interest for participating youth. These were: 1) encouraging physical interaction between humans and more-than-human nature; 2) providing meaningful opportunities for youth to be caretakers of land and waters; and 3) exposing youth to possible visions of their future selves. These infrastructures resulted from deliberate educator design choices to support environmental identity formation and reflect the park organization's philosophy that nurturing a human community is an essential part of coming into community with more-than-human nature and that direct contact with the more-than-human natural world should be driven by curiosity and must respect people's prior experiences, which may include fear. I frame these as *infrastructures* to indicate their structural nature (Penuel, Lee, & Bevan, 2014).

All three program infrastructures were deeply entwined. For example, one of the youth participants, Charlotte, engaged in physical contact with more-than-human nature primarily through watershed stewardship projects, such as building a rain garden, as well as stream surveys, which included finding, handling, and identifying macroinvertebrates. These activities were facilitated by program educators as well as guest environmental professionals, such as a restoration ecologist. Her experiences involved direct physical contact with the more-than-human natural world through stewardship and inquiry activities, as well as examples of possible careers. These helped Charlotte grow her preliminary interest into a deeper individual interest that included a vision of her future as an environmental professional.

In her interview, Charlotte articulated how inquiry and stewardship activities helped her think about her future self, describing her fascination with how the park organization was taking a regional water quality problem and addressing it in a small watershed. She was especially interested in the problem-solving aspects of watershed stewardship, which married her interests in engineering and outdoor work. On the last day of the program when she was asked to reflect on highs and lows from the summer, Charlotte brought up her new understanding of environmental work as a potential career, expressing the start of a potentially long-term environmental identity:

> I think just like knowing that working with the environment is a career option to explore cause before I was just like oh, science, something with science, and then I'm thinking I like definitely wanna do something with the environment, yeah, be out in nature.

Conclusion

This work explores how an informal science education program utilized three program infrastructures to support environmental interest and identity development by emphasizing relational processes between educators, youth, and more-than-human nature. While these findings are limited by the fact that this is a case study focused on just one program, the findings contribute to conceptualizations of effective program design for environmental interest and identity development. The park organization and other informal science programs might consider using these infrastructures to help shape future program design that supports environmental interest and identity development.

References

Carlone, H. B., Huffling, L. D., Tomasek, T., Hegedus, T. A., Matthews, C. E., Allen, M. H., & Ash, M. C. (2015). "Unthinkable" selves: Identity boundary work in a summer field ecology enrichment program for diverse youth. *International Journal of Science Education*, *37*(10), 1524–1546.

Hecht, M., Knutson, K., & Crowley, K. (2019). Becoming a naturalist: Interest development across the learning ecology. *Science Education*, *103*(3), 691–713.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127.

Marin, A., & Bang, M. (2018). "Look it, this is how you know:" Family forest walks as a context for knowledge-building about the natural world. *Cognition and Instruction*, *36*(2), 89–118.

Penuel, W. R., Lee, T. R., & Bevan, B. (2014). *Research synthesis: Designing and building infrastructures to support equitable STEM learning across settings*. *Research + Practice Collaboratory Research Synthesis*. San Francisco, CA.

Rudolph, J. L., & Horibe, S. (2016). What do we mean by science education for civic engagement? *Journal of Research in Science Teaching*, *53*(6), 805–820.

Sacco, K., Falk, J. H., & Bell, J. (2014). Informal Science Education: Lifelong, Life-Wide, Life-Deep. *PLoS Biology*, *12*(11), 11–13.

Tewksbury, J. J., Anderson, J. G. T., Bakker, J. D., Billo, T. J., Dunwiddie, P. W., Groom, M. J., … Wheeler, T. A. (2014). Natural history's place in science and society. *BioScience*, *64*(4), 300–310.

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Exploring Prompted Self-Explanation in the Context of Second Language Acquisition in Vocational Settings

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Abstract: In the Global South, English-language fluency is strongly associated with earnings. This in particular impacts young adults in low-income settings looking to start work in urban areas without past access to high-quality English language education. Evaluating English efficiency in low-resource settings is challenging due to the complexity of the popular assessment tools. In this work, we explore prompted self-explanation as a potential tool for assessing student efficacy in English grammar concepts with students undergoing a vocational training program. Using in-depth analysis of video recordings of students explaining concepts in English as a Second Language (ESL), we find that self-explanation (1) correlates with overall ESL assessment scores, and thus can be a scalable assessment tool and (2) assists learners identify and correct errors, potentially useful as a learning tool.

Problem

Throughout much of the world, especially in parts of the Global South, English-language proficiency is seen as an aspiration and opportunity to achieve higher socio-economic status. It is often considered as linguistic currency and in fact, previous studies have shown that English fluency is strongly linked to earnings (Azam et al. (2013)). In India, there is linguistic diversity in terms of number of languages spoken and there is an ambition among the youth to learn English. Young adults from underprivileged communities face learning poverty and miss out on quality English education. The increase in gig economy work available in urban centres (e.g., delivery agents, call centres) has been a further push for English language acquisition, since most of these jobs require basic ability to navigate written English and conduct telephone conversations.

Access to English education in marginalized communities is mainly via vocational education. There are numerous training centres that train adults for various skill-specific education while also training them in English. To measure the English proficiency, summative assessments are often used that involve a standard comparison. CEFR descriptors (Common European Framework of Reference for Languages) is a popular framework to create an assessment tool for measuring English proficiency. However, the insights from CEFR tools might not be helpful for the learner / trainer to capture the learning gaps. Also, non-native English speakers tend to learn English via combinations of vernacular language cues.

Self-explanation as an assessment tool

This problem motivated us to try out self-explanation due to its simplicity in evaluation of learner's mental model whose learning is based on culturally relevant information (especially for non-native English speakers). Self-explanation is an engaging learning method that has demonstrated its usefulness in other fields, consisting of students illustrating knowledge of learning materials by themselves. Prior works (Chi et al. (1989, 1994, 1996); Bielaczyc et al. (1995)) have explored the effects of self-explanation on learning across various domains like computer programming, math, and science. However, the participants in all these prior studies are mainly students from conventional schools and universities. More importantly, in majority of the studies, the language of self-explanation itself is in English. In this work, we explore the use of self-explanation by students who have l imited educational background to uncover some insights on learning of English as a Second Language (ESL).

Methodology

For this study, we partnered with a non-profit organisation that offers short-term vocational skill-development programs to youth from low-income, underprivileged communities. In our study, we worked with 16 students undergoing training to become *delivery service agents*. We asked each of the 16 students to self-explain one of the concepts in English as a Second Language (ESL). All participants were educated at most up to grade 12. As women are typically not part of the delivery agent workforce, all our participants were male.

We conducted the study with one student at a time at the training premises. We explained the project to the student and the procedure for the study. We asked the student to pick a topic that they would like to explain. The student was provided with access to a whiteboard on which they can write as they are explaining the concept. A laptop was placed facing the student which records the self-explanation session of each student. Once the student is ready with a topic, the researcher started the recording and left the premises. If a student had difficulty choosing a topic, we asked them to self-explain the *English Alphabet*.

At the end of the study, we transcribed and analysed the videos from all the students to extract multiple metrics, such as number of self-explanation inferences (Chi et. Al, 1994), and time spent on different activities like explaining the concept, providing examples, and writing down information. We use the number of self-explanation inferences as a metric to determine a student's ability to self-explain a concept.

Findings

Our analysis results in multiple conclusions. First, *Figure 1* shows the breakdown of time spent on different activities and the number of self-explanation inferences, for each student. As can be seen, while almost all students used the whiteboard to write down information, students with lower self-explanation ability (left half of the graph) spend a larger fraction of their time in writing down rote information on the white board. On the other hand, students with higher self-explanation ability spend a significant amount of time on not only explaining the concept, but also providing relevant examples. Second, we find a strong correlation (0.72) between the ability of a student to self-explain and their overall ESL abilities, showing that ability to self-explain can be an indicator of their English fluency. Third, we find that the overall time spent speaking (explain concepts and example) correlates strongly (0.81) with the ability to self-explain. Combined with the previous finding, we believe self-explanation can be a scalable tool to automatically evaluate a student's ESL abilities and understanding of specific concepts. Finally, in certain instances, students self-corrected their mental models after they identified errors in some of their previous explanations.

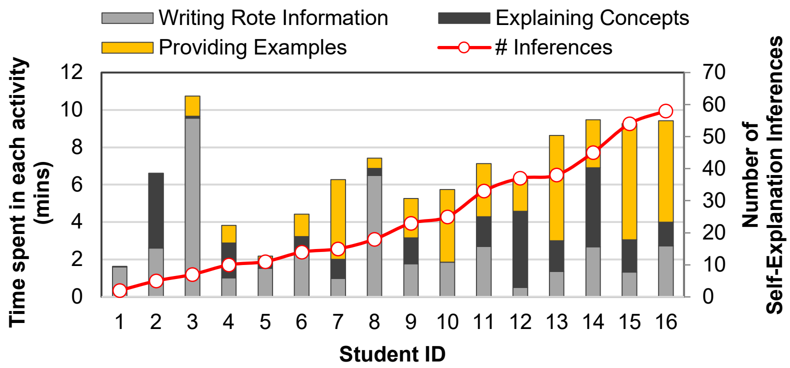

Figure 1. Time spent on different activities and number of self-explanation inferences for each student.

Discussion and conclusion

Compared to other studies, our research concentrates on underprivileged youth. However, our findings are consistent with previous work in certain aspects, such as the number of inferences produced and its correlation with the grades of students. Our analysis shows that high-explainers spend more time on examples, and their ESL scores are strongly correlated with the number of inferences they generate.

One of the drawbacks of the design of learning materials or technologies is that potential learners might not be able to express their learning difficulties and, this technique may allow us to gain more insights into the student's approaches to learning. The self-explanation method might be useful when summative assessments do not give us enough accurate reflection of learning. It can reveal insights regardless of the student's experience and skills. Our findings make a good case to show that self-explanation can be explored as an evaluation methodology.

References

Azam, M., Chin, A., and Prakash, N. (2013). The returns to English-language skills in India. *Economic Development and Cultural Change*, 61(2):335–367.

Bielaczyc, K., Pirolli, P. L., and Brown, A. L. (1995). Training in self-explanation and self-regulation strategies: Investigating the effects of knowledge acquisition activities on problem solving. *Cognition and instruction*, 13(2):221–252.

Chi, M. T. (1996). Constructing self-explanations and scaffolded explanations in tutoring. *Applied Cognitive Psychology*, 10(7):33–49.

Chi, M. T., Bassok, M., Lewis, M. W., Reimann, P., and Glaser, R. (1989). Self-explanations: How students study and use examples in learning to solve problems. *Cognitive Science*, 13(2):145 – 182.

Chi, M. T., De Leeuw, N., Chiu, M.-H., and LaVancher, C. (1994). Eliciting self-explanations improves understanding. *Cognitive science*, 18(3):439–477.

Beyond Supervision: Human / Machine Distributed Learning in Learning Sciences Research

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Abstract: Machine Learning (ML) is at the core of a new set of methodologies that are currently taking the world by storm and that have a great potential to advance research in the learning sciences. However, research has mostly focused on applying top-down methodologies effectively aiming at replacing humans. However, this hinges on the assumption of scale effects and transferability of trained ML models across populations – assumptions that may not hold in learning sciences research. We discuss the potentials and pitfalls of supervised and unsupervised ML for the learning sciences and argue that the greatest benefits from the use of ML lies in supporting humans so that researchers can tap into new data sources and enhance the validity of their inferences.

What learning machines can and cannot do

Machine Learning (ML) has greatly improved during the last decade and is commonplace in contemporary life. How can this potential be harnessed for the learning sciences? To answer this question, we draw on how Breiman (2001) conceptualized the affordances of ML. Figure 1 shows that ML comes to results about the relationship between two variables x and y by trying to find an algorithmic function *f*(x) that predicts y. It does not make any assumption about the actual process that relates the variables. On one side, the resulting algorithmic functions *f*(x) have unprecedented accuracy in terms of predicting y, on the other hand, they become increasingly uninterpretable with growing accuracy. In consequence, it is hard if not impossible to relate results from ML back to theory as ML does not yield something like regression coefficients. Another consequence of black-boxing the process model is that results from ML—at least current methods—cannot identify causation (Pearl & Mackenzie, 2018).

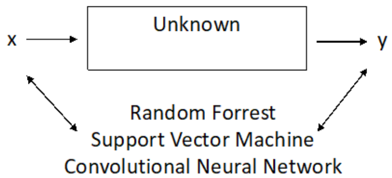

Figure 1. How ML determines the relationship between variables x and y (adapted from Breiman [2001]).

But how does ML identify the algorithmic functions *f*(x)? There are two main approaches. Unsupervised learning is used to learn structural relationships in datasets and does not require the data to have pre-existing labels. Supervised learning tries to learn a function that maps elements onto each other given a set of examples.

What supervised and unsupervised learning have in common, despite the sometimes vocal contrary claims, is that they are not bias-free (O'Neil, 2016). In unsupervised learning, bias can be introduced through the dataset in which the machine learns a structure. When researchers put together a data set, they make decisions, e.g., what to include in the data set, etc. These decisions can reflect biases. For example, if researchers try to learn the social structure of a class based on students' interactions within a chat group, bias will be introduced if students with only limited Internet access participate. Bias can also be introduced through labeled data in supervised learning. If the selected elements between which the machine is supposed to learn a function, e.g., if examples for good explanations follow a certain structure, this will result in bias against idiosyncratic but still good explanations.

In sum, ML can identify structure in unlabeled data (unsupervised learning) and identify mappings between variables based on examples (supervised learning). In both cases, ML essentially trades accuracy for interpretability as compared to classical statistics (Breiman, 2001). In consequence, results can hardly be mapped to theory. Further, results of ML are in fact susceptible to the bias inherent to the collection of data (O'Neil, 2016).

How ML is used at present in the learning sciences

Recently, meta-analyses found that the primary focus of using ML in (science) education so far has been using supervised ML to automatize the coding of students' work. Proponents of this approach often argue that automated coding allows better assessment as it purportedly allows to score open-ended and thus more valid assessments more reliably than human scorers can. This would allow to economically scale many research efforts, allowing for higher statistical power and more precise statistical estimates. In addition, automated coding is a precondition for individualized instruction with real-time feedback, which could be used to assist teachers. However, there are two fundamental problems with this argument regarding the economic advantages and the absence of bias in ML.

Replacing human coders with supervised ML only becomes more economic when sample sizes increase drastically. For the machine to learn how to code, it needs a certain number of examples: answers that have been determined by humans. If the amount of data left after what is coded for training does not massively exceed the amount needed for training, ML is not economically viable (Nehm & Haertig, 2012). Further, when the students that answer the questions change, the initially trained algorithm may produce biased results. Addressing this issue is a very active area of research in computer science but far from being solved (Pearl & Mackenzie, 2018).

The coding of students' answers needs to be valid and reliable. Quality measures of supervised ML however only consider reliability. For validity, examples from human coders are taken as the gold standard although it is well known that this assumption is problematic (Nelson, 2020). Further, a dire consequence may be that structural inequality manifest in human biases is perpetuated by machines ad infinitum (O'Neil, 2016).

In summary, ML is currently mostly used in automated scoring applications in the form of supervised ML. While this certainly has the potential to improve teaching and learning (freeing up teachers' resources, allowing real-time feedback), fundamental issues regarding the ethics and mechanics of ML are still need to be solved (O'Neil, 2016). If supervised ML cannot replace humans yet (and may never be able to), what, then, could be viable applications of ML in the learning sciences?

Human / Machine distributed learning

The learning sciences aim to understand learning and then apply that understanding to improve teaching and learning. We argue that integrating human and ML can help learning sciences research in two ways. First, ML can help the validity and reliability of the qualitative research that develops theory. Nelson (2020) has developed a framework that incorporates unsupervised ML into theory-generating research that aims at making such research more reliable and valid through a three-step process. The first step leverages the power of computers in pattern detection in large datasets. The second step leverages the interpretative power of humans to add quality and depth to the quantity and breadth of the first step. The final third step uses computers to test the reliability and generalizability of the human refined pattern detection and interpretation from the second step. Second, ML can help to explore and exploit new data sources from digital learning environments. When students answer tasks on a computer, this gives researchers additional data beyond the answer itself. This data ranges from logs of keystrokes to biomarkers from wearables. For humans, such data is usually uninterpretable unless specific task affordances can be mapped onto specific patterns in data. Computers, however, can detect patterns in such data, inviting the use of unsupervised ML techniques. Further, especially in the case of voice data, powerful computer models exist to extract valuable information relevant to the understanding of students' learning.

Conclusion

Work in the learning sciences using ML currently focuses on automating coding processes. While impressive advances have been made in this area, unresolved issues regarding the ethics and mechanics of ML make it questionable whether valid and reliable automated coding is viable in the foreseeable future given the goals and values of the learning sciences. We argue for the value of ML beyond supervised methods, i.e., approaches that use unsupervised ML, and conclude that the true potential of ML does not lie in replacing humans but in supporting humans so that human and ML can be integrated into a product that is more than the sum of its parts.

References

Breiman, L. (2001). Statistical Modeling: The Two Cultures (with comments and a rejoinder by the author). *Statistical Science*, *16*(3), 199–231.

Nehm, R. H., & Haertig, H. (2012). Human vs. Computer Diagnosis of Students' Natural Selection Knowledge: Testing the Efficacy of Text Analytic Software. *Journal of Science Education and Technology*, *21*(1), 56–73.

Nelson, L. K. (2020). Computational Grounded Theory: A Methodological Framework. *Sociological Methods & Research*, *49*(1), 3–42.

O'Neil, C. (2016). *Weapons of math destruction: How big data increases inequality and threatens democracy* (First edition). Crown.

Pearl, J., & Mackenzie, D. (2018). *The book of why: The new science of cause and effect* (First edition). Basic Books.

Students' Epistemological and Positional Framing in Uncertain Situations during a Collaborative Design Activity

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Abstract: This study examines students' epistemological and positional framing when they collaboratively resolve uncertainties in a problem-solving process. We qualitatively analyzed three teams' discourse from the sixth standard classroom based on their behaviors in uncertain situations during design activity. We identified four types of students' epistemological framing and three types of positional framing in our data.

Introduction

Students experience uncertainties all the time in academic settings and there has been growing emphasis on ideas like problematizing content (Reiser, 2004) and engendering productive failure (Kapur & Bielaczyc, 2012) to help students meaningfully engage in and learn from uncertainties. However, how learning happens in a situation depends not only on teacher instruction and strategies but also on students' personal beliefs and understanding of the task they engage in and how they view their own and others' participation in that task (Greeno, 2009). We argue that it is crucial to understand learners' propensities in situations fraught with uncertainties for helping students productively grapple with uncertainties. This study explores this direction using 'Framing' as an analytical lens. The term "Framing" is used to describe an individual's interpretation and answer to the question - "What is it that is going on here?" (Goffman, 1974). Framing shapes how people experience situations, develop expectations, and make decisions (Hutchison & Hammer, 2010). For our analysis, we are particularly interested in two types of framing – students' epistemological and positional framing. Students' epistemological framing refers to their expectations and understanding about how to engage in the knowledge that they consider relevant for a task; in this case, the task of resolving uncertainty. Positional framing, on the other hand, refers to how students position themselves and others in their interaction (Greeno, 2009).We examined students' framing in the context of collaborative engineering design tasks since ill-structured nature of the design tasks makes them rich in providing students with opportunities to experience multiple types of uncertainties (Jordan & McDaniel, 2014).

Method

We conducted an engineering design activity in a sixth-grade classroom in a metropolitan city in India. In the study, we asked learners to design a balloon powered toy vehicle that travels straight and smooth for a larger distance. We randomly divided students in the class into groups consisting of either three or four participants to form twelve teams. For data collection purposes, we chose three teams based on the team's potential for providing rich data by virtue of active conversations between the members during the initial phase, where teams discussed problems among themselves. A materials kit was provided to the teams for constructing a prototype. Two primary researchers were present in the class as observers. The primary researchers were accompanied by three teaching assistants (TAs) from the same department. The primary role of the TAs was to handle the logistics related to audio and video data collection.

We analyzed video recordings using a coding scheme developed by Jordan et al. (2014) for identifying all the uncertainties that the team members experienced during the design activity . For each of the unique uncertainty identified in this step, we traced all the episodes where learners attempted to resolve them and then we transcribed these episodes. We then qualitatively analyzed students' discourse in each episode to identify their epistemological and positional framing. The unit of analysis is individual-in-group context (Hogan & Fisherkeller, 2005). We adapted the Interpretation Framework used by Shim et al. (2018) for our analysis. For sampling episodes to present in this study, we chose all the episodes related to the uncertainties regarding the issue of choosing an appropriate nozzle for the design. Students were given three different sized nozzles for building prototypes of their designs, and they had to choose one. This decision problem frequently triggered uncertainty for the team members in the problem-solving process.

Findings

In our data, we found different types of students' epistemological and positional framing. For example, there were instances when learners framed the uncertain situation as inquiry tasks where they engage in the exploration of "what," "why," and "how" questions related to the uncertainty they experienced. For example, students try to resolve uncertainty by figuring out the relationship of the uncertainty to the task goals, finding out factors that cause or influence the uncertainty, and figuring out how they can intervene to alter those factors. In other uncertain situations, learners viewed these situations as a task to be completed or a decision to be made to move ahead and complete the activity assigned to them. In such epistemological framing, students are least bothered about making sense of the events that caused uncertainty; instead, they make quick random decisions to resolve the uncertainty. There were also situations where learners resist engaging in any form of knowledge building as they do not see any epistemic value in pursuing it. In these situations, learners do not share the uncertainty expressed by other team members in the first place. We call this type of epistemological framing "Framing uncertain situation as not worth pursuing." In this frame, learners either ignore the uncertainty or express their unwillingness to participate in the knowledge construction process through their actions. Learners also frame an uncertain situation as "resolvable by an authority figure" when they expect to construct knowledge to resolve uncertainty by receiving direct instruction from an authority figure. Instead of engaging in sensemaking activities, students desire an authority figure like a TA or a teacher to provide immediate solutions to resolve their uncertainty.

Regarding students' positional framing, one of the framings that we observed was where students positioned themselves and the other team member(s) in a "supervisor-assistant" kind of relationship. In this kind of positioning, "supervisor" is regarded as decision-making authority, and the assistant seeks the go-ahead from the "supervisor" for their work. Student positioning oneself as "supervisor" delegates work and direct instructions to those positioned as "assistant." For the cases in this category, we saw an implicit agreement of the roles students positioned for one another where team members positioned as "assistant" readily agreed to follow the "supervisor's" instructions. Students also often positioned themselves and other teammates as legitimate collaborators in the uncertainty resolution process. This kind of positioning is characterized by behaviors where students collaboratively solve uncertainty by seeking and considering each other's help, ideas, suggestions, and viewpoints. A few instances were where a participant treated other team members as unimportant or valueless to the team. Positioning a team member as an "insignificant member" is different from positioning the person as an "assistant." An assistant is regarded as a legitimate member of the team who has a specific role in the uncertainty resolution process. Positioning a person as an insignificant member indicates that the person is considered little to no value to the team's progress or success.

Conclusion

The finding also aligns with the previous studies, which show that students' framing is dynamic (Hutchison & Hammer, 2010; Shim & Kim, 2018). Students respond to various cues and accordingly keep shifting their framings. Expecting that students should always show productive framing like the "inquiry" frame might not be helpful. Instead, it would be beneficial to understand factors contributing to student framing and make efforts to orient them into the productive direction slowly. In future work, we expect to delve deeper into students' framing dynamics and have a nuanced understanding of moment-to-moment shifts in students' responses to uncertainties.

References

Goffman, E. (1974). *Frame analysis: An essay on the organization of experience.* Harvard University Press.

Greeno, J. G. (2009). A theory bite on contextualizing, framing, and positioning: A companion to Son and Goldstone. *Cognition and Instruction*, *27*(3), 269–275.

Hogan, K., & Fisherkeller, J. (2005). Dialogue as data: Assessing students' scientific reasoning with interactive protocols. In *Assessing Science Understanding* (pp. 95–127). Elsevier.

Hutchison, P., & Hammer, D. (2010). Attending to student epistemological framing in a science classroom. *Science Education*, *94*(3), 506–524.

Jordan, M. E., & McDaniel, R. R. (2014). Managing Uncertainty During Collaborative Problem Solving in Elementary School Teams: The Role of Peer Influence in Robotics Engineering Activity. *Journal of the Learning Sciences*, *23*(4), 490–536. https://doi.org/10.1080/10508406.2014.896254

Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, *21*(1), 45–83.

Reiser, B. J. (2004). Scaffolding complex learning: The mechanisms of structuring and problematizing student work. *The Journal of the Learning Sciences*, *13*(3), 273–304.

Shim, S., & Kim, H. (2018). Framing negotiation: Dynamics of epistemological and positional framing in small groups during scientific modeling. *Science Education*, *102*(1), 128–152.

International Society of
the Learning Sciences

Learning to be Open: Expansive Family Networks and Emotional Support as Connection Pathways

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Abstract: We bridge Eco's theory of openness with a connected learning framework to explore how openness supports teaching artists designing for distance learning. We used case study methods to address our overarching question, *what is the value of openness for teaching and learning?* We found that an orientation toward openness supported teaching artists in designing learning experiences that expanded family networks and provided emotional support to connect youth to teachers, peers, and family across settings.

Introduction

Openness has been explored across contexts, including Eco's (1989) poetics of openness, characterized by a plurality of co-existing interpretations of a work of art. Though some educational theorists have discussed how openness and education intersect (e.g., Campbell, 2018), little work has explored how teachers explicitly use openness as a principle for design. In this poster, we bridge Eco's theory of openness with a connected learning framework (Ito et al., 2020) to explore how openness supports teaching artists designing for distance learning, guided by the following research questions: 1) How do teaching artists define openness in the context of their teaching and curriculum? 2) To what extent does an open approach support pathways to connected learning?

Background: Openness and connected learning

Eco (1989) emphasizes the end product of a work of art as a "work in movement," which invites multiple interpretations from the audience. Campbell (2018) extends Eco's poetics of openness as a pedagogical value teachers instill as students apply their "existential credentials" to interpreting works of art. Such open-ended processes are a hallmark of connected learning where openness has meant an openly-networked learning environment and an openness to approaches and settings (Ito et al., 2020). Within a digitally mediated landscape, connected learning recognizes that youth interests, supportive relationships, and future learning pathways are critical to enduring learning experiences (Ito et al., 2020). When bridging the connected learning framework with theories of openness, we can consider how openness intersects with relationship-building, youth interests, and pathways to future opportunities.

Methods

Chicago Arts Partnerships in Education (CAPE) is an established nonprofit arts organization that fosters long-term partnerships between teachers and teaching artists who co-teach inquiry-based, arts-integrated units in K-12 classrooms and after school programs. During the 2019-2020 academic year, CAPE staff curated professional development inviting its teachers and teaching artists to explore Eco's concept of openness within their curriculum and instruction. With the COVID-19 pandemic causing schools to close, openness took on a new form, prompting reflection on issues like space, the body, student voice, and identity (Sikkema, 2020).

This poster presents a case study (Stake, 1995) to describe how CAPE teaching artists designed for openness. We triangulated across semi-structured interviews transcribed via Zoom, original Tumblr posts showcasing work teaching artists shared with their students, and written multimedia reflections. 50% (17/34) of teaching artists participated in the study, a representative sample across arts disciplines, grades taught, and years with CAPE. We selected teaching artist Aram Atamian to illustrate links between connected learning and openness. Aram taught photography and theatre and had been working with CAPE for 1 year, describing himself as an "interdisciplinary diasporan artist." We used an open approach to coding to understand how teaching artists enacted openness within their teaching and mined for evidence of how open approaches intersected with connected learning. We looked for the following themes: *focus on relationships*; *expanding youth social networks*; *sponsorship of youth interests*; *shared practices*; *shared purpose*; and *connecting learning across settings*.

Findings

We found that artists described openness as *flexibility, improv, adapting*; *a focus on process more than product*; *something for which there were intentional structures*; *about following students' lead and continual discussion*; *offering agency*; *choice, and options*; *embracing possibilities*, *exploration, and imagination*; *and 'breaking" the school day.* Openness took on a different form during the pandemic, which stretched teaching artists to be, as one artist put it, "even more open." Teaching artist Aram described openness as "getting it wrong" and "not worrying about getting it right." He created space for "emotional openness" in his lessons through informal life check-ins with students and making space for their lived experiences. He emphasized individual perspective and "continual discussion" when interpreting images. To Aram, openness was intentional and "deliberately structured." In terms of space, he described a shift in the physical layout of the classroom, using openness to rethink and "break the school day." In designing for distance learning online, Aram encouraged activities away from the digital screen such as sending students on what philosopher Guy Dubord named a dérive, or a new walk around a familiar place. For this exercise, Aram invited students to explore their homes from different levels and angles and to observe how the walk shifted their perceptions of familiar spaces and corners.

Openness to strengthen relationships and build networks between families

Aram reflected on how the pandemic created an unexpected opening to *strengthen family relationships* by inviting families to be part of the learning experiences he and his co-teacher designed. For the Poetry Chain project, Aram and his co-teacher introduced students to haikus through reading examples and explicitly teaching the "5-7-5" structure. To begin, one student wrote a haiku, which was then given to a different student to take a photograph representing the haiku. Finally, this photograph was given to another student's parents to write an additional haiku inspired by the photograph without reading the original haiku. The three elements—two haikus and the photograph—were then presented as a cohesive unit, which revealed "humorous, poignant, surprising variations of perspective between generations." A focus on family relationships allowed Aram to *connect learning across settings* to break down the boundaries between school and home and leverage family cultural assets to surface everyday practices that might otherwise go unnoticed. In reflecting on the success of the family photography unit, Aram explained that he "really wanted to design more projects that are explicitly about inter-family collaboration" and find new ways for students and families to purposefully interact. By operating from a place of "emotional openness," Aram highlighted the value of building and expanding upon youth social and family networks that could open new pathways to learning. Families can be positioned as experts who connect students to resources needed to further their interest-driven learning, including necessary materials, a place to do their work, and discipline-specific expertise (Ito et al., 2020). Social networks within the class created feelings of connectedness across families and sparked additional ways to connect to resources and opportunities.

Discussion

In this poster we demonstrated how teaching artists' orientation toward openness supported the design of online learning experiences that expanded inter-family networks and provided emotional support to students. Implications extend how openness and connected learning manifest in learning environment design, with an emphasis on how openness was translated through teaching artists' pedagogy. Our study emphasizes the value of cultivating supportive relationships between teachers and students and connection-building through family networks. Through intentional design choices motivated by openness, teaching artists can create connection pathways that strengthen family relationships and connect learning across settings.

References

Campbell, C. (2018). Educating openness: Umberto Eco's poetics of openness as a pedagogical value. *Signs and Society, 6*(2), 305–331. https://doi.org/10.1086/695567

Eco, U. (1989). *The open work.* (A. Cancogni, Trans.) Harvard University Press. (Original work published 1962).

Ito, M., Arum, R., Conley, D., Gutiérrez, K., Kirshner, B., Livingstone, S., Michalchik, V., Penuel, W., Peppler, K., Pinkard, M., Rhodes, J., Salen Tekinbas, K., Schor, J., Sefton-Green, J., & Watkins, S.G. (2020). *The Connected Learning Research Network: Reflections on a decade of engaged scholarship*. Connected Learning Alliance.

Sikkema, S. (2020). Navigating COVID-19 and school closures via a connected network of teachers, artists, and students. In K. Fashing-Varner, S. Bickmore, D.G. Hays, P. Shrader, D. Carlson & D. Anagnostopolous (Eds.), *The corona chronicles*: *On leadership, processes, commitments, and hope in uncertain times.* DIO Press.

Stake, R. E. (1995). *The art of case study research*. Sage.

Scaling Teacher Candidates' Family Engagement Training Through Simulations and Artificial Intelligence

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Abstract: This study explores a new technique to expand family engagement practice opportunities for teacher candidates, who often have limited opportunities to build family engagement skills. We designed a standardized, simulated family conference and developed a performance rubric. The rubric allows performance to be scored automatically, using semantic similarity analysis techniques, as well as by humans. This study demonstrates the potential of simulations and NLP techniques to create novel practice opportunities for teacher candidates.

Keywords: scale, family engagement, NLP, teacher education, simulations

Introduction

The overwhelming majority of novice teachers have not been well prepared on how to interact with students' families and on how to run family conferences (Dotger, Harris, & Hansel, 2008). Family conferences, also known as parent teacher conferences, happen only a few times a year and can build or damage the home-school relationship (Potter & Bulach, 200). Building teacher candidates' expertise requires realistic practice opportunities, which have been challenging to provide in field placements and coursework (Dotger et al., 2008). Some teacher educators have begun integrating simulated family conferences into their coursework as a way to increase teacher candidates' practice opportunities (Dotger et al., 2008; Walker & Legg, 2018). Simulation technologies, such as Mursion's mixed-reality platform, could allow teacher preparation programs to offer family engagement practice opportunities at a larger scale. Mursion provides an animated classroom where teacher candidates interact with student avatars that are controlled in real time by a live actor. The technology allows for standardized practice opportunities and structured transcripts that can be analyzed through NLP techniques. NLP techniques focused on semantic understanding of text have been used to automate the scoring of student work (Litman, 2016). NLP techniques have the potential to transform scoring and automate feedback for family conferences as well. In this study, we explore new ways to provide candidates with family engagement practice through integrating simulations and machine learning.

Methods

Development of standardized scenario and scoring

In spring, 2020 105 teacher candidates participated in two rounds of a seven minute simulated family conference with the father of a high-achieving, but shy student in their simulated classroom. During the meeting, the father interrupted at five set time points with questions about the teacher's experience, worries for his child, and personal information about his own challenges at work. After the simulation, each candidate's two simulation sessions were transcribed and scored using a researcher designed rubric. The rubric, which draws on Walker and Legg's (2018) rubric but is highly tailored to this scenario, has nine scoring categories, focused on teacher's rapport building during the opening of the conference and how the teachers respond to challenging comments and empathetic opportunities provided by the parent. Candidates receive a score of one, low, to three, high, in each category and the scoring rubric includes five exemplar responses at each scoring level. For example, when dad says, "Experience makes a difference and her other teachers had so much more experiences," candidates received a score of three if they responded positively, such as by saying, "I know that I'm new to teaching. That's why I wanted to reach out to you." Twenty percent of the transcripts were double coded with 82% accuracy.

Using semantic similarity analysis to automate performance scoring

We then evaluated the semantic similarity of text with a pre-defined human rubric (See Figure 1). Our approach to this evaluation includes both category identification and evaluation within each category. To identify the category, we use state of the art text classification approaches based on transfer learning (Devlin et al., 2018). Transfer learning approaches require less data for classification and are also more robust to out of distribution word patterns and usage. These techniques allow us to identify if a response belongs to, for example, the greeting or student strengths category. Within each category, evaluation is iterative. Since we have delineated evaluation criteria and exemplar responses, we can measure semantic similarity in each category to score the responses. We can examine how closely a response in a category matches exemplars for that category. For example, "I'm so sorry to hear that. Is there anything I can do?" is highly similar to "Okay, are you doing okay?... Well, I'm very sorry to hear that," and dissimilar from, "If you don't mind, let's go back to Katie." For evaluation, we followed STS benchmarks (Semantic textual similarity wiki, n.d.) and used Pearson correlation coefficients to score the semantic similarity. Downstream training of the task will improve semantic similarity across all categories.

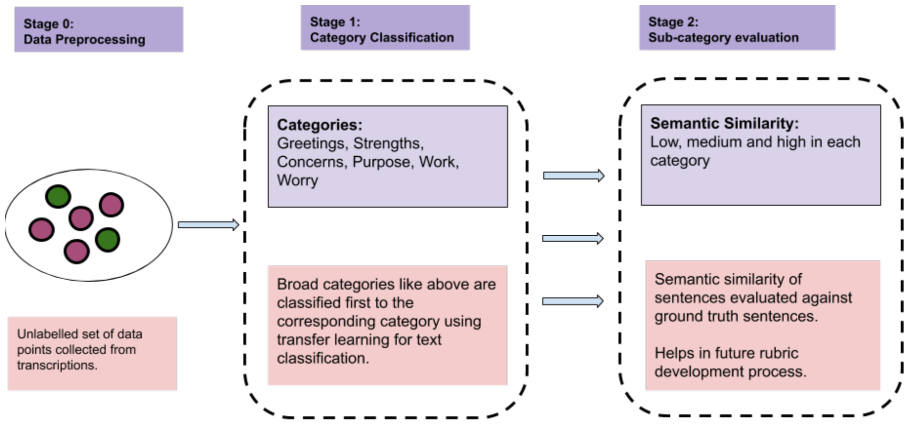

Figure 1. Evaluation protocol and architecture of NLP system.

Results and conclusion

Family conferences are two-party conversations that can go in many different directions based on the input of each party, making them challenging to standardize. We found, however, that many teacher candidates, even without training on conference, begin with a greeting, a statement of the student's strengths, and information on the teacher's concerns and the meeting's purpose, creating a natural standardization for scoring. We also used standardized lines to understand how teacher candidates respond to challenging comments and empathetic opportunities. We found that candidates' responses to empathetic opportunities varied in part on how personal the disclosures were, with teacher candidates showing more ease when the opportunities were about the child than when they were about the parent. Further, the two step classification process enabled us to build robust downstream classifiers using the latest developments in NLP and deep learning. In future, we plan to train models with larger datasets to make the evaluation process more robust. We also plan to use the findings from the machine learning analyses and what we have learned about candidates' strengths and needs to develop automated feedback on the scenario. Students and their families deserve teachers who are ready to build partnerships on day one. While our work continues, our novel approach of building NLP techniques into simulations has the potential to transform pre-service teachers' practice and feedback opportunities in family engagement and beyond.

References

Devlin, J., et al. (2018). Bert: Pre-training of deep bidirectional transformers for language understanding. *arXiv preprint arXiv:1810.04805*.

Dotger, B. H., Harris, S., & Hansel, A. (2008). Emerging authenticity: The crafting of simulated parent-teacher candidate conferences. *Teaching Education, 19*(4), 337– 349.

Litman, D. (2016). Natural language processing for enhancing teaching and learning. *Proceedings of the Thirtieth AAAI Conference on Artificial Intelligence* (AAAI-16).

Potter, L., & Bulach, C. (2001). Do's and don'ts of parent-teacher conferences. *Education Digest, 66*(9), 37-40.

Semantic textual similarity wiki (n.d.). STSbenchmark. Retrieved from http://ixa2.si.ehu.es/stswiki-/index.php/STSbenchmark

Walker, J., & Legg, A.M. (2018). Parent-teacher conference communication: a guide to integrating family engagement through simulated conversations about student academic progress. *Journal of Education for Teaching, 44*(3), 366-380.

Acknowledgements

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A Dynamic Social Network Approach to Capturing Shared Regulation Interactions in Collaborative Learning

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Abstract: Socially shared regulation, where students jointly coordinate understanding, motivation, and behaviors, is fundamental to successful collaboration. However, the social dynamics at the core of regulation are difficult to detect and understand. We apply relational event modeling, a dynamic network approach, to examine the interactional dynamics between students in different regulatory processes in a project-based learning engineering context. Findings suggest that reciprocity and shared partnerships were associated with how likely students might interact. Female students were less likely to engage in planning and monitoring exchange. We discuss implications for promoting equal participation in collaborative learning.

Introduction

To promote effective collaboration, students need the socially shared regulation strategies to jointly coordinate motivation, cognition, and behaviors (Hadwin, Järvelä, & Miller, 2011). Understanding the processes and social contexts in which students regulate shared efforts is important to detect and promote effective collaborative learning. Relational event modeling (REM) offers key affordances for understanding social dynamics in different regulation processes. First, this approach allows us to account for interactional histories between student dyads and examine how these interactions differ between regulatory processes. Second, our REM models consider potential individual differences in interaction patterns. The following questions guided our research:

RQ1. What interactional dynamics may characterize different regulated learning processes?
RQ2. How do interactional dynamics in regulated learning differ by gender and leadership positions?

Methodology

This study was part of a larger project that focuses on collaborative group exchange in a two-term, first-year project-based engineering course in Western United States. Our data came from 22 first-year students in four teams, who were taking the elective course as introduction to engineering. The sample represents the overall course demographics (22.7% women, 72.7% Latinx or Asian students).

Analyses drew from the audio and video transcripts of the teams' in-person discussion in lab at the midpoint of the semester (8-hour audio data). At this point, students had been introduced to fundamental engineering principles and started developing their group products: creating autonomous quadcopters or fitness trackers. We watched the videos of team discussion to denote the direction for the exchange. Then, we identified shared regulation by selecting the discourse chunks where students were identifying shared tasks, co-planning strategies, and executing tasks towards common goals ($n = 2{,}462$ conversational turns). We coded these discourse segments by individual talk turn for different processes of task understanding, strategic planning, execution, progress monitoring, and reflection (Nguyen, Lim, Wu, Fischer, & Warschauer, 2021). We achieved substantial agreement among the coders on 10% of the data (Cohen's $\kappa = .87$). We then applied REM on the coded dataset.

Using the REM method, student exchange can be visualized as a network of nodes (e.g., students), edges that indicate the exchange directions (e.g., sender or receiver), and the strength of connections between two nodes (e.g., frequency). A relational event can be defined as something generated by a student, that is directed toward one or more students at a particular point in time (Butts, 2008). Intuitively, the REM is a logistic regression model that predicts the probability of the next event (i.e., next interaction between students).

We ran separate REMs for the overall dataset ($n = 2{,}462$ turns), and for separate processes: Plan ($n = 435$), Execute ($n = 1{,}563$), and Monitor ($n = 216$). We excluded subsets of Task Understanding and Reflection, due to their low occurrences. Because we did not find differences in the trends of relational interactions in separate REMs for each of the teams, we focused on reporting the overall patterns. Building on prior work, our REMs (Table 1) included past events as predictors. For example, *reciprocity* (student A->B->A) plays a key role in helping teams overcome setbacks (Järvelä, Järvenoja, & Malmberg, 2019). Because the process involves multiple group members working towards shared goals, there could be *participation shifts*, where a group member who is not involved in the conversation joins the regulatory exchange (student A->B->another student Y). Alternatively, there could exist *recency* effects, where two students who are already engaged in the initial conversations sustain regulatory actions (A -> B -> A -> Y). Finally, we accounted for *outbound shared partners* (i.e., if A and B send exchange to similar partners; A and B are more likely to interact). We also included individual attributes, namely gender (female = 1) and leadership position in the group (leader = 1).

Findings

On average, within the course of the lab session, students sent 10.97 exchange ties, SD = 6.06, and received 10.31 ties, SD = 6.48. Non-parametric Mann-Whitney-U tests suggest no significant differences in the number of exchanges sent and received by female versus male students (send: W = 34; $p = .33$; receive: W = 30; $p = .20$), or group leaders versus others (send: W = 14; $p = .07$; receive: W = 19; $p = .16$).

RQ1: Reciprocity and Shared Partners are the Norm across Regulation Phases

We first examined the extent to which past interactional norms predicted subsequent shared regulation. For the overall regulation and subprocesses of planning, execution, and monitoring, we found that reciprocity significantly predicted the likelihood of an exchange (OR = 5.786, SE = .115, $p < .001$).

We found that the numbers of students that two individuals both sent exchange to affected their future rates of interactions. This likely reflects a working norm that we qualitatively observed in the project-based engineering groups, where students often divided themselves into smaller groups to work on subtasks. Consequently, partners who worked on the same subtasks may be more likely to send exchange to one another.

Notably, we found that a participation shift in progress monitoring, where the receiver of an exchange was 2.27 times more likely to direct the next exchange to another student. An example for this participation shift is when the groups were working on different subtasks and routinely checked in with one another.

RQ2: Female Students were Less Likely to Engage in Planning and Monitoring

We did not find difference in the likelihood that male and female students sent an exchange in the overall sample or in the execution phase. However, female students were .80 times less likely to engage in an interaction in planning, and .65 times less likely in strategic monitoring. Successful participation in all regulatory phases, particularly looping between planning and executing, has been associated with higher quality engineering design (Ahmed, Wallace, & Blessing, 2003). Our findings highlight the need for instructional and collaborative practices that promote equity and inclusivity across all regulatory phases. For example, in-time, direct instructional scaffolds that emphasize the input of all team members have shown promise in helping students to engage in self and shared regulation processes (Järvelä et al., 2016).

Conclusions

We explore regulation processes from the novel perspective of past social relations. We found that reciprocity and shared partnerships predicted how likely students might interact. We observed differences in regulatory processes, which suggest that not all learners were equally involved in dyadic exchange in each process. Although there was no difference in the number of exchanges on a surface level, our more nuanced analyses reveal different gender attributes and relational dynamics that contribute to student interactions, with key implications for their experiences and learning outcomes. We illuminate the affordances of accounting for individual attributes to acquire a deeper understanding of the learning processes.

References

Ahmed, S., Wallace, K. M., & Blessing, L. T. (2003). Understanding the differences between how novice and experienced designers approach design tasks. *Research in engineering design*, *14*(1), 1-11.

Butts, C. T. (2008). 4. A relational event framework for social action. *Sociological Methodology*, *38*(1), 155-200.

Hadwin, A. F., Järvelä, S., & Miller, M. (2011). Self-regulated, co-regulated, and socially shared regulation of learning. *Handbook of self-regulation of learning and performance*, *30*, 65-84.

Järvelä, S., Kirschner, P. A., Hadwin, A., Järvenoja, H., Malmberg, J., Miller, M., & Laru, J. (2016). Socially shared regulation of learning in CSCL: Understanding and prompting individual-and group-level shared regulatory activities. *International Journal of Computer-Supported Collaborative Learning*, *11*(3), 263-280.

Järvelä, S., Järvenoja, H., & Malmberg, J. (2019). Capturing the dynamic and cyclical nature of regulation: Methodological Progress in understanding socially shared regulation in learning. *International Journal of Computer-Supported Collaborative Learning*, *14*(4), 425-441.

Nguyen, H., Lim, K. Y., Wu, L. L., Fischer, C., & Warschauer, M. (2021). "We're looking good": Social exchange and regulation temporality in collaborative design. *Learning and Instruction*, *74*, 101443.

Participatory Design of Game-Based Math Learning Platform: Teacher-Researcher Negotiation and Collaboration

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Abstract: Teachers' involvement legitimizes learning artifacts design, development, and implementation. We present a case study on the teacher-researcher participatory design of a game-based math learning platform. A thematic analysis with the empirical data from two teacher workshops indicated (1) problem spaces that frame participatory design; and (2) tool that supports sustainable participatory design of game tasks. We discussed suggestions for teacher-researcher participatory designs for DGBL.

Introduction and theoretical background

The educational affordances of digital game-based learning environments (DGBL) had drawn much attention of educational researchers and practitioners. However, it is still a challenge to implement game-based learning in the classrooms. The design and implementation of game-based learning technologies cannot be successful without the involvement of teachers (Matuk et al., 2016). Research-practice partnerships, more specifically, teachers' participatory co-design with researchers should be emphasized in the process (Coburn & Penuel, 2016; Matuk et al., 2016). Teachers' participatory co-design for game-based learning is a bidirectional and reciprocal participation between researchers and practitioners. The aim is to design a more practicable learning environments and increase the scalability and sustainability of implementation (Coburn & Penuel, 2016). Participatory design engages multiple stakeholders in envisioning and prototyping of learning environments in creative design activities beyond decision-making; through positioning and situating stakeholders' rationale and input, the design can be enhanced (Bjögvinsson et al., 2012; Muller & Kuhn, 1993). In participatory design, teachers and researchers could bring different point of views. These exchanges of view, negotiation, and collaboration should be rooted in and focused on designing learning technologies to solve an educational problem with mutual agreement. Bjögvinsson et al. (2012) put it as *designing, staging,* and *infrastructuring* (p. 103). Both teachers and researchers gain legitimate participation, working on artifacts, and brainstorming about how to make the design artifacts more scalable and sustainable for use in the classrooms.

An increasing focus have been given to understanding participatory design research and partnerships between communities of researchers and practitioners (Coburn & Penuel, 2016; Matuk et al., 2016). However, there is still a gap in the literature regarding the landscape of the participatory design and "what happens" in the process despite an extensive advocacy. Thus, the following research question remains underexplored: *how do teachers and researchers negotiate and collaborate in the participatory design of a game-based math learning platform?*

Method

We collected data from the teacher workshops conducted in the southeastern US for the purpose of designing an architectural game-based math learning platform called *E-Rebuild* (Ke et al., 2019) as well as exploring game-based pedagogies with teachers. We used two artifacts of *E-Rebuild*: the learning game *per se* and the level editor (for customizable level design with the teachers). The game was intended for middle school students. We invited 10 teachers from two schools to participate in both teacher workshops and the participatory design process (Muller & Kuhn, 1993; Bjögvinsson et al., 2012). The first workshop was conducted with 3 teachers from a suburban charter school. The second workshop was held for seven teachers from a suburban public school in a fourteen-week design-based cycle. Each workshop was conducted for about eight hours. To study design-based teacher-researcher collaborations, we adopted a case study approach (Yin, 2009) for an in-depth and in situ investigation of the negotiations and collaborations between teachers and researchers. We collected data from participatory observations, screen recorded videos, semi-structured interviews, and design artifacts analysis. In the first round of data analysis, we reviewed the videos and dataset with open-coding technique to identify informative codes. Next, we engaged in the second wave of data analysis with axial coding and selective coding; we used a constant comparative method for emerging themes identification. Multiple data sources as well as reflexive journals and memos during two cycles of data analysis established trustworthiness.

Results

Problem spaces that frame participatory design

In participatory design, a mutual understanding of the *problem space* that both teachers and researchers are working on is critical. The knowledge sharing started from the recognition of the problem spaces. Researchers and teachers were observed engaging in stages of building shared understanding and orienting the *problem space* for participatory design before proceeding to the knowledge sharing stages. Teachers from two schools first acknowledged the challenges they are facing in math education: *lacking real world examples*. This shared understanding of problem was identified between the teachers and researchers. Both agreed that DGBL could be infused to resolve this problem. Specifically, the game environments and features designed could create *connections* between content learning and disciplinary practices: "*If you are going to school and teaching kids numbers, the concept of numbers, they have a purpose. You don't just go to school and put down on a paper and tell them you have to do it*" (Teacher G).

After the problem spaces have been mutually agreed, teachers were engaged in gameplay to visualize and concretize the artifacts to be co-designed. During the process, teachers contributed ideas for the game refinement by considering how the students would perceive what they are experiencing in the problem spaces. For example, one teacher commented, "*The ratio and proportion ones, they are…our kids probably can do that. But then…some bizarre ones they have to figure out. Like this one (while pointing the mouse to a Challenge of Ancient Mesopotamia in the game environment)"* (Teacher F). This perspective-taking stance is a common strategy teachers used during design collaborations. Furthermore, teachers and researchers were counterbalancing and reconciling the philosophy of teaching and learning with DGBL. Teachers brought up the reality of limited time in the classroom that makes it harder for the students to practice math thinking in the constructivism DGBL. They envisioned how DGBL could possibly complement their math instruction by saying, "*It should be used more for an enrichment thing*, *it gives more hands-on, yeah, I can see that*" (Teacher H).

Tool that supports sustainable participatory design of game tasks

When using the level editor, teachers asked the possibilities of creating a community *for* teachers to share customizable design artifacts and improve practice, "*If there is a teacher, say, in Lea county* (pseudonym)*, she made a…a question, on the same concept or levels that I am using, is there a thing that I am able to see, so that I won't have to recreate"* (Teacher I)? Moreover, teachers proposed to involve students in using the level editor as a learning-by-making tool, *"If the students use the level editor to build their own game, they will better understand the concept*, and *they will see why the problem looks like that, and they will tell the story based on that*" (Teacher H). These ideas suggested that the level editor supported sustainable participatory design for more game levels.

Conclusion and implications

The study findings portrayed teacher-researcher participatory design. They underscored the phenomena of teachers' perspective-taking as students in providing insights for participatory design in problem spaces. They also indicated the role of a participatory design tool in enacting or supporting a community for teachers' collaborative and participatory design of game-based learning tasks or artifacts. We argue that participatory design of teachers with researchers should emphasize teachers' voices to transform the process of design and implementation of DGBL, and the participatory design process should be sustainable to ground DGBL in practice.

References

Bjögvinsson, E., Ehn, P., & Hillgren, P. A. (2012). Design things and design thinking: Contemporary participatory design challenges. *Design issues, 28*(3), 101-116.

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher, 45*(1), 48-54.

Ke, F., Shute, V., Clark, K. M., & Erlebacher, G. (2019). *Interdisciplinary design of game-based learning platforms*. Springer.

Matuk, C., Gerard, L., Lim-Breitbart, J., & Linn, M. (2016). Gathering requirements for teacher tools: Strategies for empowering teachers through co-design. *Journal of Science Teacher Education, 27*(1), 79-110.

Muller, M. J., & Kuhn, S. (1993). Participatory design. *Communications of the ACM, 36*(6), 24-28.

Yin, R. K. (2009). *Case study research: Design and methods* (4th Ed.). Thousand Oaks, CA: Sage.

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Designing Narratives in Multimodal Representations for Game-Based Math Learning and Problem Solving

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Abstract: Narratives as a game feature constantly yield mixed results for learning in the literature. In this case study, we studied the design of narratives in multimodal representations for game-based math learning and problem solving with 27 student participants. Results indicated that narratives with multimodal representations situated in the game world appeared to foster math sensemaking and reasoning. However, decontextualized math problem solving was also observed. Implications for narratives and multimodality design were discussed.

Introduction and theoretical background

Digital game-based learning (DGBL) environments have been used to provide authentic mathematical experience—exploring, formulating, and experimenting with mathematical hypotheses in the game world. Although the overall effect of DGBL for math is promising, prior research findings regarding specific design features remain controversial. The effects and design features of narratives, in particular, remain murky.

According to Bruner's (1964) learning theory, an individual's meaning making process involves three modes of representation: enactive representation (e.g., motor response or action: maneuvering in-game objects), iconic representation (e.g., images, graphics, or objects in a game), and symbolic representation (e.g., symbol systems or texts). These three modes of representations can be coordinated as *multimodal representations* that set a foundation for the design and interpretation of learning in the game space (Ainsworth, 2006; Ke & Clark, 2020).

The current case study aims to examine narratives in multimodal representations for game-based math learning. Particularly, the following research question is investigated: *What are the impacts of narratives in multimodal representation on learning in a game-based math learning environment?* In the current study, we employed a 3D architectural math learning game called *E-Rebuild* (Ke & Clark, 2020). The system of narratives in multimodal representation in *E-Rebuild* consist of (1) task narratives (i.e., explaining the task of each level for the learners), (2) contextual narratives (i.e., providing a storyline at the beginning of the task narratives), (3) math notation (i.e., a mouseover feature inscribed on the game creates), (4) concrete stimuli (i.e., tool to retrieve symbolic math information), and (5) environmental cues (i.e., popups reminding learners what went wrong). Measuring, trading, building, and allocating items in the 3D game world are major game actions designed to integrate mathematical learning actions while simulating architecture-themed problem-solving processes.

Method

To examine how the players use and interact with the narratives designed in the multimodal representation, we adopted a heuristic case study method in which each participant is a case (Merriam, 1998). As part of a longitudinal design-based research, 27 college students with variant genders, gaming experiences, and academic backgrounds were recruited as users to inform our designs in this study (Merriam, 1998). These participants played the game for one and a half hours individually, with a researcher closely observing the gameplay and providing technical support as needed. Immediately after the gameplay, a thirty-minute semi-structured interview was conducted to further collect the data on participants' gameplay experiences and perceptions. Rich data were triangulated between observations, video recordings, semi-structured interviews, and gameplay artifacts created by the learners. We performed three phases of data analyses: (1) open and descriptive coding techniques. (2) revisited the codes, revised and developed themes emerged from the data; created visuals and displays to demonstrate the relationships of the themes delineated. (3) executed queries. We wrote memos and kept reflective journals, as well as analyzed deviant cases for confirmability and credibility (Miles et al., 2020). We focus on general themes and highlight salient cases with displays in this paper.

Results

Narratives in multimodal representation supported math problem solving

In general, the narrative system in multimodal representation functioned to support math problem-solving exploration. To elaborate, all participants started their gameplay by reading the task narratives. However, it wasn't natural for some participants to engage in math problem solving after reading the task narratives. Specifically, a random trial-and-error stage was observed, as demonstrated in the following example (See Figure 1, Right). After several rounds of trial-and-error, the narrative system prompted Participant 19 to purposefully engage in math reasoning and problem solving. He collected the task-related math information (*the height and width of the container*) from distributed task narratives (e.g., in the Task Panel and object-related tool tips). He then organized the task information while adjusting his hypothesis with the task (see *Stage 3* in Figure 1, Right). He strategically and carefully adjusted the number of families to each container. During the process, he carefully read the math notations while calculating the space needed in the 3D game world. His math reasoning process was prompted and mediated by the narrative system in multimodal representation that legitimized math-related gameplay strategies during game-based problem solving.

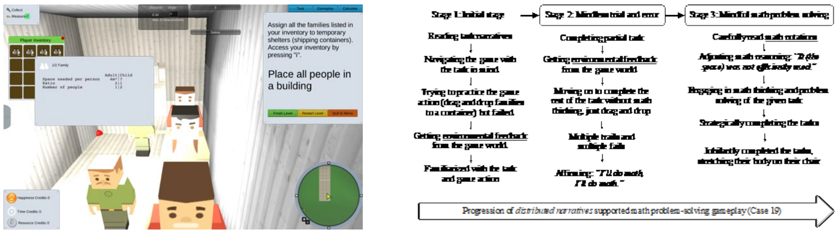

Figure 1. (Left) An example of narratives system in the game. (Right) A visual display of Participant 19's gameplay supported by distributed narratives

"Decontextualizing" math problem and the narratives

Although a body of evidence from participants supports that narratives in multimodal representation are useful in mediating math problem solving in the game world, some case analysis still indicated a deviant phenomenon. Take participant 4 for example, the multimodal narrative system did not make him cognitively flexible. In a level where he needs to process the concept of ratio in the math notation to tackle the design task, he got stuck and showed frustration. Instead of interpreting the given math notation, he used the measure tool to *measure the height* of the game object to calculate the *surface area* in square meter: "*when I do math, I feel like to measure*." He kept trying the same strategy rather than searching for alternative solutions or clues embedded in the game world. This behavior demonstrated that he was not flexible in terms of math thinking and problem solving given his consistent efforts contributed to the same solution or strategy. The case highlighted the essential role of providing a mechanism in multimodal representation to promote flexibility in experimenting with and comparing alternative problem-solving strategies.

Conclusion and implications

In this case study, distributed narratives designed in the math learning game appeared to coordinate and enhance math sensemaking and reasoning (Ainsworth, 2006). Yet, this learning process did not naturally occurred in a single form of representation (i.e., task narratives in symbolic representation). Instead, it was the narratives in multimodal representation that mediated and prompted mindful math problem solving. There are two implications for designing narratives in DGBL. First, DGBL narrative features should be intrinsically integrated into the game environments to provide a coherent system that engages learners in mindfully doing and thinking math. Second, deviant cases speak to the importance of designing narratives that stimulate cognitive flexibility. Future research should continue to explore how narratives can afford multimodal feedback for flexible math problem solving.

References

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and instruction, 16*(3), 183-198.

Bruner, J. S. (1964). The course of cognitive growth. *American Psychologist, 19*, 1-15.

Ke, F., & Clark, K. M. (2020). Game-based multimodal representations and mathematical problem solving. *International Journal of Science and Mathematics Education, 18*(1), 103-122.

Merriam, S. B. (1998). *Qualitative research and case study applications in education*. San Francisco, CA: Jossey-Bass.

Miles, M. B., Huberman, A. M., & Saldaña, J. (2020). *Qualitative data analysis: A methods sourcebook* (4th ed.). Thousand Oaks, CA: Sage Publications.

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International Society of the Learning Sciences

Assessing Pedagogical Practices to Support Self-Regulated Learning in Science

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Abstract: The goal of this study is to examine how teachers implement opportunities for students self-regulated learning (SRL) provided by computer-based student-centered and interactive digital curricula, through pedagogical practices in natural classroom contexts. To meet this goal, we developed an observation tool that distinguishes varying extents to which teachers apply SRL-supportive practices. Our ultimate goal is to raise teachers' awareness of best practices with respect to SRL, thereby supporting them in improving their teaching.

Keywords: Educational technology, pedagogy, self-regulated learning, student-centered learning

Major issues and significance

Self-regulated learning (SRL) is the proactive process through which students become masters of their own learning and performance (Pintrich, 2000). Supporting students in developing their SRL skills is regarded as one of the major goals of education, and is important from both cognitive and socio-emotional perspectives. SRL is not spontaneous, and can be developed by means such as: Scaffolded computer-based learning environment, student-centered curricula, and teacher's pedagogy and instructional practice. Although observing teachers' promotion of self-regulated learning in naturalistic classroom settings is a promising approach for both theory and practice, studies that apply this method are rare. Therefore, the overarching goal of our research is to illuminate teachers' pedagogical practices with respect to SRL. To meet our goal, we developed an observation tool, and used it to examine the degree to which different teachers take advantage of the opportunities for SRL afforded by a computer-based student-centered and interactive digital curriculum, in a typical classroom context. Ultimately, our research strives to optimize teachers' pedagogical practices.

Conceptual and theoretical framework

In this study, we adopt the Pintrich (2000) framework, which focuses on different kinds of SRL strategies, and lends itself more to large-scale quantitative investigations that can inform interventions to support specific SRL strategies. According to Pintrich (2000), SRL is characterized by four phases: (1) Forethought, planning and activation; (2) monitoring; (3) control; and (4) reaction and reflection. Each of these phases has four different areas for self-regulation: cognition, motivation/affect, behavior and context. For our current study, and in this paper, we have focused on the cognitive dimension of SRL, while further research will examine additional aspects of self-regulation.

Methods and data analysis

Three female, 3rd grade elementary teachers from different schools in a Midwest US state participated in this study. Each of the teachers had more than a decade of teaching experience, and had classes ranging from 28 to 32 students with similar demographic makeups. The teachers engaged students in a NGSS-aligned project-based learning science curriculum using *Collabrify*, a computer-based learning environment. In *Collabrify*, lessons are implemented as digital roadmaps, which visualize the lesson as a concept-map, where students tap a linked node in order to perform a learning activity. The digital roadmap lessons provide opportunities for students to navigate and control their learning to varying degrees. All teachers and students were new users of *Collabrify*. We conducted videotaped observations, coupled with informal interviews. Using both a priori theory of SRL (Pintrich, 2000), and a grounded theory approach using constant case comparison (Hoops, Yu, Wang & Hollyer, 2016), we developed the Opportunities for Self-Regulation observation rubric (Opp4SRL) that enables examination of teachers' implementation of a roadmap lesson in their classroom. For each of the four phases within the cognitive aspect of SRL, we identified four levels of instructional practices (Levels 1-4). The higher the level, the more supportive of SRL is the teachers' pedagogical practice within that phase (see example for *planning* in Table 1, the complete Opp4SRL rubric will be presented at the conference). We used the Opp4SRL rubric to code and score teachers' pedagogical practices with regard to SRL in three 45min lessons per teacher.

Table 1: An example of the Opportunities for Self-Regulated Learning (Opp4SRL) rubric

Planning (a sub element within the *forethought, planning and activation* phase)***: (Level 1) Provides no overview of the lesson:*** Does not provide the students with an overview of the*;* ***(Level 2) Provides an overview and imposes lesson plan:*** Provides students with an overview of the lesson, and enables only one possible path to achieve the goals of the lesson; ***(Level 3) Provides an overview and negotiates lesson plan***: Provides students with an overview of the lesson, and provides multiple optional paths to achieve the goals OR exhibits willingness to negotiate the paths to achieving the goals; ***(Level 4) Provides an overview, negotiates lesson plan and provides students with strategies to choose between options***: Provides students with an overview of the lesson, and provides multiple optional paths to achieve the goals OR exhibits willingness to negotiate the paths to achieving the goals, explains the differences between them, and provides the students with strategies that enable them to make an informed decision about which path to follow.

Results and findings

The Opp4SRL observation tool enabled us to discern among teachers' practices, and identify varying levels of supportive or constraining SRL pedagogies. Table 2 presents examples for several sub-elements within the *forethought, planning and activation* phase. While teachers' scores varied, we identified three distinct types of instruction: *Pre-SRL* (*Teacher A*)- the teacher fully regulates students' learning and provides almost no opportunities for students to engage in SRL; *Developing SRL* (*Teacher B*)- the teacher mostly regulates students' learning but provides some opportunities for engagement in SRL; *Proficient SRL* (*Teacher C*)- the teacher positions herself as a guide, and enables students to self-regulate their learning, while providing the necessary strategies. Our results indicate that while computer-based student-centered and interactive digital curricula are prerequisites, teachers' pedagogical practices have a crucial role in supporting students' engagement in SRL.

Table 2: Examples for teachers' practices with regard the forethought, planning, and activation phase

Teacher A	**Teacher B**	**Teacher C**
Planning: Provided only a brief description of the lesson before diving into the lesson. She did not use roadmap as a tool to support planning, and is task-by-task oriented - all students complete the same tasks together (*Level 1*)	***Planning:*** Though projected the roadmap on the board, *Teacher B* did not use it to provide students with an overview of the lesson but rather to support her teaching. Task-by-task oriented instruction (*Level 1*)	***Planning:*** Provided an overview of the lesson using roadmap as a visual scaffold. Although all students followed the same path with the map, they could complete their activities at their own pace. During the lesson, students moved around the class involved in different activities (*Level 2*)
Prior knowledge activation: Only the teacher provided the necessary prior knowledge for the lesson. Although she used prompts to trigger students to answer, it was mostly the teacher who answered the questions (*Level 2)*	**Prior knowledge activation:** Conducted comprehensive discussion and triggered students to share prior knowledge. She addressed knowledge associated with both content and inquiry practices (*Level 3*)	**Prior knowledge activation:** Triggered and encouraged students to bring in their prior knowledge and ideas. She directed students to additional resources (e.g., books) and explains why they should refer to them (*Level 4*)
Meta-cognitive knowledge activation: When engaging in modeling, *Teacher A* reminded students to label their components clearly, however did not explain to the students the rationale behind this strategy. No additional strategies were observed (*Level 2)*	**Meta-cognitive knowledge activation:** Explicitly addresses many strategies, such as: discussions with elbow partners, re-read questions, state in your own words. Does not provide guidance about the applicability of strategies (*Level 2)*	**Meta-cognitive knowledge activation:** Before completing a collaborative activity, *Teacher C* facilitated a discussion about collaboration and knowledge building: She triggered students to share strategies and debated their effectiveness. She enabled students to choose which strategy to implement (*Level 4*)

References

Hoops, L. D., Yu, S. L., Wang, Q., & Hollyer, V. L. (2016). Investigating postsecondary self-regulated learning instructional practices: The development of the self-regulated learning observation protocol. *International Journal of Teaching and Learning in Higher Education, 28*(1), 75-93.

Pintrich, P. R. (2000). The role of goal orientation in self-regulated learning. In M. Boekaerts, P. R. Pintrich, & M. Zeidner (Eds.), *Handbook of Self-Regulation* (pp. 451–502). San Diego: Academic Press.

International Society of the Learning Sciences

Boundary Spanning Roles and Power in Educational Partnerships

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Abstract: Navigating boundaries between contexts is essential for RPP effectiveness, yet much work remains to establish a conceptual framework of boundary spanning in partnerships. Our longitudinal case study draws from three long-term partnerships to construct a model of boundary spanning roles in RPPs from a graduate student perspective, with particular attention to the ways in which power permeates partnership work. We aim to promote the development of effective strategies to support graduate student boundary spanners.

Introduction

Research-practice partnerships (RPPs) represent a promising strategy for improving educational systems. The success of partnerships depends on adept navigation of sociocultural and organizational differences (Farrell, Harrison, & Coburn, 2019). Boundary work has been a prominent subject of scholarly study, particularly in educational contexts (Akkerman & Bakker, 2011; Weerts & Sandmann, 2010), but the conceptualization of boundary spanning in RPPs remains an emerging topic (Penuel, Allen, Coburn, & Farrell, 2015). The structure and effectiveness of RPPs depend on boundary spanning roles and practices that are frequently relegated to graduate students. Despite the crucial positionality of graduate students, research that explicitly examines their experiences and roles in educational partnerships is limited.

The present study builds on the conceptual work of Penuel et al. (2015), Akkerman and Bakker (2011), and Weerts and Sandmann (2010) to develop a model of boundary spanning in RPPs. Particular attention is given to power dynamics and equity (Denner et al., 2019). We draw from qualitative analyses of three long-term partnerships to construct a pragmatic and theoretically salient framework. By elaborating a model grounded in the experiences of graduate students, we aim to inform new methods of supporting early career scholars, encourage the development of effective RPP strategies, and more broadly, increase understanding of experiences and processes at educational boundaries. We pursued three overlapping research questions:

1. What are the boundary spanning roles of graduate students in educational partnerships?
2. What features of RPPs can influence graduate students' role negotiation?
3. How do power dynamics manifest in graduate students' boundary navigation?

Methods

Our present study is based on three RPPs that involve two school sites and one out-of-school program. As graduate student researchers employed by our university, we conducted the bulk of the work in the RPPs. The data sources for the present study were artifacts and field notes from partnership meetings spanning three years. We structured our analyses as a longitudinal case study. First, we organized all of our data materials by interaction type. We then reviewed the data with particular attention to our own positionality in the partnerships. Themes from each type of meeting were inductively generated. We triangulated the themes using available data sources and iteratively conducted rounds of review to ensure cohesion and accuracy of the generated themes, as well as establish relationships between the themes.

Findings

In response to our research questions, we developed a model of boundary spanning based on our experiences as graduate students in educational partnerships (Figure 1). Our framework elaborates on boundary spanning roles shaped by contexts of interaction and partnership characteristics across multiple dimensions.

Contexts

We identified three contexts in our partnership work: practitioner site, university site, and informal spaces. Examples of each type of space are shown in Figure 1. The contextual categories are consistent with Penuel et al.'s (2015) distinctions between researchers and practitioners in joint work at boundaries.

Partnership dimensions

We identified four dimensions that describe the systems in which partnership work is embedded: organizational, cultural, relational, and historical. Examples of features of these dimensions are provided in Figure 1. All partnership roles were influenced by partnership characteristics in each dimension. Power often manifested as control over resources that are relevant in each domain.

Role spectrums

We found five distinct spectrums on which our roles varied. First, consistent with Weerts and Sandmann (2010), our attention could be characterized as between entirely partner-focused or entirely university-focused extremes. Second, the type of tasks that we engaged in could be described as some proportion of technical tasks and socioemotional tasks (also aligned with Weerts and Sandmann, 2010). Third, our role varied between that of an experienced expert and an inexperienced novice, depending on the context and characteristics of the partnership. Fourth, under some circumstances, we needed to enact a role as a partnership advocate, whereas in other situations, a critical perspective was required. Fifth, sometimes we took on (or were given) a role as an authority with decision-making responsibility, whereas in other instances, we were submissive or passive recipients. Power was unevenly distributed across the role spectrums. Depending on the particular context and circumstances, different roles were imbued with varying degrees of power. A general level of empowerment was necessary to allow the freedom to explore (or openly discuss) our own roles and the roles of others. This role flexibility was essential to the effectiveness of our partnership work.

Conclusion

Locating ourselves on each of the five spectrums provided a comprehensive description of our boundary spanning roles in any given situation in the partnership. The prominence of each role depended on which aspects were salient for the specific partnership interactions and circumstances. We found that responsively acting in a partnership entails intentionally adapting roles to meet the conditions of the context and dimensional characteristics of the partnership work. Our research builds on emerging RPP literature regarding boundary work (Penuel et al., 2015), roles (Farrell et al., 2019), and power (Denner et al., 2019). A full documentation of our study is currently in press at *AERA Open*.

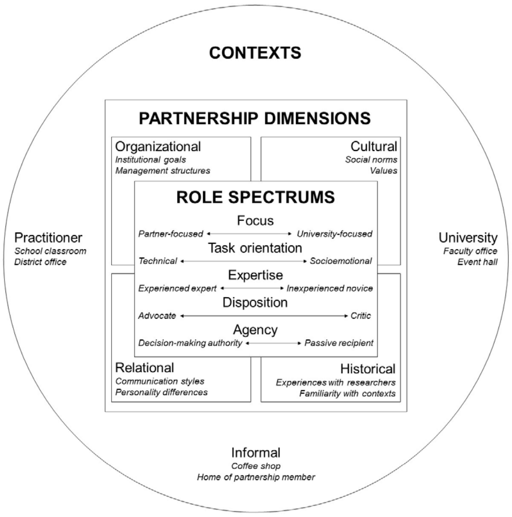

Figure 1. Diagram of our boundary spanning model. Examples of each feature are provided in italics.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary crossing and boundary objects. *Review of educational research*, *81*(2), 132-169.

Denner, J., Bean, S., Campe, S., Martinez, J., & Torres, D. (2019). Negotiating trust, power, and culture in a research–practice partnership. *AERA Open, 5*(2), 1-11.

Farrell, C. C., Harrison, C., & Coburn, C. E. (2019). "What the hell is this, and who the hell are you?" Role and identity negotiation in research-practice partnerships. *AERA Open*, *5*(2), 1-13.

Penuel, W. R., Allen, A. R., Coburn, C. E., & Farrell, C. (2015). Conceptualizing research–practice partnerships as joint work at boundaries. *Journal of Education for Students Placed at Risk*, *20*(1-2), 182-197.

Weerts, D. J., & Sandmann, L. R. (2010). Community engagement and boundary-spanning roles at research universities. *The Journal of Higher Education*, *81*(6), 632-657.

International Society of the Learning Sciences

Identifying and Coding STEM Interest Triggers in a Summer Camp

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Abstract: Our work investigates interest triggering, a necessary component of sustaining and developing long-term interest in STEM. We gathered interview data from middle school aged learners (N = 7) at a science-focused Minecraft summer camp over a period of one week. We first identified STEM interest triggering episodes, then categorized each episode based on codes developed previously by Renninger and Bachrach (2016). Our initial findings show differences in the frequency of interest triggering episodes across individuals and suggest that *personal relevance* and the use of Minecraft played prominent roles.

Keywords: videogames, technology, summer camp, interest development, STEM learning

Introduction

Our research examines how interest, operationalized as a psychological construct and motivational variable (Renninger & Hidi, 2016), can be identified in student interviews regarding their experience in a science-themed summer camp. We define interest as heightened attention and engagement, as well as continued voluntary re-engagement with subject matter (Hidi & Renninger, 2006). We build on and address the gaps within existing work about interest triggering in out-of-school learning settings. Renninger and Bachrach (2015) analyzed interest triggers of middle school-aged learners in an out-of-school biology workshop where they elaborated on a five-step content analysis on existing interest literature and theory. This work produced eight codes describing triggers for interest within the science workshop context: *autonomy, challenge, computers/technology, group work, hands-on activity, instructional conversation, novelty*, and *personal relevance*. They adopted literature from different content areas, such as reading, for the science workshop context. In this paper, we use the same approach, but in the context of a STEM-focused summer camp that leverages Minecraft as the primary learning environment.

Our study is a contribution to the examination of interest triggers within a digital learning environment, a field of research still in its early stages. We utilize the popular video game, Minecraft, for participants to explore, to make observations, and to ask questions about hypothetical versions of Earth customized by our laboratory (refer to Yi et al., 2018; Yi et al., 2020). Minecraft provides an ideal space for our work because of the variety of science concepts that can be conveyed through the game, as well as being a space to collect data and conduct research on how gameplay reflects interest (Lane et al., 2017).

Methods

Participants were recruited from a local youth center for a five-day STEM-focused summer camp in 2020 (N = 7; 43% female; M = 12 years old). The majority of participants self-identified as African American (4) while others identified as biracial (2) and White or Caucasian (1). Due to the pandemic, we adapted our usual face-to-face intervention to a hybrid form of staff and participants attending in-person and the research team attending remotely. One-on-one interviews were conducted in a separate Zoom breakout room on the last day of the intervention. The interview protocol for middle school students consisted of 16 questions and covered topics on home and school life, long-term interest, Minecraft play preferences, astronomy knowledge, and camp feedback.

Analysis

Two researchers sectioned interview data into STEM interest triggering episodes, using the *unknown* label for codes that did not fall under the coding scheme. *Unknown* interest triggering episodes will undergo thematic analysis to create new codes or subcodes that wholly capture the out-of-school science learning experience. Each episode is distinguished by a particular interest topic. For example, when asked about engagements with science content, the interviewee may report how much they enjoyed their latest trip to a science museum, then relate the science museum experience to an enjoyable classroom lesson in the past.

Inter-rater Reliability (Cohen's Kappa)

In the identification of interest triggering episodes, there was a substantial agreement between the two researchers, $\kappa = .73$. All disagreements were resolved in conference. There was an almost perfect agreement between two researchers when using Renninger and Bachrach's coding scheme based on two interviews, κ = .94. All disagreements were resolved in conference.

Findings

Each STEM interest triggering episode was then coded using Renninger and Bachrach's (2015) scheme for interest triggers (see Table 1). Columns where interest triggers occurred are highlighted in orange.

Table 1: Interest trigger counts (in columns) based on Renninger and Bachrach (2015) codes

#	Auto-nomy	Chall-enge	Comp/ Tech	Group work	Hands-on activity	Instructional conversation	Novelty	Personal relevance	Unknown
701	0	0	0	0	0	0	1	2	3
702	0	0	1	0	0	0	1	4	6
703	0	0	2	0	0	2	0	4	2
704	0	0	1	0	0	0	4	4	2
705	0	0	1	0	0	2	0	8	2
706	0	0	2	0	0	0	3	5	4
708	0	0	2	0	0	0	0	5	3

Conclusions and implications

Our preliminary results show a prominent role for *personal relevance* which specifically relates to Minecraft use by using a familiar platform to build on prior knowledge, such as experiencing a difference in gravity (a previously learned concept) on the Moon. *Personal relevance* also relates through a desire to reengage in camp content—choosing our server instead of outdoor play during free time—and when expressing positive affect regarding future participation of camps. One advantage of using Minecraft is the capability of most learners to immediately engage the science content due to the game's relevancy and familiarity through previous play. Another reason for the high frequency of personal relevance triggering episodes may be related to the design and structure of our intervention that evokes feelings of personal relevance within the activities.

There were several interest triggering codes without any instances (i.e., *autonomy, challenge, computers/technology, group work, hands-on activity*). This may be due to the wording of our interview questions and/or the structure of our camp. Another possible reason is that we followed Renninger and Bachrach's coding scheme strictly and only allowed one type of code per episode. Future research designs using the coding scheme by Renninger and Bachrach (2015) should consider the use of multiple codes per episode.

References

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist*, *41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

Lane. H. C., Yi, S., Guerrero, B., & Comins, N. (2017). Minecraft as a Sandbox for STEM Interest Development: Preliminary Results. In Hayashi, Y., et al. (Eds.), *Workshop Proceedings of the 25th International Conference on Computers in Education* (pp. 387-397). New Zealand: Asia-Pacific Society for Computers in Education.

Renninger, K. A., & Bachrach, J. E. (2015). Studying triggers for interest and engagement using observational methods. *Educational Psychologist*, *50*(1), 58–69. http://doi.org/10.1080/00461520.2014.999920

Renninger, K. A., & Hidi, S. E. (2016). *The Power of Interest for Motivation and Engagement*. New York: Taylor & Francis. https://doi.org/10.4324/9781315771045

Yi, S., Lane, H. C., & Delialioğlu, O. (2018, August). What if we were twice as close to the Sun? Interview findings from a science summer camp serving underrepresented youth. In F. Khosmood et al. (Eds.), *Proceedings of the 14th International Conference on the Foundations of Digital Games*. San Luis Obispo, CA, USA: Foundations of Digital Games.

Yi, S., Gadbury, M., & Lane, H.C. (2020, June). Coding and analyzing scientific observations from middle school students in Minecraft. In M. Gresalfi & I. S. Horn (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 3* (pp. 1787-1788). Virtual Nashville, TN, USA: International Society of the Learning Sciences.

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Proof of Concept: Applying Recurrence Quantification Analysis to Model Fluency in a Math Embodied Design

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Abstract: We report a subset of results from an exploratory study that modeled mathematics learning using a dynamical systems lens. This study applied Recurrence Quantification Analysis to model participants' interactions with a touchscreen-based embodied-design learning environment for proportionality, conducting both qualitative (case study) and quantitative (linear regression) analyses. Findings indicate an abrupt change in the RQA meanline metric associated with increased fluency, suggesting a phase transition into a new mode of interaction. These findings suggest theoretical and methodological traction for modeling embodied math learning as phase transitions in a human–technology dynamical system.

Dynamical systems theory (DST) approaches suggest that the complex interactions within and between body and environment shape cognition (e.g. Kelso, 1995; Richardson & Chemero, 2014; Thelen & Smith, 1994). How might a DST approach apply to higher-order cognition such as mathematics learning? We explored this question using a DST tool, *Recurrence Quantification Analysis (RQA),* on touchscreen data from a mathematics learning task. RQA begins with the construction of a recurrence plot, a way to map the alignment in states between two time series (Marwan et al., 2007) (Figure 1). RQA metrics quantify features of the recurrence plot. Our analysis explored five RQA metrics, but here, in the interest of space, we will present only the meanline metric. Meanline is the average length of diagonal lines on the plot. It reflects the level of predictability and stability of a system. Meanline trends are representative of those found across a panel of RQA metrics.

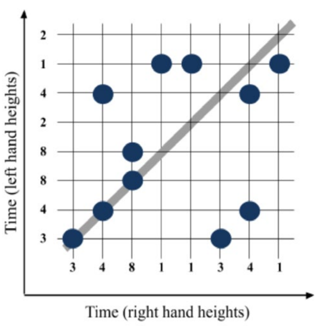

Figure 1. Example RQA plot for mock data of left and right hand heights (scale: 1-10 centimeters). Every position of each hand is compared to every position of the other hand. Aligned states are marked with a point.

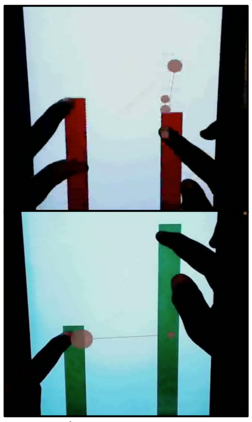

Figure 2. User interacting with the MIT-P. Upper image: bars are red. Lower image: The height of the left bar is half that of the right; bars turn green.

We conducted a secondary analysis of touchscreen and video data of students learning in an embodied-design environment (Abrahamson et al., 2020): the Mathematics Imagery Trainer Parallel Bars problem (MIT-P) (Figure 2). In this task, participants manipulated red bars on a touchscreen with the goal of turning the bars green and maintaining them green while moving them. The bars were set to turn green only when the ratio of the left to right bar was 1:2; moving-in-green required participants to move the right bar at twice the rate of the left. This movement problem was designed to ground concepts from proportional reasoning.

Our research question was: How does the predictability of hand coordination dynamics evolve as fluency increases in a math embodied-design learning task? To answer this, we conducted continuous cross-RQA of bimanual touchscreen data. We: (1) used linear regression to compare changes in meanline over time across all participants; and (2) analyzed the evolution of the meanline RQA metric for a pair of contrasting participants, one of whom reached fluency ("Nils") and the other of whom did not ("Liam"). For the regression analysis, we split each participants' time series into three phases—Exploration, Discovery, and Fluency—and regressed meanline on phase. We defined the onset of Discovery as when participants sustained green feedback above 50% of the time for 20 seconds, and of Fluency as when learners moved both hands at the same time in green at 80% of their personal best.

Regression results showed no statistically significant change from Exploration to Discovery. From Discovery to Fluency, meanline increased by an estimate mean of 14.8 deciseconds ($t=3.01$, $d.f.=85$, $p=0.003$), reaching about double the estimated meanline length of 15.63 deciseconds during the initial Exploration phase.

Examining the contrasting case studies (Figure 3), Nils' (reached fluency) meanline dynamics mirrored that of the overall group with longer meanline in the Fluency phase. His meanline increased abruptly synchronously with the onset of fluent moving-together-in-green (between the second dotted line and the second filled line in Figure 3, left) just after he articulated aloud an arithmetic rule to "make half" with his hands, identifying a multiplicative relation. In contrast, Liam's (did not reach fluency) meanline actually decreased over the course of the task. He, too, articulated a rule aloud, to "keep the right hand higher." Liam's qualitative rule did not yet appear to offer him as strong of a grip on the problem as with Nils: Liam did not manifest increased coordination fluency, nor an increase in meanline.

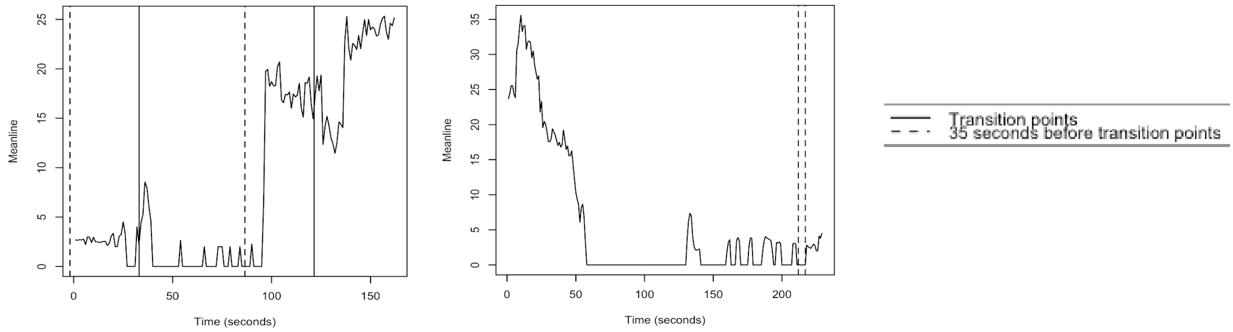

Figure 3. Windowed recurrence plots of meanline over time for Nils and Liam.

We found Fluency but not Discovery to be associated with increases in the RQA meanline metric, such that stability and predictability dynamics transformed when enacting moving-together-in-green. In the case study of a learner who attained fluency, meanline analysis showed an abrupt qualitative change. This finding evokes the dynamical-systems-theory phenomenon of a *phase transition*, whereby a system abruptly shifts from one state to another, such as from liquid to gaseous state of water. Our results suggest that the onset of fluent movement in the embodied learning of math content might constitute a phase transition in the learner–technology system. To the extent that we view higher-order cognitive activity, such as mathematical reasoning, as emerging from recurrent patterns of perceptually guided motor action (Varela et al., 1991), the Mathematics Imagery Trainer appears to constitute a *field of promoted action* (Reed & Bril, 1996) geared to foster transition into a new conceptually-salient ways of moving.

This study illustrates the traction of RQA on embodied learning data. RQA is apt for dynamical systems analyses, because it does not carry the assumption of linearity inherent in traditional quantitative methods, nor does it treat variability as noise. This proof-of-concept suggests that RQA can serve to characterize and potentially predict key moments of transition in learning. More broadly, RQA shows promise for studying the evolution of embodied-interaction learning dynamics as they unfold in time.

References

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E. R., Soto, H., & Alibali, M. W. (2020). The future of embodied design for mathematics teaching and learning. *Frontiers in Ed., 5*(147).

Kelso, J. A. S. (1995). *Dynamic patterns: The self-organization of brain and behavior.* MIT Press.

Marwan N., Romano M.C., Thiel, M., & Kurths, J. (2007). Recurrence plots for the analysis of complex systems. *Physics Reports, 438*, 237–239.

Reed, E. S., & Bril, B. (1996). The primacy of action in development. In M. L. Latash & M. T. Turvey (Eds.), *Dexterity and its development* (pp. 431–451. LEA.

Richardson, M. J., & Chemero, A. (2014). Complex dynamical systems and embodiment. In L. Shapiro (Ed.), The Routledge handbook of embodied cognition (pp. 39–50). Routledge.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* MIT Press.

Varela, F. J., Thompson, E., & Rosch, E. (1991). *The embodied mind: Cognitive science and human experience*. MIT Press.

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Using Sequence Mining to Explore the Representational Flexibility Development of Adolescents with Autism Spectrum Disorder in Virtual Reality-Based Flexibility Training

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Abstract: We explored the representational flexibility development of adolescents with autism spectrum disorder (ASD) during VR-based simulation design and problem solving. We collected behavioral data of three adolescents with ASD from ten one-hour VR-based flexibility training sessions. The results of sequential data mining indicate that adolescents with ASD experienced different difficulties with representational flexibility during VR-based design problem solving. The study findings suggest that promoting the performance of attention switching and alternative representation tends to foster the performance of other representational flexibility processes.

Introduction

Representational flexibility is individuals' ability to flexibly switch attention between tasks, as well as identify and exploit various uses of representations (Rau, 2017). Recent research has studied the VR-based learning environment that engages adolescents with ASD in creative design and problem solving (Author, 2016). Despite the reported benefits of the VR-based training for adolescents with ASD (Didehbani et al., 2016), the 3D VR learning space tends to be visually-overwhelming and open-ended, and may create distraction and cognitive overload. It is critical to track students' competency development to provide learning supports adaptively and dynamically. However, there is a lack of empirical research that tracks the performance and development of representational flexibility in a digital learning setting. Using sequence mining, we aim to study the representational flexibility development of adolescents with ASD during VR-based design problem solving. Specifically, the study addressed the following research question: How did the representational flexibility performance of adolescents with ASD portray during VR-based design problem solving?

Method

VR-based flexibility training and data collection

Using Opensimulator—an open-source VR platform, we implemented ten VR-based flexibility training sessions that engaged adolescents with ASD in 3D scientific simulation design and encoding. Three adolescents with ASD (Average: 13.3 years old, SD = 1.24) attended nine 1-1.5-hour sessions during the training. In this study, the intervention task examined is developing computerized, non-player characters (NPCs or virtual agents). An NPC is a virtual character that conveys predetermined responsive or reactive behaviors. The adolescents with ASD needed to prototype the logics of computer scripts to encode NPCs that perform simplistic social interactions. During the NPC design task, the participants got to choose a preferred NPC simulation context (e.g., a cafeteria and a hotel reception) and designed an NPC tailored to the simulation context. An embedded scaffolding feature for representational flexibility is a 3D flow maker that assists participants in conceptualizing, visualizing, and designing the pathways of NPC interactions. Two facilitators observed and provided technical support as needed at every training session. For the data collection in the current study, we sampled the adolescents' computer logs that recorded their interaction behaviors with the 3D flow maker in all intervention sessions.

Data analysis

We conducted sequence mining procedures: (1) sequential pattern mining (SPM) and (2) sequential analysis. First, based on the collected computer logs, we implemented SPM to compute each individual's frequent behavior patterns, indicating how their performance of representational flexibility appeared (algorithm = SPAM, minimum support = 0.6). Using pre-defined behavior codes (Moon, Ke, & Sokolikj, 2020), we coded all behavior event transitions as either positive or negative occurrences related to the component facets of representational flexibility. Table 1 outlines the definition of each component facet of representational flexibility. Using the extracted sequences from SPM, we then conducted sequential analysis to identify how the adolescents' performance or states of representational flexibility (RF) changed during training. We calculated the transition probabilities of the RF states (cut-off probability: 30%).

Table 1: Component facets of representational flexibility (RF)

Facets of RF	Definition
Attention Switching / Mental set-shifting (AS)	Ability to switch attention or action based on changed rules and contextual demands
Alternative Representation (AR)	Capability to identify and apply multiple representations
Pattern Development (PD)	Ability to identify and delineate a pattern (or rules) during design problem analysis and solving
Pattern Contextualization (PC)	Ability to either identify an implementation context of the endorsed pattern or customize the pattern.

Findings

Using SPM, we identified the study participants' states of RF. As shown in Figure 1-a, all three adolescents with ASD generally increased the performance of attention switching and pattern development during the training. On the other hand, both participants A and B showed higher negative portrayals of attention switching and pattern contextualization; participant C showed worse performance in alternative representation.

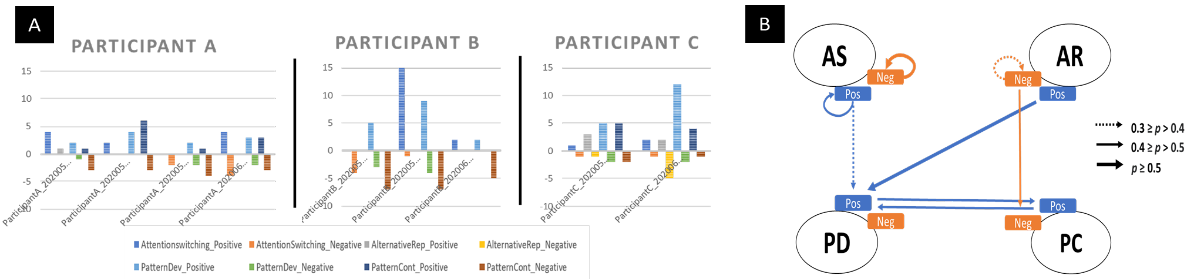

Figure 1. Competency development states of the study participants in the VR-based training (a) / Transition probability estimation of the competency states (b)

In addition, we calculated the transition probabilities of representational flexibility in terms of the four component facets. The transition probability estimation result confirms that adolescents with ASD were likely to show the iterative and unsuccessful performance of attention switching and alternative representations (Figure 1-b). On the other hand, if they performed successfully in attention switching and alternative representations, they had more chances to perform pattern development and pattern contextualization successfully.

Implication and limitation

The study findings indicate that adolescents with ASD experienced different difficulties with representational flexibility during VR-based design problem solving. It is necessary to present learner-adaptive, individualized supports in the VR-based learning environment. Promoting and scaffolding participants' performance of both attention switching and alternative representation will potentially promote the performance of other representational flexibility processes.

Reference

Didehbani, N., Allen, T., Kandalaft, M., Krawczyk, D., & Chapman, S. (2016). Virtual reality social cognition training for children with high functioning autism. *Computers in Human Behavior*, 62, 703-711.

Moon, J., Ke, F., & Sokolikj, Z. (2020). Automatic assessment of cognitive and emotional states in virtual reality-based flexibility training for four adolescents with autism. British Journal of Educational Technology, 51(5), 1766-1784.

Rau, M. A. (2017). Conditions for the effectiveness of multiple visual representations in enhancing STEM learning. *Educational Psychology Review*, 29(4), 717-761.

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Engagement in MOOCs Discussion Forums: Dimensions and Indicators

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Abstract: This poster aims to clarify the notion of engagement in MOOCs discussion forums as perceived by students. The analysis of the 11 semi-structured interviews conducted with MOOC students highlights three main findings. First, engagement in MOOCs forums as a construct with four dimensions (behavioral, affective, cognitive and social). Secondly, a clear distinction between these dimensions using the related indicators we identified. Finally, the dynamic aspect of engagement. These results provide a socially and contextually grounded definition of engagement in MOOCs forums. That ensures the development of reliable and essential tools for measuring it and observing its quality over time.

Background and issues of the project

This study is part of a larger project that focuses on the concept of students' engagement in the context of discussion forums in MOOCs (Massive Open Online Courses). Our interest in this topic is supported by several studies, which show that students who frequently interact with others in forums are those who are the most successful in MOOCs (e.g., Poellhuber & al., 2019). Thus, we assume that by encouraging students' engagement in MOOCs forums, it would be possible to improve completion rates, which vary between 5 and 10%. However, engagement is studied mainly as a general phenomenon in distance learning and MOOCs (Molinari & al., 2016) and there is still little knowledge of the specificity of engagement in MOOCs forums, which are characterized by low interactions and participation rates reaching 3% (Margaryan & al., 2015). Moreover, research focused only on a few forms of engagement such as behavioral engagement, generally with indicators that are not commonly shared by researchers. It is, therefore, necessary to define more clearly, what it means to be engaged and disengaged in a MOOC forum, to identify the different dimensions of engagement and associated indicators.

Theoretical framework

We refer to the work of Fredricks & al. (2016) who define engagement as a construct with four interdependent dimensions, influenced by the students' perceptions of themselves and their learning environment. First, the behavioral dimension refers to the directly observable manifestations of learners' engagement in terms of participation, presence of positive behavior and absence of disruptive behavior during learning activities. Behavioral indicators of engagement in MOOCs forums may be the number of questions and answers posted (Onah & al., 2014). Cognitive engagement is a dimension that refers to the quality of the learning processes and strategies that learners implement. This dimension can be assessed based on the use of learning and self-regulatory strategies and also on the mental time and effort to implement these strategies. In MOOCs forums, the use of management strategies such as justifying answers to questions with relevant resources have been widely used as indicators of cognitive engagement (Quentin & Condé, 2016). Third, we have affective engagement that refers to interest and value placed on learning tasks as well as to positive and negative emotions experienced when completing them. Research mainly used positive (e.g., altruism for Cheng, 2014) and negative emotions as indicators to explore emotional engagement in MOOCs. There are still few studies that focus on such type of engagement in MOOCs forums. Fourth, social engagement is the last dimension studied by Fredricks and colleagues. Based on Molinari & al. (2016), we assume that students are socially engaged when they jointly try to both maintain positive interpersonal relationships and build upon each other's contributions in a MOOC forum.

Method and data analysis

Based on this theoretical framework, our aim was to investigate the dimensions and indicators of students' engagement in MOOCs forums. To that end, we carried out 11 semi-structured individual interviews (45-60 minutes) with certified students of the MOOC "*Introduction aux droits de l'Homme"* proposed by the University of Geneva on Coursera. Participants, who volunteered to be part of our study, were gradually invited to take part in the interviews until we judged that (1) new participants would no longer add significant new data to the description of the studied phenomenon (theoretical saturation) and that (2) the topics obtained offered a sufficient explanatory framework with regard to the data collected (theoretical sufficiency). Only men agreed to participate in these in-depth interviews. An interview guide was developed based on that one used in Fredricks & al. (2016) and contained the following questions: (1) what does it mean for you to be engaged and disengaged in a MOOC forum?; (2) what do students do when they are engaged and disengaged in a forum?; (3) In your opinion, what influences engagement and disengagement in a forum? In the present paper, we report on the answers to the first two questions. There were two main steps in the analysis. First, we have appropriated the content of the answers by replaying the audio recordings, retaining the richest interviews, transcribing the selected interviews, choosing the units of analysis and drawing up a provisional coding manual. Second, the transcripts were coded and the codes were grouped into categories anchored in the conceptual framework of engagement and, finally, the results were interpreted. The results are the perceptions of adult respondents (8/11 over the age of 30) from 10 countries, postsecondary level and living in urban African (6/11), Latin American (3/11) and Haitian (2/11) areas.

Results and future work

The results show that indicators used by students to conceptualize engagement in MOOCs forums may be categorized into the four dimensions identified in the theoretical framework: behavioral, cognitive, affective and social. Behavioral indicators (e.g., asking questions and answering to questions from others; providing others with quick answers) allow for direct observations of engagement because they correspond to the traces left by students in the forums. Then, emotional indicators (e.g., being happy to participate in a forum; being interested in the topics of the discussions) relates to the interest and value placed by students on the forum discussions as well as the emotional intensity of the discussions. Besides this, three types of cognitive indicators are proposed. The first type refers to the use of learning strategies, in particular to organization and elaboration strategies (e.g., synthesizing discussions; arguing and clarifying answers to questions) while the second type refers to self-regulatory strategies including metacognitive (e.g., trying to understand one's mistakes during exchanges) and management strategies (e.g., doing further research on the topic addressed by the posted question). The third type of indicators refers to time needed to implement those cognitive strategies (e.g., dedicating enough time to participate in forum). Finally, social engagement is described, on the one hand, by relational indicators (e.g. commenting on the others' ideas and opinions with respect and empathy) in order to maintain positive relationships in discussion forums. On the other hand, by socio-cognitive indicators (e.g., combining one's own ideas with those of others to answer questions that seem difficult) related to the students' attempt to engage in high transactive social modes.

What about disengagement? Disengagement is described by indicators reflecting a lack of engagement at the behavioral (e.g., not asking and even answering questions), cognitive (e.g., not using the forum to understand a concept) and social (e.g., not discussing ideas with others, not helping others solve problems) levels. Students also provided indicators related to low quality or low level of engagement such as allocating little time to participation in the forum discussions, answering in a superficial way to questions, answering questions without seeking more information about the topic at hand or making comments that may offend the others. Moreover, emotions expressed to describe disengagement (e.g., fear, disinterest, dissatisfaction, frustration) are opposed to those given for emotional engagement. All these results suggest that engagement in MOOC forums is a dynamic phenomenon, as it can be absent, low or high among students, and also can fluctuate throughout the discussions.

In our future work, we will use the indicators we have identified to develop an assessment tool able to measure the fluctuation of students' engagement in MOOCs forums. We will also identify factors that may explain this fluctuation. Our project's results will help to identify those students who are most likely to disengage from MOOCs forums activities and to design more targeted pedagogical interventions to strengthen their engagement.

References

Cheng, C. Y. (2014). An exploratory study of emotional affordance of a Massive Open Online Course. *European Journal of Open, Distance and E-learning*, *17*(1), 43–55.

Fredricks, J. A., Wang, M. Te, Schall Linn, J., Hofkens, T. L., Sung, H., Parr, A. & Allerton, J. (2016). Using qualitative methods to develop a survey measure of math and science engagement. *Learning and Instruction*, *43*, 5-15.

Margaryan, A., Bianco, M. & Littlejohn, A. (2015). Instructional quality of Massive Open Online Courses (MOOCs). *Computers and Education*, *80*, 77-83.

Molinari, G., Poellhuber, B., Heutte, J., Lavoué, E., Widmer, D. S. & Caron, P.-A. (2016). L'engagement et la persistance dans les dispositifs de formation en ligne: regards croisés. *Distances et médiations des savoirs*, (13).

Onah, D. F. O., Sinclair, J. E. & Boyatt, R. (2014). Exploring the Use of MOOC Discussion Forums. *Proceedings of London International Conference on Education*, 1-4.

Poellhuber, B., Roy, N. & Bouchoucha, I. (2019). Understanding Participant's Behaviour in Massively Open Online Courses. *International Review of Research in Open and Distributed Learning*, *1*(20), 221-242.

Quentin, I. & Condé, J. (2016). Les rôles endossés par les apprenants les plus actifs dans un forum de MOOC: le cas d'ItyPA2. *Distances et médiations des savoirs*, (15).

Exploring Self-Efficacy Shifts within an Informal STEM Program

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Abstract: Engaging in informal learning activities can support non-dominant learners' identity development, agency, and interest in STEM. In this paper, we build on the potential of community-based settings in engaging non-dominant learners (n=10) to explore learners' science self-efficacy. We find that overall self-efficacy improved, but not all students followed a similar learning trajectory. We explore these differences using examples from interviews and close by discussing methodological suggestions to address such emerging differences.

Introduction

In this poster, we build on previous work that demonstrates the potential for informal learning activities to create equity-oriented learning spaces and pedagogy that support non-dominant learners in STEM fields (e.g., Barton & Tan, 2010; Pinkard et al., 2017). Here, we attempt to identify methods for understanding shifts in science self-efficacy within the context of Palestinian learners' engagement in an out-of-school community-based program in Israel. Understanding learners' science self-efficacy within this context is important for both practical and theoretical reasons. Historically, Palestinians in Israel have been experiencing a systematic marginalization, rooted in settler-colonial citizenship dynamics within this political context (Rouhana & Sabbagh-Khoury, 2015). On a practical pedagogical level, cultivating self-efficacy is a major motivation of our collaborators at Al-Rowad for Science and Technology working with Palestinian Arab learners from their society in Israel. Understanding the role of context expands our methodological tools towards applied research with local communities and is a generative way of engaging with local communities (e.g., Medin & Bang, 2014). At a theoretical level, self-efficacy is defined as the belief that one is capable of taking part in an action or an activity at a designated level affecting learners' perceptions of their capability to complete a task (Bandura, 1997). Measuring self-efficacy towards science with careful attention to the context in which activities are situated can give an understanding of the complexity of such effects. Here we ask: Does science self-efficacy shift after engaging in an out-of-school, community-based program? If so, how?

Activities

This study is part of a larger project that aims to better understand the engagement and participation of learners within a community-based organization's transdisciplinary STEM learning program. This paper explores science self-efficacy shifts after students participated in the 4-day program (8 hours total). The program consisted of four major transdisciplinary hands-on activities designed by the organization: *Super Absorbent Polymer (SAP),* where learners were introduced to concepts and phenomena like colors and diffusion; *Newton's Disc,* which focused on light, color, and mechanical motion; *Illuminating Board,* where learners explore characteristics of light, dark, and illuminating materials in objects and animals; and *Oil & Water,* where students were exposed to volcanism, density, and reactions between substances. These activities were transdisciplinary by design. For example, each activity involved an artistic element, providing opportunities for transdisciplinary learning (Mawasi et al., 2021).

Methodology

Ten fifth- and sixth-grade learners (five girls, five boys) participated in the program. All participants are Arabic-speaking and attended all four days of the program. We used a pre-post learner questionnaire that included questions about learners' science interests, technology engagement in general, and science self-efficacy. The pre-post questionnaires were translated to Academic Arabic. After the program activities were completed, we conducted semi-structured interviews, where we asked them to elaborate on selected items from the questionnaires. Importantly, learners were not asked to explain why they chose the answer on the posttest. Instead, they were asked the question anew, encouraging them to answer based on how they were thinking at that moment.

Findings

Overall, we find a trend towards learners' science self-efficacy improving from pretest ($M=3.2$, $SD=.36$) to posttest ($M=3.5$, $SD=.38$), ($t(9)=-2.15$, $p=.06$). However, when looking at the items separately, we see that this trend is driven by a single item: "I can use science to solve problems in everyday life" (Pretest $M=2.6$ ($SD=.97$), Posttest $M=3.6$($SD=.52$), ($t(9)=-3.0$, $p=.015$). We observed that learners' answers shifted between the posttest and interview, with interview answers more closely aligning to responses given on the pretest. We use the qualitative data to explore how students are describe these concepts in order to better explain these findings. An inductive analysis (Thomas, 2006) allowed an understanding the ways of thinking that mediate learners' responses. Stances were interpreted and analyzed by the first author, who is from the local community (fluent in both Academic Arabic and Palestinian Arabic) and studying in the United States. The first author then created codes in English, and the stances that reflected codes were translated to English. Then the first author and second author (from the United States) discussed the codes. A major theme we identified is that there is neither internal nor external consistency in the way that students operationalize the term *science*. By external consistency, we mean that within an item, some students used the term to mean the school subject, whereas others took a more holistic approach. By lack of internal consistency, we mean that individual students changed the way they defined the term between questions (e.g., for the item "I can learn science easily," a student might have described doing well in science class, but for the item, "I can use science to solve problems in everyday life," a student might describe a scientific phenomenon that occurs at home). Results from the interviews reflect that learners demonstrated diverse ways of contextualizing science. For each item, the learners referred to either school, the program, everyday life, or general science, or a combination of these.

Discussion and implications

The findings reflect descriptive shifts in students' self-efficacy; however, these shifts were driven by a single item. Yet, the interviews show various ways of conceptualizing science across items. We explain these variations through the diverse ways students reflected on their engagement, including attending to knowledge they learned (procedural and declarative), describing how they used the activities at home, and perceived self-efficacy in relation to the physical artifacts they created. These results reflect that some learners' perceptions of what counts as science connects to their conception of doing well in school science. We also see that it is important to revisit the methodological tools applied within this local context. First, to be linguistically open, to expand ways for students to express their thinking and learning process (e.g., being prepared to use both Academic and spoken Palestinian Arabic, diverse use of dialects). Second, it is also important for the process of creating and iterating on assessments to understand learners' perceptions of learning and the teacher's role, as well as the various ways that learners perceive artifacts, and the social and political context mediating learning activities. Finally, it is important to be open to involve, share, and discuss results and design with community members throughout the process. We believe that collaborating with local community members to develop measurements, rather than relying solely on dominant scientific instruments that do not account for context, will deepen our understanding of learning.

References

Bandura, A. (1997). Self-efficacy: The exercise of control. New York: Freeman.

Barton, A. C., & Tan, E. (2010). We be burnin'! Agency, identity, and science learning. The Journal of the Learning Sciences, 19(2), 187-229.

Mawasi, A., Wylie R., & Mishra P. (2021) Expanding Science Learning within Community-Based Hands-on STEAM Experiences. 1st International Society of the Learning Sciences Annual Meeting. ISLS.

Medin, D. L., & Bang, M. (2014). Who's asking?: Native science, western science, and science education. MIT Press.

Pinkard, N., Erete, S., Martin, C. K., & McKinney de Royston, M. (2017). Digital youth divas: Exploring narrative-driven curriculum to spark middle school girls' interest in computational activities. Journal of the Learning Sciences, 26(3), 477-516.

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. The Journal of the Learning Sciences, 19(3), 322-357.

Rouhana, N. N., & Sabbagh-Khoury, A. (2015). Settler-colonial citizenship: Conceptualizing the relationship between Israel and its Palestinian citizens. Settler Colonial Studies, 5(3), 205-225.

Thomas, D. R. (2006). A general inductive approach for analyzing qualitative evaluation data. American journal of evaluation, 27(2), 237-246.

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Expanding Science Learning within Community-Based Hands-on Transdisciplinary STEAM Experiences

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Abstract: In this paper, we examine how a four-day out-of-school program planned and taught by a community-based organization allowed for a range of educational possibilities, specifically unlearning "school science" by participating in transdisciplinary STEAM activities, which in turn, offered generative ways to develop STEAM-related identities. These outcomes enabled learners to expand the ways they view science learning. Implications of this experience for designing and studying learning experiences for non-dominant learners are shared.

Transdisciplinarity: Thinking beyond disciplines to engage non-dominant learners in informal STEAM activities

Transdisciplinarity allows learners to creatively connect "different solutions, viewpoints, or perspectives" across disciplines (p. 24, Mishra et al., 2011). In the past decade, education research has stressed the importance of developing transdisciplinary STEAM curricula that encourage learners to view science, technology, engineering, and math as interconnected and to think critically and ethically about STEM disciplinary practices (e.g., Rosebery et al., 2010; Takeuchi et al., 2020; Mishra et al., 2011). In STEAM environments designed for non-dominant and historically marginalized learners, transdisciplinarity allows educators to leverage learners' assets (e.g., using culturally-relevant artifacts or linguistic resources) and diverse range of identities (Gee & Parekh, 2018; Nasir et al., 2006) to expand learning possibilities beyond the constraints of one specific discipline (Takeuchi et al., 2020). Such equity-oriented approaches allow for diverse forms of engagement and participation within learning environments. This allows learners to forge connections between learning environments that are both in and out of schools, connect knowledge across disciplines, and connect their learning activities to their identities, therefore linking these fields to their lived experiences (Sengupta-Irving & Vossoughi, 2019).

These opportunities are particularly relevant for the work that our collaborators, Al-Rowad for Science and Technology, do with Palestinian youth in Israel, a non-dominant population in STEAM and a historically marginalized population. While framing their work as "Science and Technology," the organization aims to increase individual and societal self-efficacy towards science by intentionally engaging learners with transdisciplinary hands-on activities that connect science, technology, engineering, art, and math.

Learning environment context at Al-Rowad for science and technology

We collected data from a four-day program for 10 fifth- and sixth-grade learners, led by two educators from the organization. Each day focused on a different concept and included didactic teaching, discussions, and hands-on activities. The instruction was often structured as a series of questions that prompted students to connect science concepts to everyday phenomena. The lead teacher would emphasize that "there is no right or wrong answer" to encourage students to share their thoughts. She respected learners' choice to not participate in the discussion, acknowledging that some students have different preferences about sharing in large groups. After these discussions, learners were given hands-on toolkits and instructions to build and complete the day's hands-on activity artifact. Students were then encouraged to take the completed activity home to share with family. In total students completed four activities: Super Absorbent Polymer, Newton's Disc, Illuminating Board, and Oil & Water.

Methodology for data collection and analysis

The data for this paper comes from a series of semi-structured interviews with participants (n=10) following the four-day (8 hour) workshop. The interviews were 40-60 minutes long (average time = 48.4 min, SD=8.9 min). An initial inductive coding was followed by a close reading of the interviews, first cycle coding of interviews, and writing summative memos about each student's experience (Saldaña, 2015).

Findings

Although the program was centered on scientific issues and promoted as focusing on science, participants engaged in activities that crossed disciplinary boundaries. This engagement and participation allowed learners to expand their knowledge of STEAM possibilities (i.e., STEAM practices as interconnected and connected to varied disciplines). For instance, these activities included not just working and playing with colors and lights, but also processes of thinking, planning, drawing, and prototyping that unite the arts, science, and engineering. This transdisciplinary approach provides an alternative to traditional modes of school science and thereby expands what counts as authentic science, pushing participants to *unlearn school science* as reflected through the students' perceptions.

Since the hands-on activities incorporated *a transdisciplinary* connection between science, technology, and arts, this allowed learners to build multiple hands-on tools which serve as modeling for phenomena they discussed in class. On the other hand, not all learners described the activities as transdisciplinary. Examples in interviews indicate that STEAM learning is an emergent transdisciplinary process. While learners, in some cases, did not necessarily identify certain practices as tied with specific disciplines, they were attempting to think about STEAM through their own identities (e.g., I imagine, I draw) or activities they themselves do (e.g., drawing, playing with family). While at a surface level, it might read as if learners are not engaged in talking about STEAM disciplinary practices or discourses, it can be an opportunity for expanding ways in which non-dominant learners enact STEAM in relation to their everyday lives and self-identities. We expand on this idea of emergent identities below.

We identified varieties in how students perceive their STEAM activities, practices, and roles. These varieties reflect how each student's unique learning trajectory may be shaping their perceptions of engagement and participation within the program. The unique ways learners expressed their thinking enabled us to identify *emergent identities* in relation to the students experiences with activities. For instance, a student perceiving an artifact as an art, enabled them to see themselves as an artist and build connections between art and science.

Summary

The program activities that these learners participated in align with Dewey's (1956) fourfold areas of interest for learning: "the interest in conversation, or communication; in inquiry, or finding out things; in making things, or construction; and in artistic expression" (p. 48). Through these activities, learners engaged in (a) conversations and communication about STEAM practices both within and outside the program's in-person activities; (b) observation and inquiry; (c) making and constructing artifacts with scaffolds provided by instructors; and finally, (d) artistic expression through working with colors, drawing, and the aesthetics of the final artifact.

Looking beyond the specifics of this project, we suggest enabling a space for learners to expand agency towards the ways they see, engage, and perceive science activities, by viewing STEAM learning as an emergent process, rather than a process with science learning as its sole outcome. It is through the thoughtful design of pedagogy and activities that learners can go beyond seeing science as a disconnected array of facts taught in school, and instead approach it as an organic body of knowledge that is connected with other disciplines and with their personal lives and identities.

References

Dewey, J. (1956). The child and the curriculum; and The school and society (Combined ed., Phoenix books). Chicago: University of Chicago Press.

Gee, E., & Parekh, P. (2018). Gender in the Making: Literacies and Identities in Girls' Self-Initiated Making Activities. In Literacies, Sexualities, and Gender (pp. 54-65). Routledge.

Rosebery, A. S., Ogonowski, M., DiSchino, M., & Warren, B. (2010). "The coat traps all your body heat": Heterogeneity as fundamental to learning. The Journal of the Learning Sciences, 19(3), 322-357.

Saldaña, J. (2015). The Coding Manual for Qualitative Researchers. London, UK: Sage

Sengupta-Irving, T., & Vossoughi, S. (2019). Not in their name: re-interpreting discourses of STEM learning through the subjective experiences of minoritized girls. Race Ethnicity and Education, 22(4), 479-501.

Takeuchi, M. A., Sengupta, P., Shanahan, M. C., Adams, J. D., & Hachem, M. (2020). Transdisciplinarity in STEM education: a critical review. Studies in Science Education, 1-41.

Mishra, P., Koehler, M. J., & Henriksen, D. (2011). The seven trans-disciplinary habits of mind: Extending the TPACK framework towards 21st century learning. Educational Technology, 22-28.

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The research work was partially supported by the Arizona State University GPSA Jumpstart and the Graduate Research and Support Program of ASU Graduate College. We also acknowledge and thank Al-Rowad for their participation in this project. Any opinions, findings, and conclusions are those of the authors and do not necessarily reflect the views of ASU or Al-Rowad.

Promoting Science Self-Concept with Inquiry-based Curricula

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Abstract: Science self-concept is a strong predictor of engagement in science learning and career choice. Students who report higher science self-concept display more self-efficacy and greater achievement in their science courses, which positions the construct as a potential target of curriculum interventions. Here, we report our interim findings regarding the potential of a technology-infused guided-inquiry curriculum, The Connected Chemistry Curriculum, for improving students' chemistry self-concept. Using data from a longitudinal study of the curriculum's efficacy, we analyzed improvements in 1048 students' chemistry self-concept after using Connected Chemistry for an academic year. The results show that CCC significantly improves students' chemistry self-concept compared to business-as-usual practices.

Keywords: Self-concept, Inquiry, Science Education

Introduction

The Connected Chemistry Curriculum (CCC, Stieff, Nighelli, Yip, Ryan, & Berry, 2012), a technology-infused guided inquiry curriculum, is a self-contained chemistry curriculum that makes central use of visualization software to facilitate learning in secondary chemistry. Like other science curricula that emphasize the use of educational technologies (e.g., SimCalc, PhET), CCC aspires to serve the dual purpose of supporting learning while providing youth with an opportunity to increase their experience and proficiency with digital mediums. The curriculum has been under iterative development for 18 years, and studies of CCC have focused mainly on its efficacy for improving conceptual change and representational competence in the discipline. Here, we report our initial efforts to examine the potential of the curriculum to impact socio-affective factors, such as self-concept.

Present study

We present here our preliminary analysis of the long-term impact of a 9-month implementation of CCC on self-concept. We conducted an implementation study that compared changes in students' self-concept in chemistry, math, and general academics in classes taught by the same group of teachers with or without implementing CCC. Specifically, we tested whether students in CCC classes reported higher levels of chemistry self-concept.

Study context

The data reported on here were collected during 2017-2019 in the context of an ongoing efficacy study of CCC. Participating schools were located in one of three urban/urban-fringe school districts in the U.S. Great Lakes region. 31 participating teachers taught chemistry with business-as-usual (BAU) methods for one year before implementing CCC in the consecutive year. An implementation of CCC consisted of implementing a minimum of one lesson from each of CCC's 9 curriculum modules throughout the year. In both years, research personnel made visits to the participating classrooms approximately once per month to collect field observations, collect data on fidelity of implementation, and administer pre- and post- measures to students.

Instrument

Self-concept was assessed with The Chemistry Self-Concept Inventory (Bauer, 2005), a measure for assessing self-concept related to chemistry, mathematics, and academics. The 40-item Likert survey assesses students' self-concept of themselves as learners and includes 5 subscales: chemistry learning, mathematics learning, academics in general, academic enjoyment, and creativity.

Participants

2366 students taught by 31 teachers completed the self-concept inventory at the beginning and end of each school year. The survey was administered in class within the first two weeks and last two weeks of each school year.

Results

Before analyzing the effect of the CCC implementation, we tested the validity and reliability of the survey in this study. 1301 completed surveys administered during the first two weeks of the BAU data were sequestered for this analysis. Four of the five subscales had good reliability (Chronbach's $\alpha > .72$). Via Confirmatory Factor Analysis, we found that a four-factor model with the Creativity subscale ($\alpha = .44$) removed best fit the data, ($X^2(521) = 3568.528$, $p < .001$, CFI = .81, RMSEA = .067).

We constructed a multilevel model (MLM) to determine the effect of CCC implementation (BAU vs. implementation) on student self-concept (gain scores). For this analysis, only students who completed 100% of all pre- and post-test survey items were included, which resulted in 1048 students. Individual students were nested within their teacher for this analysis. All subscales were normally distributed based on visual inspection of the histograms. For most of the subscale pairs, there was a general linear trend as shown by a scatterplot matrix. There was no multicollinearity between the dependent variables, with all Pearson correlations below $r = .41$, $p < .05$. Levene's test for homogeneity showed that one subscale, chemistry, did not meet this assumption, $F(1,1046) = 6.284$, $p = .012$. A MLM was run for each of the four dependent variables (subscales) with students nested within teacher. Only one model had significant fit: chemistry self-concept ($F(1,1039.813) = 35.275$, $p < .001$). All other models were nonsignificant (Table 1). For the significant model, a statistically significant difference was found between BAU and CCC Implementation Years (B = -.2642, SE = .0445, $p = .001$). Upon implementing CCC, students within the same teacher improved their chemistry self-concept by a factor of .26.

Table 1: MLM fit statistics for each model.

Self-concept subscale	Model fit	B	SE	p
Chemistry	$F(1,1039.813) = 35.275$, $p < .001$	-.2642	.0445	.001
Math	$F(1,1042.718) = .200$, $p = .654$	-.016585	.0370	.654
Academic	$F(1,1043.552) = .058$, $p = .810$	-.008963	.0374	.810
Academic Enjoyment	$F(1,1046) = .260$, $p = .610$	-.0196	.0385	.610

Conclusions

Our results suggest that implementations of CCC can yield improvements in students' self-concept and that this improvement is specific to chemistry. We observed a significant improvement in chemistry self-concept in CCC classrooms relative to business-as-usual practices, but no concurrent improvements in other attitudinal factors. The specificity of this effect is consistent with other reports (e.g., Scherer, 2013) that have identified domain-specific aspects of science self-concept. Importantly, the specificity of the finding suggests that CCC works to improve students' science self-concept in classrooms where it is implemented but does not lead to general improvements in academic self-concept or enjoyment. Our interim findings lend empirical support to earlier predictions (Jansen, Scherer, & Schroeders, 2015) that inquiry curriculum can better develop students' science self-concept relative to other designs and suggest that self-concept may be an important target for future design-based research studies.

References

Bauer, C. F. (2005). Beyond "Student Attitudes": Chemistry Self-Concept Inventory for Assessment of the Affective Component of Student Learning. Journal of Chemical Education, *82*(12), 1864-1869.

Jansen, M., Scherer, R., & Schroeders, U. (2015). Students' self-concept and self-efficacy in the sciences: Differential relations to antecedents and educational outcomes. *Contemporary Educational Psychology, 41,* 13-24.

Scherer, R. (2013). Further evidence on the structural relationship between academic self-concept and self-efficacy: On the effects of domain specificity. *Learning and Individual Differences*, *28*, 9–19.

Stieff, M., Nighelli, T., Yip, J., Ryan, S., & Berry, A. (2012). *The Connected Chemistry Curriculum (Vols. 1-9).* University of Illinois: Chicago.

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Towards a Theory of Mathematics Teacher Learning Ecologies

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Abstract: Research on mathematics teachers' learning typically focuses on single activities or programs and does not acknowledge the interactive impacts of multiple experiences in different settings. In contrast, from a teacher perspective, teacher learning happens across time and settings, through a complex web of learning experiences. In this conceptual paper, I propose how we could extend interactionist approaches to include a systems-level lens, towards a theory of teacher learning ecologies.

Introduction and purpose

The main premise of this paper is that teacher learning happens across time, settings, and activities (Borko, 2004; Clarke & Hollingsworth, 2002; Horn et al., 2013). While these ideas are not new, they have not yet been worked into theories and designs for teacher learning. Consequently, as a field, we seldom study and design teacher learning across the multiple sites of its development. In a review of 106 research studies about mathematics teacher learning, Goldsmith et al. (2014) claimed that none of the studies "prospectively laid out an iterative, multidomain theory of action for the intervention" (Goldsmith et al., 2014, p. 20). This is a problem, because employing simplistic conceptualizations of teacher professional learning limits our ability to explain — and consequently to support — different paths for such learning (Clarke & Hollingsworth, 2002; Opfer & Pedder, 2011). With this discrepancy in mind, rather than describing a certain activity, or certain features of activity, as optimal for teacher learning, the goal of this study is to work towards a more holistic conceptualization that highlights possible relationships between learning processes, settings, and activities. My point is neither to diminish the value of research on the effects of specific activities (or certain features of activities) on teacher learning, nor to claim that every study of teacher learning must include all possible aspects of teachers' learning ecologies. Rather, I claim that (1) attempts to look at subsystems must be understood as partial (Opfer & Pedder, 2011) and (2) employing more complex theories of teacher professional learning would extend our ability to explain and consequently to support teachers (Clarke & Hollingsworth, 2002). The goal of this paper is to work toward such conceptualization.

Extending interactionist perspectives to include system-level analysis

Research on teacher learning in math education tends to focus on the effect of PD interventions, where learning itself is not the main object of study but rather an indicator of the effectiveness of specific curricula, programs, or features of activity (Goldsmith et al., 2014). Interactionist perspectives on teacher learning break out of these constraints and privilege context, complexity, interactions, and questions such as why, how, what, and under what conditions teachers learn. At the center of interactionist perspectives on teacher learning is the sociocultural notion that learning is social and talk plays a main role in learning processes (Horn & Bannister, 2020). Interactionist researchers operationalize learning in a variety of ways: They detect specific learning moments within meetings; follow processes of collaborative and individual meaning-making and knowledge construction; and underscore conditions that are productive for learning (Lefstein et al., 2020). More generally, learning is mostly seen through changes in discourse in the immediate PD setting. Less prominent in interactionist perspectives is explicit attention to accounts of learning that are distributed across settings as part of participation in a broad range of activities, more and less formally structured (for exceptions, see Ehrenfeld et al., 2020; Horn et al., 2013). For example, in their review, Lefstein et al. (2020) noted that researchers in this field rarely attend to broader contexts of teacher conversations; "rather, they primarily focus on the immediate context of the setting or intervention" (p. 6). Accordingly, I argue that studies that take an interactionist perspective of teacher learning typically make rich connections between learning and its immediate contexts, but pay less attention to connections among different settings and activities teachers participate in. My approach in this paper is to extend interactionist approaches to include system-level analysis. That is, I suggest that to fully realize the affordances of interactionist theories for teacher learning, we need stronger theoretical connections between different scales where such learning takes place (see Figure 1).

The claim that we need stronger theoretical connections between the immediate and larger contexts of teacher learning reflects more general calls in the Learning Sciences. One such example comes from the recently published Handbook of the Cultural Foundations of Learning, wherein Nasir et al. (2020) conceptualize learning as "occurring along culturally organized learning pathways—sequences of consequential participations and transitions in learning activities that move (or do not move) one towards greater social recognition as competent in particular learning domains and situations" (p. 195). Nasir et al. made the overall claim that focusing only on local learning interactions limits our understanding of the cultural, relational, affective, and contextual nature of learning and their intersections with systems of power. I build on this example and other system-level models for learning to start imagining directions for theorizing teacher learning ecologies. Specifically, I recognize different forms of system-level learning as possible directions of research that would potentially explicate mechanisms of learning across settings, where teachers' practices shift over time.

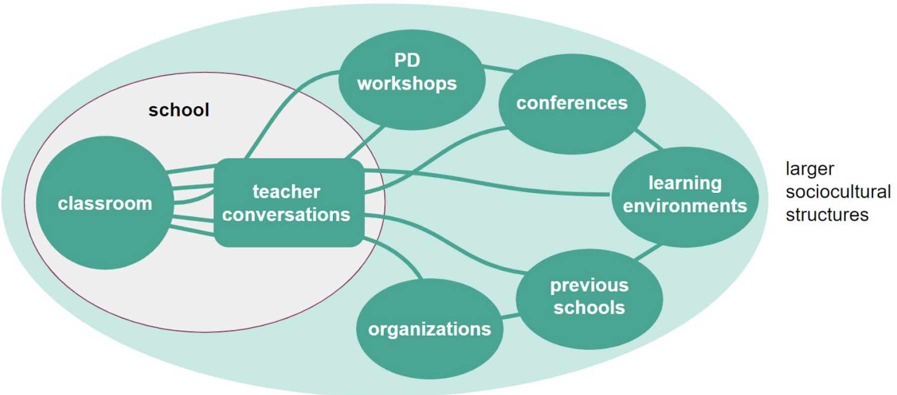

Figure 1. Suggested scope of an ecological perspective on teacher learning.

Significance

To support mathematics teachers, it is critical to understand how teachers learn across settings and to characterize the patterns of such processes (Borko, 2004; Horn et al., 2013; Opfer and Pedder, 2011). Interactional programs of research offer strong connections between learning and the immediate teaching context. Yet, these studies are typically bounded in specific activities and overlook broader learning contexts. I suggest extending interactional perspectives to encompass system-level analysis of learning. Such a perspective would open new spaces for thinking about, seeing, and designing for ecological teacher learning.

References

Borko, H. (2004). Professional development and teacher learning: Mapping the terrain. *Educational Researcher, 33*(8), 3–15.

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education, 18*(8), 947–967.

Ehrenfeld, N., Schneeberger McGugan, K., Marshall, S. A., & Garner, B. (2020). Reconciling contexts and external conceptual resources in mathematics teachers' collaborative sensemaking. In *Proceedings of the 42nd meeting of the Psychology of Mathematics Education North America*. Mazatlán, Mexico.

Goldsmith, L. T., Doerr, H. M., & Lewis, C. C. (2014). Mathematics teachers' learning: A conceptual framework and synthesis of research. *Journal of Mathematics Teacher Education, 17*(1), 5–36.

Horn, I. S., & Bannister, N. A. (2020). Interactionist perspectives on mathematics teachers' collaborative learning: Implications for intervention design. In H. Borko, & D. Potari (Eds.), *Proceedings of ICMI study 25* (pp. 126-133). Lisbon, Portugal.

Horn, I.S., Nolen, S.B., & Ward, C.J. (2013). Recontextualizing practices: Situative methods for studying the development of motivation, identity and learning in and through multiple contexts over time. *Interpersonal Regulation of Learning and Motivation: Methodological Advances*. Routledge.

Lefstein, A., Louie, N., Segal, A., & Becher, A. (2020). Taking stock of research on teacher collaborative discourse: Theory and method in a nascent field. *Teaching and Teacher Education, 88*, 102954.

Nasir, N. S., McKinney de Royston, M., Barron, B., Bell, P., Pea, R., Stevens, R., & Goldman, S. (2020). Learning pathways: How learning is culturally organized. In N. S. Nasir, C. D. Lee, R. Pea, & M. McKinney de Royston, (Eds.), *Handbook of the Cultural Foundations of Learning*. Routledge.

Opfer, V. D., & Pedder, D. (2011). Conceptualizing teacher professional learning. *Review of Educational Research, 81*(3), 376–407.

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Embodied Discourse Analysis of Online Student Study Sessions: A Novel Method of Screen Recording Research

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Abstract: Understanding the experience of nontraditional learners in distance learning is important for course design and facilitation and may illuminate issues that contribute to high attrition rates. This study used a novel approach to capture and analyze the engagement and distractions of students as they participated in online classes. Students recorded their screens along with webcam and audio, and this data was analyzed using embodied discourse analysis. Findings suggest that mother-students were particularly challenged with balancing these two roles at home during the COVID-19 pandemic but redesigning the environment and utilizing self-regulated learning strategies may be beneficial.

Introduction and background

While participation of adult learners in distance education has steadily increased (MacDonald, 2018), the sudden expansion of remote learning due to the COVID-19 pandemic has made it especially important to understand the experience of students who are learning from home with all of the distractions that entails. Our research questions are, *1) How do we explore nontraditional students' engagement in online learning tasks by using embodied discourse analysis? 2) How can we identify distractions in the learning environments of nontraditional students that contributes to or are a barrier to their success?*

Student engagement and distraction: Discourse Analysis Approach

Researchers have conceptualized engagement in terms of observable student behaviors, emotions, cognitive dimensions like self-regulated learning, and academic aspects like time on task. A newer and related area of research in online learning is the study of distractions (Blasiman et al., 2018; Hollis & Was, 2016), which can be barriers for student engagement. Coding methods for identifying student engagement during in person class time are well-established (Kubany & Sloggett, 1973), but a consistent method does not yet exist for distance learning.

An embodied discourse analysis approach can be helpful in more fully understanding an event as this enables us to move beyond the surface actions of an event and see the more subtle and compelling power dynamics at play among the participants (Rowe, 2004). In our study, the discourse is the actions the students is taking, the discursive practice is the prosocial behaviors of the student that conform to instructor expectations, and the sociocultural practice is the home context where the practice of being a student intersects with the home life and other identities of the students.

Methods

Our collective case study included four academically high achieving working mothers who were all experienced in distance learning prior to the pandemic. Students were given unique *Zoom* links and instructed to share their screen, enable their webcam, and microphone to record ambient audio during study sessions. Interview transcripts were organized in *Dedoose*, a qualitative analysis software, and screencast annotations were organized in *Google Sheets*. Students' actions on the screen were annotated in a spreadsheet, including mouse movements on the screen, active windows, the gaze of the student, other movements captured on the webcam, and ambient audio in the room where the student was studying.

Data analysis and findings

We watched each recording in whole and in parts several times at various playback speeds, identifying the type of interaction (student action on the screen), tenor (level of distraction as evidenced by gaze and noises in the environment), and field (environment of the student and situation within the course) (Rogers, 2003). We made a separate spreadsheet for each study session using a template created in *Google Sheets*, which could easily be shared among the researchers, enabling multiple researchers to code the excerpts and determine inter-rater reliability. Each excerpt was described by the researchers with annotations. We used an inductive approach to develop process codes across participants (Charmaz, 1996). We labeled each excerpt objectively as either *undistracted* or *distracted*. For example, loud noises from a television were coded as *distracting*, whether or not the student was actually distracted by it.

We noticed that at times, the student worked through the distractions, so we also marked the level of engagement of the student: *continues working*, *stops working*, or *undetectable*. These two levels of coding helped to identify whether the loud noises from the environment were actually distracting the student. Each undistracted excerpt was coded for the type of learning activity in which the student was engaged: *reading*, *writing/creating*, *watching a video*, or *navigating/searching*. Each distraction was coded by the type of the distraction (*switching windows/scrolling*, *cell phone*, *social media*, *looking away from the screen*, *engaging with another person*, *walking away*, *drinking/eating*, *movement*, *talking*, *noise*, or *technology*) as well as the source of the distraction (*self*, *adult*, *child*, *animal*, or *other*). Codes were defined to ensure uniformity in application throughout the sessions analyzed.

The excerpts were sorted and totaled to determine total time spent being distracted, in recovery, or undistracted, as well as the percentage of the total time. Codes were totaled for each session and frequency of each was determined. Excerpts were grouped by distraction, learning activity, source, and engagement to determine correlations and triangulate with interview responses. This process allowed us to draw conclusions around the engagement-distraction interaction in each study session and synthesized as a whole.

Results showed that nearly half of the recorded study session time included distractions. Participants were able to work through varying amounts of distraction, mediated by the urgency of their children's needs, the interest in or relevance of the content to the learner, and the instructional design. For example, in an activity where learners were scaffolded over several lessons through the process of using financial reports to analyze familiar companies, the learners were able to persist through distractions, particularly when they read aloud or spoke to themselves about what they were doing. Students were also more actively engaged during generative activities versus more passive learning activities like reading or watching videos.

Contributions and limitations

The findings in this study have helped us to understand how working mothers participate in distance education. For the most part, students work in small chunks of time whenever they can, preferably in the least distracted location in their home. Children were the biggest source of distraction for these mother-students. Maintaining these two roles in the home environment was challenging for these participants. It will be important for further study to analyze the experience of caretakers of other genders as well as students without caretaking responsibilities to understand the student experience from an equity perspective. Students who struggle academically should be studied in this way to determine what level of distractions they face as this may be a determining factor in their lack of persistence. Results highlight the importance of considering the high level of distraction present in the home environment during distance learning. The close analysis used in this study provided important insights into the experience of nontraditional learners in distance education and further study using these methods of data collection and analysis can be beneficial in illuminating the challenges and strategies that students use.

References

Blasiman, R. N., Larabee, D., & Fabry, D. (2018). Distracted students: A comparison of multiple types of distractions on learning in online lectures. *Scholarship of Teaching and Learning in Psychology*, *4*(4), 222–230. https://doi.org/10.1037/stl0000122

Charmaz, K. (1996). The search for meanings-grounded theory. In J. A. Smith, R. Harré, & L. Van Langenhove (Eds.), *Rethinking Methods in Psychology* (pp. 27–49). Sage Publications.

Hollis, R. B., & Was, C. A. (2016). Mind wandering, control failures, and social media distractions in online learning. *Learning and Instruction*, *42*, 104–112. https://doi.org/10.1016/j.learninstruc.2016.01.007

Kubany, E. S., & Sloggett, B. B. (1973). A coding procedure for teachers. *Journal of Applied Behavior Analysis*, *6*(2), 339–344. https://doi.org/10.1901/jaba.1973.6-339

MacDonald, K. (2018). A review of the literature: The needs of nontraditional students in postsecondary education. *Strategic Enrollment Management Quarterly*, *5*(4), 159–164. https://doi.org/10.1002/-sem3.20115

Rogers, R. (Ed.). (2003). *An introduction to critical discourse analysis in education*. Erlbaum.

Rowe, S. (2004). Discourse in activityand activity as discourse. In R. Rogers (Ed.), *An Introduction to Critical Discourse Analysis in Education* (pp. 79–96). Lawrence Erlbaum Associates. https://dinus.ac.id/-repository/docs/ajar/An-Introduction-to-Critical-Discourse-Analysis-in-Education.pdf#page=110

International Society of the Learning Sciences

Rethinking Technology-based Educational Studies in the Evolving Classroom Environment: An Interview Study with US Teachers

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Abstract: Despite the prevalence of conducting classroom studies using educational technology, it is underexplored what practical benefits classroom studies with educational technology offer to teachers and students, and what concerns or challenges they perceive. Our interviews found that teachers view study participation as a meaningful learning opportunity but also shared challenges and concerns, some of which are related to remote learning during the COVID-19 pandemic. We offer strategies that researchers can employ when conducting classroom studies.

Introduction

For decades, researchers of educational technologies have studied the effectiveness and use of educational technologies in the school classroom context (e.g., "in vivo" experiments, by Koedinger et al., 2009) to advance the science of learning. From a pragmatic viewpoint, however, it is essential that not only researchers benefit from classroom data collection but also that practitioners (i.e., teachers and students) find practical benefits in participating in research studies with educational technology (Coburn & Penuel, 2016), which has not been explored thoroughly in the literature.

Understanding practical benefits and associated challenges and concerns in participating in classroom research is even more important in times of crisis. In the year 2020, due to the spread of the coronavirus disease (COVID-19), a vast number of schools have been forced to make a transition to remote instruction to continue teaching and learning. It has significantly affected teachers and students in various ways, resulting in problems such as teachers' increased workload (Reich et al., 2020). Under such a drastic change to school environments, conducting classroom studies may cause additional stress and workload for teachers and students, who are already struggling with adjusting their practices. To explore how educational technology researchers can ensure that practitioners benefit from participating in classroom studies especially during the pandemic, we conducted interviews with US teachers, exploring *what practical benefits, challenges, and concerns teachers perceive for participating in classroom research in general and specific to the remote teaching setting.*

Method

We remotely interviewed seven middle- and high-school mathematics teachers in the US. We targeted teachers who either had expressed an interest in participating in classroom studies or had participated in a classroom study with us during the pandemic. Two graduate students analyzed approximately 11 hours of video-recorded data following an Affinity Diagramming approach. They generated a total of 179 codes and clustered into 70 mid-level themes, which were then grouped into eight major themes.

Results

Our analysis revealed eight major themes across two categories: perceived benefits and concerns/challenges in participating in classroom studies (Table 1). We discuss one theme from each category due to the page limit.

Table 1: Perceived benefits and concerns/challenges in participating in classroom studies

Benefits	**Concerns/challenges**
Teachers consider that students will benefit by meeting researchers *in the wild*	Teachers find it hard to know what level of interventions and facilitation is appropriate during studies
Teachers consider that students will be motivated to contribute to science	Teachers prefer customizability and flexibility regarding research participation and content to-be-covered
Teachers will have an opportunity to understand their students from a different perspective	Teachers are concerned with lack of synchronous, immediate support for remote students
Teachers view participating in educational research as professional development opportunity	Teachers are concerned with students' various learning environments during a pandemic

One benefit: students will benefit by meeting researchers *in the wild*

Teachers strongly emphasized the importance of connecting their students with researchers. Teachers view welcoming researchers in the classroom as an opportunity for students to learn about research as a real job (e.g., knowing what researchers do) and about opportunities that exist outside the classroom. One teacher stated that their students had had very limited exposure to the outside world even before the COVID-19 pandemic: "[we] are a very small community, so a lot of kids don't know what's out there. They haven't been out in the real world. A lot of them haven't even traveled beyond our edge of our city." They indicated that the need for real-world connections to material presented in classrooms has become more important due to the pandemic because students have fewer opportunities to interact with the world outside the classroom and their home.

One concern/challenge: lack of synchronous, immediate support for remote students

All teachers expressed concern regarding what to do if a student would face technical trouble or struggle with the content in the educational technology used in a study in which they might participate (e.g., students might have trouble when they log into the system). Supporting students remotely during such an event would be challenging, compared to doing so in the in-person regular classroom, especially struggling students who "do not reach out to [the teacher] or to their friends and they wind up being stuck or they just give up because they're frustrated."

Discussion: recommendations for researchers

The interviews revealed findings regarding teachers' motivations for participating in research. First, study participation itself can and should be conceptualized as a learning opportunity for practitioners. Second, by participating in classroom research with educational technology, whether during a pandemic or not, teachers and students can not only learn about the learning materials used in the research but could also learn about aspects of educational research and a researcher's job. The interviews also uncovered concerns and challenges they perceive regarding participating in research, many of which are related to and may be unique to the remote teaching setting. We believe that conducting classroom studies virtually will remain important as schools may consider a virtual learning environment as one of the several possible teaching modes for the next several years. Based on the findings and recommendations from teachers, we provide three practical strategies that researchers can consider when conducting remote classroom studies during and after the COVID-19 pandemic:

First, we suggest that *researchers collect data about individual students' learning environment.* Under the remote learning setting, it is critical to understand and document that students may have different learning environments and that the amount and quality of support they get from parents and peers may be highly variable. Such differences could impact their participation, engagement, and learning during a classroom study.

Second, we suggest that *researchers make study participation simple and allow for flexibility*. Teachers are concerned about not being able to provide immediate support to students during the study, especially during remote instruction. This support pertains not only to content support but also to technical aspects such as logging in to the technology and streamlining the task procedure. Also, researchers should discuss with teachers what activities are most meaningful for their students to ensure that the study aligns with their classroom practice.

Lastly, it is important that *researchers make themselves present in classrooms and communicate with students appropriately.* Teachers reported that researchers' presence would motivate students. We recommend that researchers make themselves available virtually or in other ways, and offer an opportunity for students to interact with researchers whenever possible (e.g., by creating dedicated time for students to ask questions during a study session).

References

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher*, *45*(1), 48-54.

Koedinger, K. R., Aleven, V., Roll, I., & Baker, R. (2009). In vivo experiments on whether supporting metacognition in intelligent tutoring systems yields robust learning. In D. J. Hacker, J. Dunlosky, & A. C. Graesser (Eds.), *Handbook of metacognition in education*, 897-964.

Reich, J., Buttimer, C. J., Coleman, D., Colwell, R. D., Faruqi, F., & Larke, L. R. (2020). What's lost, what's left, what's next: Lessons learned from the lived experiences of teachers during the 2020 novel coronavirus pandemic. https://doi.org/10.35542/osf.io/8exp9

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Learner Behavior and Career Benefits in Business Massive Open Online Courses

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Abstract: Adult learners claim career benefits from earning MOOC certificates, yet it is unclear if learning behaviors are correlated to these career benefits. This study examines the relationship between the learning behaviors and career benefits of learners who completed one or more of fifty business MOOCs. In a sample of 4063 learners, learning behaviors associated with persistence (videos watched and assessment attempts) were shown to be more strongly associated with perceived career benefits than either social behaviors (forum posts, comments, and views) or grades.

Purpose of study

Massive Open Online Courses (MOOCs), especially those in business or technical fields, can provide reputable and accessible educational content at an affordable price. Initially seen as a technological disruption of higher education (Yuan & Powell, 2013), they are now marketed as the solution to the ever-widening skills gap (Buhl et al., 2018). Recent scholarship shows that learners are reporting career gains from taking MOOCs (Hollands & Kazi, 2019a) and that learners who complete MOOCs to learn new skills are using the certificates earned in these courses to get hired or promoted (Hollands & Kazi, 2019b). Work has been done linking some forms of within-course behavior to career advancement, but only in one course (Wang et al., 2017). A study of behaviors associated with student completion in MOOCs was conducted across many courses (Andres et al., 2016), but this study did not examine career advancement after completion. The goal of this study is to determine if the learning behaviors which are correlated to completion across MOOCs are also linked to career benefits.

Methods

Wharton Online MOOCs are hosted on the Coursera platform which records learning behaviors such as video views, assessment attempts, forum posts, forum comments, forum views, and grades. A survey designed to measure career benefits was sent to a total of 101,986 learners who had completed at least one Wharton Online course through the Coursera platform from September 2015 through October 2019. The survey incorporated elements of a survey on motivation and career advancement developed by Hollands and Kazi, used with permission. Respondents were asked to rate whether or not they experienced career benefits on a 4-point Likert-style response from "Definitely yes" to Definitely no." "Completion" in Wharton Online courses is defined as earning a grade average of 70% or higher, which resulted in learners earning a certificate.

6321 learners began the survey, a 6.1% response rate, and 6189 learners (97.9%) consented to the study. 4341 learners answered Question 10 about whether or not they had experienced career benefits after taking the course(s). These learners' survey responses were matched to their course records, which included course grades, videos watched, assessment attempts, forum posts, forum comments, and the forum lurking ratio (i.e. forum views over forum posts). 278 learners were excluded from analysis because their survey email could not be matched to a learner i.d. Learning behaviors (videos watched, posts within forums, forum comments, forum views, grades on assessments, course grades earned) of 4063 survey respondents were tested for association with post-course career advancement using the non-parametric, Mann-Whitney U test to compare groups. The Benjamini & Hochberg (1995) method was used to control for false discovery rates: to verify that findings are not obtained solely due to running too many statistical tests.

Findings and discussion

Overall, the majority of learners reported that they experienced career benefits from Wharton Online MOOCs. 4319 learners answered the question about career benefits, and 3158 (73.1%) reported career benefits, while 1161 (26.9%) reported no benefits. Seven learning behaviors were examined: course performance (grades), videos watched in browser, assessment attempts, forum posts, forum comments, forum views, and the forum lurking ratio (forum views over forum posts). Each of these behaviors has been correlated with MOOC completion across multiple studies (Andres et al., 2016). However, only two of these seven behaviors—assessment attempts and videos watched in browser—correlated with career benefits (Table 1). Although forum activity has been correlated with post-course career development in earlier MOOCs (Wang et al., 2017), forum activity seems to have declined in more recent MOOCs (Poquet et al., 2018). One might reasonably assume that those learners who had higher grades would be more likely to report career benefits, yet that was not found. Correlation between assessment attempts and videos watched in browser could be due to grit (Wang & Baker, 2018) and/or self-regulated learning strategies (Kizilcec, Pérez-Sanagustin, et al., 2017), both of which have shown to be correlated to course completion. Another explanation for the correlation between assessment attempts and videos watched in a browser is the difficulty of the MOOC for learners. Learners who find the content new and/or more challenging may gain more knowledge and/or skills than those learners who engage less frequently with content.

Table 1: Results of Mann Whitney U Test and Adjusted α for Learning Behaviors by Career Benefits

Behavior	Mann Whitney U	Adjusted α
Course Grades	U(Nbenefits=2604, Nno benefits=935)=1171541, z=-1.711, p=.087	.021
Assessment Attempts	**U(Nbenefits=2965, Nno benefits=1098)=1523776, z=-3.141, p=.002**	**.007**
Video Starts Browser	**U(Nbenefits=2965, Nno benefits=1098)=1538169, z=-2.796, p=.005**	**.014**
Forum Posts	U(Nbenefits=2965, Nno benefits=1098)=16217951, z=-.653, p=.513	.043
Forum Comments	U(Nbenefits=2965, Nno benefits=1098)=1626243, z=-.081, p=.935	.05
Forum Views	U(Nbenefits=2965, Nno benefits=1098)=1626243, z=-.081, p=.935	.029
Lurking Ratio	U(Nbenefits=2965, Nno benefits=1098)=1610393, z=-1.050, p=.294	.036

Conclusion

The findings of this study show that the majority of learners who complete Wharton Online MOOCs report career benefits, particularly those who engage more with course content by attempting assessments more frequently and watching more videos in a browser. Because MOOCs can be taken by learners "in the flow of work" (Arets, 2016), they may be a source of more immediate career benefits than residential degree programs. This research can provide guidance for faculty and instructional designers in developing interventions that encourage those learning behaviors that are correlated with career benefits and may be useful for learners seeking career benefits.

References

Andres, J. M. L., Baker, R. S., Siemens, G., Gašević, D., & Spann, C. A. (2016). Replicating 21 findings on student success in online learning. Technology, Instruction, Cognition, and Learning, 313-333. Arets, J. (2016). 702010 Towards 100% performance. Sutler Media.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: a practical and powerful approach to multiple testing. Journal of the Royal statistical society: series B (Methodological), 57(1), 289-300.

Buhl, M., & Andreasen, L. B. (2018). Learning potentials and educational challenges of massive open online courses (MOOCs) in lifelong learning.

Hollands, F., & Kazi, A. (2019). Benefits and Costs of MOOC-Based Alternative Credentials https://er.educause.edu/articles/2019/6/mooc-based-alternative-credentials-whats-the-value-for-the-learner.

Hollands, F. & Kazi, A. (2019b). Benefits and Costs of MOOC-Based Alternative Credentials: 2018 - 2019 Results from End-of-Program Surveys. Center for Benefit-Cost Studies of Education, Teachers College, Columbia University.

Kizilcec, R. F., Pérez-Sanagustín, M., & Maldonado, J. J. (2017). Self-regulated learning strategies predict learner behavior and goal attainment in Massive Open Online Courses. Computers & education, 104, 18-33.

Poquet, O., Dowell, N., Brooks, C., & Dawson, S. (2018, March). Are MOOC forums changing?. In Proceedings of the 8th International Conference on Learning Analytics and Knowledge (pp. 340-349). ACM.

Wang, Y. E., Baker, R., & Paquette, L. (2017). Behavioral Predictors of MOOC Post-Course Development. In Proceedings of the Workshop on Integrated Learning Analytics of MOOC Post-Course Development.

Wang, Y., & Baker, R. (2018). Grit and intention: Why do learners complete MOOCs?. International Review of Research in Open and Distributed Learning, 19(3).

Zheng, S., Rosson, M. B., Shih, P. C., & Carroll, J. M. (2015, February). Understanding student motivation, behaviors and perceptions in MOOCs. In Proceedings of the 18th ACM conference on computer supported cooperative work & social computing (pp. 1882-1895). ACM.

Associations between Parenting Stress and Children's Academic Engagement when Schools were closed during the COVID-19 Pandemic: Risk and Protective Factors

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Introduction

When many governments announced nationwide school closures in March 2020 to contain the spread of the COVID-19 pandemic, the context for and nature of educational interactions changed radically (Parczewska, 2020). Simultaneously, millions of parents were turned into "accidental homeschoolers" (Burke, 2020). Informed by the Family Stress Model (Masarik & Conger, 2017), the present study investigated associations in homeschooling during the COVID-19 pandemic between parenting stress and children's engagement, i.e., children's active involvement in a learning activity. The Family Stress Model argues that economic hardship and pressures increase the risk of parental distress, which in turn increases the probability of interparental relationship problems and disrupted parenting. When parenting is affected by these dynamics, child adjustment problems tend to emerge and influence children's development. Various factors may exacerbate (risk factors) or mitigate (protective factors) the family stress process (for a review see Masarik & Conger, 2017).

The present study investigated associations between parenting stress and children's academic engagement when school were closed during the first spike of COVID-19 infections in spring/early summer 2020. More specifically, main and interactive effects of various risk and protective factors of parenting stress in relation to children's engagement in at-home education were examined, where children's engagement was viewed in four dimensions: behavioral, agentic, cognitive, and emotional. We hypothesized that parenting stress is negatively associated with children's engagement. We also expected risk factors to be related with higher levels of self-reported parenting stress and lower levels of children's engagement, and supportive factors with lower levels of self-reported parenting stress and higher levels of children's engagement.

Methods

Participants were recruited in the United States from advertisements on Facebook and by word of mouth. The total sample included 78 US-American families. For these families, data was available from 75 mothers and 54 fathers who completed the survey. Parents were asked to refer to their firstborn child who was homeschooled at the time of data collection as the subject of this study. Complete information from mother-father-child triads was available for 40 families. Partially complete information was available for mother and child in 46 families, and for father and child in 40 families.

Parents were asked to report their perceived parenting stress. Assessed risk factors included spousal relationship quality, health problems, number of children homeschooled and time in week in emergency homeschooling. Protective factors included perceived support from school and satisfaction with school support, and parents' online social network. The child was asked about his/her liking of homeschooling and engagement with homeschooling. The same questions about the child's engagement with homeschooling were also included in the parent survey.

All engagement variables, as well as, parenting stress, interparental relationship problems, and parent health problems were modeled as latent variables. Engagement variables were assessed using a modified scale from Reeves (2013). To measure parenting stress, we used the parenting stress items from the Fragile Families and Child Wellbeing Study (Cooper, McLanahan, Meadows, & Brookes-Gunn, 2009). Both interparental relationship problems and parent health used subscales from the Parenting Stress Index (PSI; Abidin,1995). All other variables included in the study were measured as manifest variables.

To account for the different respondents, the models were run with various combinations of respondent-reported variables. Models varied by which respondent reported parenting stress, risk/protective factors, and child's engagement. The combinations included mother-reported parenting stress and risk/protective factors on mother-reported child engagement (model M-M), mother-reported parenting stress and risk/protective factors on child-reported child engagement (model M-C), father-reported parenting stress and risk/protective factors on father-reported child engagement (model F-F), and father-reported parenting stress and risk/protective factors on child-reported child engagement (F-C). Due to the number of models run, a Bonferroni alpha correction was applied (yielding a minimum significance level of $p<0.0125$).

Additionally, we created interactions between parenting stress and the protective and risk factors, as well as an interaction between parenting stress and child liking of homeschool. Models were run first with only main effects, then again with the interactions. Models were trimmed using the Bonferroni alpha correction to only include significant interactions.

Results and discussion

Contrary to our hypothesis, no significant direct associations between parenting stress and children's engagement were found. This is true apart from model F-F, in which case parenting stress had a negative relationship with behavioral and emotional engagement.

However, when including interactive effects with parenting stress, the interactions were found to have significant associations with children's engagement. This indicates that parenting stress does have a significant association with children's engagement when considered in combination with other factors. For model M-M and model F-C, the interaction between parenting stress and children's liking of school was found to be significantly associated with children's engagement. More specifically, in model M-M, the interaction was significantly associated with all four types of children's engagement, and, in model F-C, the interaction was significantly associated with behavioral and agentic engagement. Plots of the interactions confirmed the same conclusion that the optimal combination for a high engagement score resulted from high child-liking of homeschooling with low parenting stress. For model M-C, the interaction term significantly associated with children's engagement, namely behavioral, cognitive, and emotional engagement, was parenting stress combined with length of homeschooling. In the context of high levels of parenting stress, possible negative effects on children's engagement were buffered when the homeschooling lasted for fewer weeks. Model F-F had no significant associations between any interaction terms and children's engagement.

For models M-M and M-C, our hypothesis of risk factors relating to higher parenting stress and lower children's engagement was not evident in terms of the main effects. However, the interaction of the risk factor length of homeschooling with parenting stress did have a significant association with children's engagement in model M-C as mentioned above. For models F-F and F-C, a relationship between risk factors and parenting stress emerged, while no relationship between risk factors and children's engagement was evident. In model F-C, parent's health had a negative relationship with parenting stress and in model F-F, parent's health as well as number of children homeschooled had a negative relationship with parenting stress.

For supportive factors, models M-M and M-C indicated relationships between supportive factors and parenting stress but not children's engagement while models F-F and F-C indicated relationships between supportive factors and children's engagement but not parenting stress. In models M-M and M-C, school support for at-home education had a positive relationship with parenting stress and the size of the mom's online social network had a negative relationship with parenting stress. In model F-F, both the father's satisfaction with school support and intensity of content management on social media related to at-home education had a positive relationship with emotional engagement. In model F-C, the size of the father's online social network had a positive relationship with agentic engagement.

In summary, our study identified potential risk and protective factors of children's engagement that could inform prevention and intervention at multiple levels to promote academic functioning, in particular among children at risk of falling behind.

References

Burke, L. (2020). Schooling during the COVID-19 pandemic: How Emergency Education Savings Accounts can meet the needs of every American child. Retrieved May 14, 2020 from https://www.heritage.org/education/report/schooling-during-the-covid-19-pandemic-how-emergency-education-savings-accounts

Cooper, C. E., McLanahan, S. S., Meadows, S. O., & Brooks-Gunn, J. (2009). Family structure transitions and maternal parenting stress. Journal of Marriage and Family, 71(3), 558–574. https://doi.org/10.1111/j.1741-3737.2009.00619.x

Masarik, A. S., & Conger, R. D. (2017). Stress and child development: a review of the Family Stress Model. Current Opinion in Psychology, 13, 85-90. http://dx.doi.org/10.1016/j.copsyc.2016.05.008

Parczewska, T. (2020). Difficult situations and ways of coping with them in the experiences of parents homeschooling their children during the COVID-19 pandemic in Poland. Education 3-13, DOI: 10.1080/03004279.2020.1812689

Reeve, J. (2013). How Students Create Motivationally Supportive Learning Environments for Themselves: The Concept of Agentic Engagement. Journal of Educational Psychology, 105(3), 579–595. https://doi.org/10.1037/a0032690

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An Interplay of Problem-Solving Modes and Authority: Framework for Equitable Collaboration in Undergraduate Physics Labs

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Abstract: We use the Adaptor-Innovator Theory and the Influence framework to interpret undergraduate physics laboratory students' approaches to – and bids for – intellectual and directive authority. Students display behaviors that utilize structure and work within a defined system (adaptor) and, separately, behaviors that work outside the system (innovator), the latter often by engaging directly with equipment. Adaptors exhibit high authority by asserting experimental understanding, whereas innovators are attributed with high authority through their frequent, direct handling of the equipment. We interpret equitable collaborations as those in which students 1) have full access to the experimental or conversational floor adaptively or innovatively while being 2) acknowledged in their authority by their group.

Keywords: problem-solving, equity, collaboration, Adaptation-Innovation Theory, authority

Theoretical framework

Although group work is an important form of learning for undergraduate STEM students, improving problem-solving skills and content understanding, identity-based performance gaps persist (Heller & Hollabaugh, 1992; Madsen et al., 2013). We examine undergraduate physics lab students' group dynamics, integrating the Adaptor-Innovator Theory (AI Theory) and the Influence Framework to interpret problem-solving behavior and frame a definition for equitable collaborations (Kirton, 2011; Langer-Osuna, 2016).

In AI theory, *adaptors* approach problems methodically, using given structures (Simpson, 2019). We observe three adaptor mode behavioral markers: i) seeking instruction, ii) defining the system, and iii) adhering to a manual. Conversely, *innovators* "problem solve by working outside of the system, sometimes creating radical changes" (Simpson, 2019). Innovator mode behavioral markers include: i) frequently handling equipment, ii) generating new ideas, and iii) exploring with curiosity. Individuals can exhibit both modes, and behaviors exist on a continuum, with the degree depending on context (Kirton, 2011; Kirton, 1980).

Students negotiate problem-solving modes through authority, and seek acknowledgment in their preferential approaches. The Influence Framework defines two types of authority: *intellectual authority* is perceived "as credible sources of information pertinent to the particular task at hand", while *directive authority* makes commands or suggestions to steer a course of action (Langer-Osuna, 2016). We find that acknowledgement in authority differs with the AI mode accessed: innovators are *attributed* with authority as they handle the equipment, whereas adaptors *claim* authority by asserting experimental understanding.

Table 1: Behavioral markers of adaptor and innovator modes and authority.

Adaptor-Innovator Theory		Influence Framework	
Modes	**Behavioral Markers**	**Authority**	**Behavioral Markers**
Adaptor	•Asks for and seeks instruction •Defines the system at hand •Appeals to lab manual	**Intellectual Authority**	•Perceived as an important source of information, asked questions by peers •Makes claims about experiment
Innovator	•Frequently handles equipment, not afraid to make changes. •Generates ideas outside of manual •Expresses curiosity in equipment	**Directive Authority**	•Makes directives to peers •Prompts actions on the equipment •Perceived as one that confirms bids

Methods

In this study, one researcher observed videos of students collaborating on advanced physics lab experiments at a public research university in the midwestern United States. The course is populated by second- and third-year physics majors and minors. After transcribing student discourse, the researcher coded for moments of high or low levels of intellectual and directive authority and when students approached problems adaptively or innovatively. Codes were confirmed with another researcher, who separately analyzed the videos, and organized into the codebook shown in Table 1, which describes the various behavioral markers.

Manifestation of problem-solving modes and authority and frame of equity

Students demonstrated behavioral markers of adaptors and innovators, moving fluidly between the two. For example, we observed a student to initially access the innovator mode, saying, “I kind of want to just start trying things” (unafraid to make changes on equipment), and later access the adaptor mode, saying, “We have to be really careful because of the cord in the back…that's what the manual was talking about” (appeals to lab manual). When a group attempts to access different problem-solving modes simultaneously, they express a preference through bids for authority. Their level of authority depends on how their peers respond to their ideas, and does not necessarily correlate with confidence or AI modes. For example, one innovator says, “I’m gonna start flipping these knobs…I don’t know.” Though he is unsure of his actions, the group affords him intellectual authority, perceiving him as a source of important information. In another group, an adaptor claims directive authority by proposing tasks and responsibilities: “Someone should be the ring measurer, someone should keep an eye on voltage.” She opens up the conversational floor—indicating influence—by asking “Who wants to be the ring measurer?” Her partners acknowledge her directive authority by taking on various roles and asking clarifying questions. Students with high intellectual authority are acknowledged by their peers; students with low intellectual authority, in contrast, are often unheard by the group even after expressing their thoughts.

We observe low authority when students are not given access to the conversational nor experimental floor, despite explicit bids. For instance, when one student suggests that the group ask the professor for confirmation, a partner rejects this bid for directive authority and instead asks the third member: “Should we turn it to, like, 500 and plug it in just to see?” The second student nevertheless persists, interjecting “Yeah, I would just say. Test it first and then we can actually start taking data.” Bids for authority may be rejected when students have differing problem-solving modes. In this example, we observed an adaptor reading from the lab manual in a bid for directive authority, which is rejected by the innovators directly handling the equipment.

We interpret equity as the ability to access the experimental or conversational floor and be acknowledged in one’s authority to approach problems adaptively or innovatively. For example, a student adjacent to a monitor may be unable to see the lab equipment, and thus have limited access to the experimental floor. Participation would therefore require explicit interjection into ongoing discussions, which are often ignored. When one student asks, “Do you know how to use an oscilloscope?”, the other responds with “Kind of,” ignoring the marginalized third member’s response of “Yes.” Here we see the inequity of access to the conversational and, thus, experimental floors to decrease group productivity, as the member with knowledge has been denied intellectual authority. When student authority is acknowledged, students can participate fully and thus equitably in their problem-solving collaboration. Inequities, however, are produced when students are marginalized by peers that dominate in authority or do not recognize bids because of a different problem-solving mode. The balance fluctuates throughout a lab, with moments of inequity interspersed with moments of equity.

References

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. *American Journal of Physics*, *60*(7), 637–644.

Kirton, M. J. (2011). Adaption-innovation in the context of diversity and change. London: Routledge.

Kirton, M. J. (1980). Adaptors and innovators in organizations. *Human Relations, 3*, 213-224.

Madsen, A., McKagan, S. B., & Sayre, E. C. (2013). Gender gap on concept inventories in physics: What is consistent, what is inconsistent, and what factors influence the gap? *Physical Review Special Topics - Physics Education Research*, *9*(2), 1–15.

Simpson, C. (2019). *Exploring STEM Identity Development, Motivation and Problem-Solving Preferences of African American Men Pursuing Undergraduate Degrees*.

Langer-Osuna, J. M. (2016). The Social Construction of Authority Among Peers and Its Implications for Collaborative Mathematics Problem Solving. *Mathematical Thinking and Learning*, *18*(2), 107–124.

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Multimodal Deep Learning Model for Detecting Types of Interactions for Regulation in Collaborative Learning

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Abstract: This paper reports a design science research methodology (DSRM) study that develops, demonstrates, and evaluates a deep learning model utilizing multimodal data to automatically detect types of interactions for regulation in collaborative learning (RegCL) by using features extracted from electrodermal activity (EDA), video, and audio data involving secondary school students (N = 94). RegCL offers novel and essential opportunities to advance research on Socially Shared Regulation of Learning in groups (SSRL).

Keywords: Self-regulated learning, socially shared regulation, design science research, collaborative learning, machine learning.

Multimodal deep learning model to detect interactions for regulation in collaborative learning (RegCL)

In recent years, the social aspects of regulation in general, and socially shared regulation in collaborative learning in specific, have gained the increasing attention from educational researchers (Malmberg et al., 2017). However, it is still challenging to assess and support the regulatory processes in interactions because of the "unobservability" of the processes at all levels, including cognition, metacognition, emotions, and motivation. In this study, we attempt to complement the design science research methodology (DSRM) approach with learning theories and machine learning algorithms to create a multimodal deep learning model for detecting types of interactions for regulation in collaborative learning. The model is conceptualized from self-regulated learning and socially shared regulation theory and designed based on multimodal data collected from a collaborative learning context.

We capture students' physiological activities through the measurement of Electrodermal Activity (EDA), and the visual and acoustic data reflecting engagement in learning activities in the classrooms' natural setting involving secondary school students (N = 94) working collaboratively in groups of three or four during five physics lessons. The types of interactions for regulation were classified using four separate labels: 1) metacognitive interaction, 2) socio-emotional-interaction, 3) task execution and 4) other interactions. Through the design and development of the deep learning model, we provide preliminary answers to the following research question: Is there evidence that SSRL processes can be automatically detected within the challenging learning situations and their related interactions? In other words, do we have evidence in favor of the feasibility of using multimodal and advanced technologies in support of SSRL?

Based on a review of previous multimodal deep learning frameworks, we designed a multimodal deep

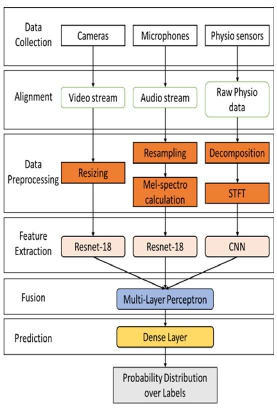

Figure 1. Multimodal Deep Learning Model to Detect Regulation Interactions in Collaborative Learning (RegCL)

learning model to detect interactions for regulation in collaborative learning (RegCL) as demonstrated in Figure 2. RegCL transforms the multimodal data from three modalities (i.e., video, audio, and electrodermal activity (EDA)) through a series of stages including Data Collection, Alignment, Preprocessing, Feature Extraction, and Fusion then passed through what is called a dense layer for the final prediction.

We conducted deep learning experiments on a randomly selected subset of the collected multimodal data with 3232 data pieces splitting into a training set (2459 data pieces), validation set (392 data pieces), and test set (381 data pieces) with the ratio of 8:1:1. The testing results show that fusing the features of multimodalities (audio-video-EDA) has significantly higher performance than models using video ($t = 5.509$, $p < 0.001$) or EDA ($t = 4.036$, $p < 0.001$) alone. Our demonstration and evaluation of the RegCL model provides evidence supporting the research proposition by Järvelä et al. (2019) provisioning that using advanced technologies on multimodal data holds to potential to reveal the "invisible" process of regulation in learning.

Discussion and conclusion

This study introduced the potential of multimodal deep learning to recognize types of interaction closely related to regulation in collaborative learning. It is important to note that we did not yet study regulation as such, since additional data and a qualitative approach is needed to understand that. The use of data collected from different modalities such as textual dialog transcripts, interaction events, video, and psychophysiological data offers a substantial promise for addressing the problem of understanding regulation in collaboration (Järvelä et al., 2020). The literature has also recognized several issues related to unfolding the social aspects of learning regulation to advance the operationalization of the concept of socially shared regulation in collaborative learning (Järvelä et al., 2019; Malmberg et al., 2017). This study attempts to bring together the powerful capabilities of affective computing and machine learning to address the methodological challenges for leveraging theoretical and practical foundations of learning regulation. The adoption of advanced technologies such as deep learning and multimodal data in this preliminary investigation have provided a proof-of-concept offering hope for eventually addressing the identified challenges.

References

Järvelä, S., Gašević, D., Seppänen, T., Pechenizkiy, M., & Kirschner, P. A. (2020). Bridging learning sciences, machine learning and affective computing for understanding cognition and affect in collaborative learning. *British Journal of Educational Technology*, bjet.12917. https://doi.org/10.1111/bjet.12917

Järvelä, S., Järvenoja, H., & Malmberg, J. (2019). Capturing the dynamic and cyclical nature of regulation: Methodological Progress in understanding socially shared regulation in learning. *International Journal of Computer-Supported Collaborative Learning*, *14*(4), 425–441. https://doi.org/10.1007/s11412-019-09313-2

Malmberg, J., Järvelä, S., & Järvenoja, H. (2017). Capturing temporal and sequential patterns of self-, co-, and socially shared regulation in the context of collaborative learning. *Contemporary Educational Psychology*, *49*, 160–174. https://doi.org/10.1016/j.cedpsych.2017.01.009

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"A Person with a Big Lengua": Productive Callouts in Whole Class Discussions

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Abstract: Voice can be conceived of as a project developing across time and situation as teachers and students co-construct how voice is locally defined through the social organization of classroom interactions. Using sociocultural theory as a grounding framework, this study illustrates how sixth grade students "had a voice" in whole class conversations and discusses implications for supporting collaborative, democratic, and heterogenous discussion spaces.

Introduction

Voice has been conceived of as a project developing across time and situation that can be supported in schools and classrooms (Lensmire, 1998). Here I build from Lensmire's conception of voice as a project to frame voice as an interactional accomplishment related to how sixth grade students and a teacher (myself) participated in whole class discussions as part of a visual arts unit focused on making art about student-defined social issues (e.g., immigration, racism). Within the social organization of the visual arts classroom, I am interested in how students "had a voice" in whole class conversations. This poster focuses on how voice developed on the interpersonal plane (Rogoff, 1995) with consideration of the research question: *How did the teacher and students co-construct voice in the local classroom context during whole class discussions about social issues and art making?*

Voice as an interactional accomplishment in a whole class participation frame

In classrooms, students orient toward one another within different participation frameworks (e.g., Goodwin, 2007) that influence what they notice and attend to. Classrooms also operate within historical and cultural frames that carry traditional norms of participation (i.e., teachers stand at the front of the class and teach, students sit, listen, and learn), yet participant roles and norms are in constant negotiation as students and teachers align with, resist, and disrupt these traditional norms in sociocultural interactions. Rogoff (1995) argues that sociocultural development operates on "three planes": the community/institutional, the interpersonal, and the personal. This study focuses on *the interpersonal plane* constituted by social interactions in whole class discussions.

Methods

The study site was a sixth grade visual arts class (n=32) at a public charter middle school named Esperanza Prep, situated in a working class Latinx community in Los Angeles County. 97% of students identified as Latinx, and 92% qualified for free or reduced-price lunch. I was previously the kindergarten through third grade visual arts teacher at the school and so many participants were my former students. Sociocultural theories of learning informed my approach to teaching and instructional design of a 20-lesson visual arts unit in which students made art about self-defined social issues. Relevant data sources included lesson activity logs, video transcripts, and field notes. For this study, in analysis of activity logs of all whole class discussions, I used an iterative, open coding process to find common patterns of interaction that were consequential for how participants "had a voice."

Findings

Table 1: Patterns of interaction consequential for co-construction of student voice in whole class discussions

Pattern of voice	What did the pattern *do for students*?	What did the pattern *mean for voice*?
(1) Bursts of prompted and unprompted conversation	Students could test, elaborate, and refine ideas in a smaller group before sharing more publicly	Voice is collaborative and builds from multiple contributions before being public
(2) Taking up of on-topic callouts	Students had agency to participate in ways that made sense to them and construct new norms	Voice is democratic; voice is co-constructed on the public floor
(3) Encouraging extension of ideas and offering different interpretations	Students elaborated on existing ideas and offered different perspectives based on prior experiences	Voice is heterogeneous; voice is a collection of diverse ideas shared in the public space

Table 1 shows the three salient patterns of interaction, including what they did for students and defining voice. Below, I illustrate the second pattern through an example from the third lesson during which students talked about social issues to motivate their art making. After sharing with partners, I asked students to make a class list of social issues. During this whole class conversation I began by calling on students in a traditional classroom turn-taking structure. Student contributions included "cyberbullying," "DACA," "deporting/la migra," and "police."

Students jumped in to add ideas, resulting in a repeated pattern of several students calling out at once. One student, Ariel, then offered the example of “Donald Trump” as a social issue, explaining:

> The NFL took the knee, they were doing the flag something and what’s going on with Mexico, and they had an invitation to the White House, but Donald Trump doesn't want them to go to the White House, and now he gave the invitation to some sport that only white people do.

Many students then started talking at once. In moments like these when the class took over, I noticed that students were participating in ways that made sense to them; their engagement was evident as some were physically getting out of their seats to contribute. In this case, I was aware of students’ desire to be heard as well as my positionality as a white woman within Ariel’s comment. Rather than elaborating on Ariel’s contribution, my intentional move of stepping back to listen left space for other students to speak. Once the conversation quieted, I offered the floor back to Ariel. She elaborated and others continued to make on-topic callouts, including Ken’s declaration that Trump is just “a person with a big lengua” in Excerpt 01, turn 02. The continued exchange reified on-topic call outs as a legitimate form of participation, strengthening its position as a new class discussion norm.

<u>Excerpt 1.</u>

Turn	**Speaker**	**Talk and *Action***
01	Ariel	It's kind of like that, but like when he speaks, he doesn't know how to stop his tongue 'cause he just doesn't think about it. *Teacher nods and says okay; many students nod or utter agreement*
02	Ken	He's a person with a big lengua *Ken calls out; many students laugh*
03	Mrs. Dahn	I'm gonna put in like a question mark, Donald Trump, to think about-
04	Benjamin	*Benjamin calls out* -racism
05	Oscar	*Oscar calls out* He doesn't want Curry to go to the White House
06	Mrs. Dahn	He, he makes us think about a lot- *Some students continue talking about the topic*
07	Ariel	*Ariel calls out* -and he wants to create America better again. How is that happening? *Many students talk at once*

Because the topics discussed were meaningful and emotional for students, they felt comfortable calling out, adding on, and supporting one another’s contributions in the whole class discussion space. Their overlapping talk and collective storytelling became a co-constructed part of the classroom culture and defining voice. By stepping back and allowing students to take over conversations, as the teacher, I offered students opportunities to take up space. This pattern of interaction allowed for public testing of private ideas. Voice was therefore democratic and about bringing individual and privately constructed ideas to the public floor to be further developed.

Discussion

The three patterns—bursts of partner talk, taking up of productive, on-topic callouts, and extending ideas about art and offering conflicting interpretations—–illustrate broadly how students and I co-constructed voice in whole class discussions. The second pattern illustrated here supported the co-construction of having a voice as something that was democratic and vetted on the interpersonal plane (Rogoff, 1995). This study has implications for how researchers conceive of student voice in classrooms as it takes students’ and teachers’ interactions and norm disruptions as part of a process (and project) of co-constructing voice. Additionally, this study has implications for design of collaborative, democratic, and heterogenous classroom discussion spaces.

References

Maxwell, J. A. (2013). *Qualitative research design: An interactive approach*. SAGE Publications.

Goodwin, C. (2007). Participation, stance and affect in the organization of activities. *Discourse & Society*, *18*(1), 53-73.

Lensmire, T. J. (1998). Rewriting student voice. *Journal of Curriculum Studies*, *30*(3), 261–291.

Rogoff, B. (1995). Observing sociocultural activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In J. V. Wertsch, P. del Rio, & A. Alvarez (Eds.), *Sociocultural studies of mind* (pp. 139–164). Cambridge University Press.

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Engagement patterns in an asynchronous virtual classroom: Different use of active observation and ICAP framework

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Abstract: This study investigates the impact of active observation mode in an asynchronous virtual classroom. Active observation, operationally defined as observing the learning activities of oneself or other learners, was compared to the modes suggested from ICAP framework. It was found that high-performing learners engaged more frequently in monitoring oneself and other's activities (active observation), while low-performing learners engaged more frequently in simply watching video lectures (Passive mode of ICAP framework).

Objectives and research question

This case study aims to propose the use of *active observation* for the design of an asynchronous virtual classroom. Based on the ICAP framework, the guiding ideas of this study were: (a) if the behavioral engagement pattern in active observation mode is distinguished from the other modes of ICAP framework, and (2) if the impact of active observation is different from the impact of other modes, then the active observation can be included as the additional mode of ICAP framework in online learning. Research question was generated: In an asynchronous virtual classroom, does the access patterns are different between high- and low-performing learners to each mode of the ICAP framework and active observation mode?

Backgrounds of the study

One of the biggest challenges of an asynchronous virtual classroom is to promote learning engagement. In this sense, the ICAP framework proposes that the distinguished nature of overt learning activities brings different levels of cognitive engagement (Chi & Wylie, 2014). ICAP modes of engagement include: **P**assive mode: receiving information (e.g., watching videos); **A**ctive mode: actively manipulating learning materials (e.g., pausing video); **C**onstructive mode: generating outputs (e.g., posing questions); and **I**nteractive mode: an action followed by other's reactions (e.g., discussion). **I**nteractive activities lead to deeper cognitive engagement than **P**assive activities (Chi & Wylie, 2014).

However, more studies are needed to use ICAP framework for designing virtual classroom. Existing sudies suggest that learners may find it challenging to access **I**nteractive and **C**onstructive modes in the online learning environment (e.g., Haney et al., 2016). In contrast, Wekerle and colleagues (2020) suggested that learners feel more encouraged when they are engaged in **C**onstructive activities.

An asynchronous virtual learning environment provides a learning experience that is hard to attain in a face-to-face classroom. *Active* ***o****bservation* in this study is operationally defined as *observing how learners (including oneself and others) engage in online learning*. According to ICAP framework, observation is regarded as *passive* mode, but it does not cover observing learners. Also, manipulating learning materials (**A**ctive) is more overt behavior than active observation, which does not include bringing any kinds of visible changes. **A**ctive **o**bservation is also not involved in **C**onstructive or **I**nteractive mode. When learners generate ideas and post them on the discussion board (**C**onstructive), other learners can read them and reflect accordingly. It can happen even when they do not engage in discussion (**I**nteractive).

Active observation is a distinguished affordance provided in virtual learning environments. Herrington and colleagues (2003) stated that providing opportunities for learners to reflect on their learning is one of the defining characteristics of authentic online learning environments. When learners engage in activities online, those remain as learning-footprints for other learners and as records for themselves. These facilitate internal feedback (learning by comparing and reflecting; Nicol, 2020) and observational learning (Bandura, 2008).

Methods

In this case study, the *participants* included 36 female undergraduate students from the college of education who were enrolled in the instructional design class. Course materials and online activities were uploaded weekly using the Moodle-based Learning Management System (LMS). After four weeks, students participated in online quizzes.

Learning Materials were developed as follow: **P**assive mode: accessing video lectures (week 1-4); **A**ctive observation mode: accessing various types of boards where learners can postings or comments others uploaded (week 1-4); **C**onstructive mode: the number of uploading posts (week 1-4); **I**nteractive mode: uploading comments to other's postings or comments (week 1, 3-4). In this class, **A**ctive mode in the original ICAP framework was not included due to the technological constraints of the LMS.

Measurement and analysis used for this study are as follows. *Log data* was collected from the Moodle-based LMS. The data contained the frequency of access by the users. Since the number of content varied each week, the data were standardized to t-value. For example, to calculate an individual's t-value for the Passive mode in the 1st week, the sum of the frequencies of access to two video lectures was calculated and standardized to t-value based on the average of the total frequency of access among all participants. The *outcome* was measured using an online quiz.Ten multiple-choice type questionnaire items were presented. The analytical processes are as follows: First, based on the final quiz score, the top 40.0% (13 participants, high-performing learners, HL) and the bottom 40.0% (14 participants, low-performing learners, LL) were selected from the data for comparison. Second, the average of t-values for each mode was calculated.

Results

The access patterns of each mode over time was different from each other (see Figure1). In terms of **P**assive mode, the LL participated more frequently than HL for all weeks. For the **A**ctive **o**bservation mode, The HL participated more frequently than the LL except in week 2. Regarding **C**onstructive mode, inconsistent pattern was observed across weeks. For the **I**nteractive mode, HL participated more frequently than LL except for week 1.

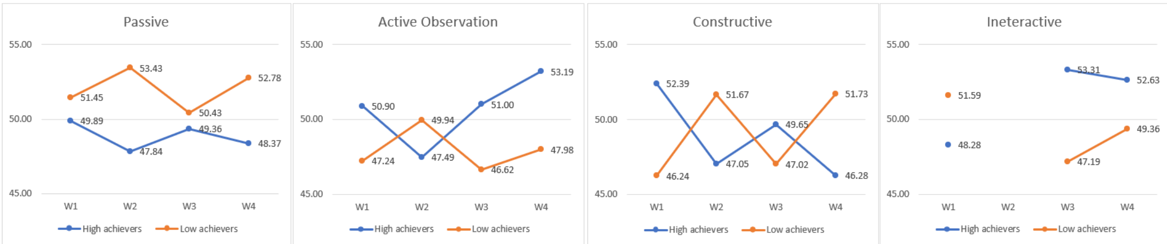

Figure 1. Access patterns over time for each mode

Implications for virtual classroom design

Implications are suggested based on the results. First, in an asynchronous virtual classroom, designing **I**nteractive modes may be more desirable than Passive modes: The result showed the differential access patterns under **P**assive and **I**nteractive modes between the HL and LL, as reported in the previous studies (Chi et al., 2018; Lim et al., 2019). Second, the differential access patterns for **a**ctive **o**bservation under the other ICAP modes support the study hypothesis. HL group engaged more in active observation overall except during the 2nd week, in contrast to the LL group, which engaged more in **P**assive mode in all weeks. This shows that although both **P**assive and **a**ctive **o**bservation modes entail observation, the target of observation in online learning can elicit different impacts on learning outcomes. It is also worth note that although both HL and LL learners engage in generating ideas, high-achieving learners tend to monitor and reflect based on observing how others do for learning.

References

Bandura, A. (2008). Observational learning. In *The International Encyclopedia of Communication,* John Wiley & Sons, Ltd.

Chi, M. T. H., Adams, J., Bogusch, E. B., Bruchok, C., Kang, S., Lancaster, M., Levy, R., Li, N., McEldoon, K, L., Stump. G, S., Wylie, R., Xu, D., Yaghmourian, D. L. (2018). Translating the ICAP theory of cognitive engagement into practice. *Cognitive Science, 42*, 1777-1832.

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219-243.

Haney, C. L., Atiq, M. S. Z., DeBoer, J., & Cox, D. (2016, June). Comparing Different Learning Activities in a Global Neuroscience MOOC. In Paper presented in *ASEE Annual Conference & Exposition*.

Herrington, J., Oliver, R., & Reeves, T. C. (2003). Patterns of engagement in authentic online learning environments. *Australian Journal of Educational Technology, 19*(1), 59-71.

Nicol, D. (2020). The power of internal feedback: Exploiting natural comparison processes. *Assessment & Evaluation in Higher Education,* 1-23.

Wekerle, C., Daumiller, M., & Kollar, I. (2020). Using digital technology to promote higher education learning: The importance of different learning activities and their relations to learning outcomes. *Journal of Research on Technology in Education*, 1-17.

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Considering K-12 Learners' Use of Bayesian Methods

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Abstract: Bayesian statistical methods have become increasingly widely-used by statisticians, scientists, and engineers, yet their use has remained within the purview of professionals—and not learners, especially those at the K-12 level. At the same time, decades of developmental research indicates that children learn about the world in ways that align with Bayesian models of cognition. In this paper, we review prior research on Bayesian methods and learning, and offer specific, targeted areas where we think that Bayesian methods could have make an impact, and then discuss future directions for Bayesian methods as a conceptual and statistical tool for learners.

Introduction

From a Bayesian perspective, probability and degrees of certainty are central. From this perspective, probability is used to describe the state of our knowledge about the world. Bayes Theorem, then, provides a rigorous and coherent mathematical framework to update our knowledge about the world, that is, learn, based on data and what we already know. Results from a Bayesian analysis quantify our (un)certainty about parameters.

Bayesian methods allow us to make statements based on our prior knowledge as well as the data; statements such as "Given much earlier studies and the data we collected in our study, the credible range of the length of *Ambystoma maculatom* is from 5.85-6.42 cm., with 6.17 as the most likely length." In contrast, a frequentist perspective conceptualizes probability in terms of infinite repeat sampling: Frequentist methods aim at estimating the value of the one true parameter based on models about the sampling process and sampling distribution. In consequence, results from a frequentist analysis would phrase the result about salamander lengths in the following terms: "Over many samples of *Ambystoma maculatom*, 95% of length measurements will fall in the confidence interval of 5.85-6.43 cm. (β = 6.20, SE = .44, p < .05)" In sum, Bayesian methods readily allow analysts (at any age) to incorporate existing subject-matter knowledge into their analysis and to interpret results in a more intuitive way that aligns better with how people think about the world.

Bayesian methods have not only been used by statisticians, although that is their provenance: Recent research has translated Bayesian ideas beyond their statistical provenance, particularly into the domain of developmental science. This work, broadly, highlights how children intuitively view the world in a Bayesian way (Gopnik, 2012). This paper is predicated on the possibility that the utility of Bayesian ideas to questions about how children *develop* might also have a bearing on how children and youth *learn*, especially in the context of interest on the part of learning scientists in data science and statistics education (Wilkerson & Polman, 2020).

Our goal, then, is to introduce Bayesian methods as an underutilized tool for learners. To do so, we offer two examples of the potential for Bayesian ideas and methods in learning sciences-related areas of research.

The potential for Bayes in learning sciences-related areas of research

Bayesian methods have the potential to bring a new perspective to questions that learning sciences researchers presently ask. In the following, we outline two examples—one from science education and one on the topic of conceptual change—of how a Bayesian perspective may help to redress existing learning-related challenges.

Probability and chance events play an important role in the life sciences, particularly in evolutionary processes and learning about them (Tibell & Harms, 2017). Recently, Fiedler et al. (2019) found that statistical reasoning accounted for nearly a third of the variance in students' knowledge about evolution. Thus, supporting students' statistical reasoning could greatly improve their learning about evolution. Given that research on students' statistical reasoning in the context of evolution has been predominantly approached from a frequentist paradigm (e.g., Fiedler et al., 2019), the potential of a Bayesian perspective remains largely unexplored. Bayesian methods could be useful because a Bayesian view of probability may align better with the ideas about statistics that learners already possess (Gigerenzer & Hoffrage, 1995) or amassing evidence suggesting that human cognition generally follows Bayesian principles (Gopnik, 2012). Thus, we think Bayesian methods could have particular utility in learning about evolutionary processes, and, more generally, probabilistic processes in scientific phenomena.

Bayesian models of cognition may also help to solve a riddle that has vexed the conceptual change literature for some time – the refutation text effect (Broughton et al., 2010). In contrast to traditional expository texts, refutation texts a) state a misconception, b) explicitly show how the misconception does not fully address the issue at hand, then c) present the accepted scientific position as an alternative. Numerous studies have demonstrated that such texts are very effective in facilitating conceptual change across a range of topics and domains; however, the nature of these effects remains to be little understood and an active area of research (e.g., Mason et al., 2019). Bayesian models of cognition offer a straightforward explanation of many different findings concerning the effects of refutation texts: Students' misconceptions are ideas about concepts acquired through everyday observations which prove to be effective in the contexts in which they are acquired. As an example, consider how children often think that only living things have energy (Watts, 1983). From a Bayesian perspective, the evaluation of the question can be framed as follows: the misconception that only living things have energy reflects a very strong prior for the association between being alive and having energy. A refutation text could help the reader to reevaluate their prior knowledge, and, thus, to weight new information (e.g., information about airplanes in flight having energy) more relative to their prior ideas. Scholars have begun to successfully model students' conceptual development in a Bayesian framework (Bonawitz et al., 2019). This and the above example illustrate how Bayesian methods can be applied to already-active areas of research. In the future, Bayesian methods may also invite new research questions for learning scientists.

Future directions for research

Advances in technological tools and statistical software may make the conceptual accessibility of Bayesian methods more technically accessible; one encouraging example of such a technological tool is the JASP statistical software (JASP Team, 2020), which allows for Bayesian models to be estimated as easily as frequentist models (even for models as foundational as *t*-tests and linear models); JASP also has features that are in line with what is known about the development of statistical software that is useable by learners (McNamara, 2019). Technological tools coupled with design-based research may prove to be helpful for understanding whether, when, and how Bayesian methods and tools have a role in K-12 contexts.

Looking ahead, Bayesian methods have proven to be useful to professionals, and Bayesian ideas about how individuals develop (e.g., Gopnik, 2012) suggest that there are opportunities to connect the thinking that children already do with how they learn. Though it may appear far-fetched for tenth-grade students, for example, to apply advanced statistical methods, we are collaboratively working to integrate Bayesian methods into science classrooms—including one of this paper's author's classroom—by shifting the focus away from hypothesis testing and toward understanding variation in data and exploring how arguing from evidence can serve as a context for learners to bring their ideas about how the world works into their scientific explanations.

References

Bonawitz, E., Ullman, T. D., Bridgers, S., Gopnik, A., & Tenenbaum, J. B. (2019). Sticking to the evidence? A behavioral and computational case study of micro-theory change in the domain of Magnetism. *Cognitive Science, 43*(8). https://doi.org/10.1111/cogs.12765

Broughton, S. H., Sinatra, G. M., & Reynolds, R. E. (2010). The nature of the refutation text effect. The *Journal of Educational Research, 103*(6), 407–423. https://doi.org/10.1080/00220670903383101

Dollard, C. (2011). Preservice elementary teachers and the fundamentals of probability. *Statistics Education Research Journal, 10*(2), 27-47.

Fiedler, D., Sbeglia, G. C., Nehm, R. H., & Harms, U. (2019). How strongly does statistical reasoning influence knowledge and acceptance of evolution? *Journal of Research in Science Teaching, 56*(9), 1183-1206.

Gigerenzer, G., & Hoffrage, U. (1995). How to improve Bayesian reasoning without instruction: frequency formats. *Psychological Review*, *102*(4), 684.

Gopnik, A. (2012a). Scientific thinking in young children: Theoretical advances, empirical research, and policy implications. *Science*, *337*(6102), 1623-1627.

Lee, V. R., & Wilkerson, M. (2018). *Data use by middle and secondary students in the digital age: A status report and future prospects.* Commissioned Paper for the National Academies of Sciences, Engineering, and Medicine, Board on Science Education, Committee on Science Investigations and Engineering Design for Grades 6-12. Washington, D.C

Tibell, L. A., & Harms, U. (2017). Biological principles and threshold concepts for understanding natural selection. *Science & Education, 26*, 953–973. https://doi.org/10.1007/s11191-017-9935-x

Watts, D. M. (1983). Some alternative views of energy. *Physics Education, 18*(5), 213. https://doi.org/10.1088/0031-9120/18/5/307

Wilkerson, M. H., & Polman, J. L. (2020). Situating data science: Exploring how relationships to data shape learning. *Journal of the Learning Sciences*, *29*(1), 1-10.

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Investigating Children's Problem-Solving Patterns in Digital Game-Based Learning for Computational Thinking Development

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Abstract: Developing computational thinking (CT) in digital game-based learning through problem solving is challenging to younger children. In this study, we investigated 79 children's in-game sequential problem-solving patterns in a CT game – *Penguin Go*. We found three in-game problem-solving patterns (i.e., solution implementation, consecutive implementation, and solution evaluation) and confirmed that children's problem-solving patterns predicted CT development at near and far transfer on CT. Based on the study findings, we also discuss design implications.

Keywords: Digital game-based learning, computational thinking, problem solving, sequential data analytics

Introduction

The recent prevalence of modern computing technologies and artificial intelligence has drawn attention to computing education for the next generation. Hence, increasing interest arises regarding how to incorporate the notion of computational thinking (CT) into the elementary curriculum worldwide (McGill & Decker, 2020) Several DGBL studies aimed at promoting children's CT development through in-game problem-solving experiences (Zhao & Shute, 2019). Specifically, DGBL benefits students to understand underlying game logics and rules that drive CT development by in-game failures and success experiences.

However, research has indicated that young children are likely to experience cognitive challenges in gameplay. Such challenges may yield unsystematic behaviors during in-game problem solving and learning transfer failure due to their limited uses of cognitive and metacognitive resources (Liu et al., 2017). Understanding children's in-game problem-solving patterns is essential because it indicates students' gameplay patterns representing diverse needs and challenges at different learning stages.

In this study, we aim at investigating the relationship between children's in-game problem-solving patterns and CT development through identifying emerging behavioral patterns by sequential pattern mining. Our research questions are:

(1) What are children's in-game problem-solving patterns in the game *Penguin Go*?
(2) To what extent do the in-game problem-solving patterns predict children's CT development?

Method

Study procedure

Penguin Go (PG) is an educational game teaching block-based programming language designed to enhance young children's CT development (Zhao & Shute, 2019). Seventy-nine children between 9 to 11 years old from diverse ethnic backgrounds were randomly assigned to either the treatment or the control version of Penguin Go. The control group accessed only the basic game mechanism support, while the treatment group received additional cognitive supports in the form of information prompts and partial worked-examples during the gameplay. Participants played *Penguin Go* for 135 minutes.

Gameplay data and sequential pattern mining

We collected computer logs from *Penguin Go* to identify students' game interactions. The log data contains students' game ID, game action, level, code, and timestamp. We conducted sequential pattern mining (SPM) to indicate students' emerging in-game problem-solving patterns. We aggregated individual gameplay data and arranged them based on each students' game ID and gameplay sequences. We used the *cSPADE* algorithm (Zaki, 2000) to identify frequent behavior patterns among various in-game sequences in a given time period (*max_gap* = 2, *min_sup* = 0.5).

Results

RQ1. What are children's in-game problem-solving patterns in the game

A total of 28 gameplay sequences containing five unique behaviors were identified. Based on the characteristics of the identified gameplay sequences, we classified the identified sequences into three pattern categories (Table 1). Second, in comparison to SI and CI patterns, children showed less SE patterns, which denote that children tended to have trouble with systematic problem-solving. Third, the SPM result demonstrated children's rare interactions with embedded learning supports during gameplay.

Table 1: In-Game Problem-solving Pattern Categories

Category	Pattern description	Implications
Solution implementation (SI) (average support value = 0.81)	Start with a series of *Create Blocks* and end with *Run Blocks*.	Implements and executes a solution with a clear algorithm in mind. The frequent occurrence of the SI behavior indicates an inefficient problem-solving heuristic (e.g., trial-and-error).
Consecutive implementation (CI) (average support value = 0.80)	Only contains consecutive *Create Blocks* with no *Run Blocks*.	Does not have a clear plan of the algorithm, which indicates unsystematic exploration or sometimes random block creation.
Solution evaluation (SE) (average support value = 0.64)	Contains *Reset Blocks* in combination with *Run Blocks* or *Reset Blocks*.	Interrupts the solution execution. Involves prediction of where the penguin is moving and the evaluation of the solution. Often associate with debugging.

RQ2. Effect of in-game problem-solving patterns on CT development?

We then examined how the frequency of the in-game problem-solving patterns across all in-game sequences predicted children's CT performance at the near and far transfer level. In terms of the in-game problem-solving patterns, the results indicated that the CI pattern was a statistically significant predictor for the near transfer (t = 2.33, p = .02) but not for the far transfer performance (t = 1.21, p = .23). On the other hand, the frequency of SE behavior predicted the far transfer performance (t = 1.92, p = .06) with a marginal significance instead of the near transfer performance (t = -.94, p = .35). This result infers that debugging-related behaviors influenced learning transfer in the long run, although this pattern was not efficient for learning immediately. The frequency of SI pattern was not a significant predictor for neither near transfer performance nor the far transfer performance.

Discussion and conclusion

The results displayed that children experienced inefficient and unsystematic problem-solving during gameplay. Such results echoed with the literature that students are likely to demonstrate inefficient behaviors due to the high cognitive load in a digital learning environment (Kirschner, Sweller, & Clark, 2006). The key design challenge we confirmed here is that children are difficult to distill abstract knowledge out of their learning experience with high cognitive load (Mulder, Bollen, de Jeong, & Lazonder, 2016). Therefore, demonstrating knowledge and skill transfer across contexts can be challenging. Therefore, it is essential to present a learning support that reminds children of what certain blocks and their combinations they can experiment with further. Further regression analysis also highlights the importance of evaluation- and prediction-related actions in gameplay.

References

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86. https://doi.org/10.1207/s15326985ep4102_1

Liu, Z., Zhi, R., Hicks, A., & Barnes, T. (2017). Understanding problem solving behavior of 6–8 graders in a debugging game. *Computer Science Education, 27*(1), 1-29.

McGill, M. M., & Decker, A. (2020). Tools, languages, and environments used in primary and secondary computing education. In *Proceedings of the 2020 ACM Conference on Innovation and Technology in Computer Science Education* (pp. 103-109). Trondheim, Norway.

Mulder, Y. G., Bollen, L., de Jong, T., & Lazonder, A. W. (2016). Scaffolding learning by modelling: The effects of partially worked-out models. *Journal of research in science teaching*, *53*(3), 502-523.

Zaki, M. J. (2000, November). Sequence mining in categorical domains: incorporating constraints. In Proceedings of the 9th International Conference on Information and Knowledge Management (CIKM '00), Agah, A., Callan, J., and Rundensteiner, E., (Eds.,) ACM Press, 422–429.

Zhao, W., & Shute, V. J. (2019). Can playing a video game foster computational thinking skills?. *Computers & Education, 141*, 1-13.

The Role of Parents in the Development of Youths' Interest in an Engineering Workshop

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Abstract: Parents support and facilitate youths' interest in informal education settings; however, this has not been fully explored in all informal contexts. We investigate how family interactions influence youth interest during an informal engineering workshop, analyzing one family's interactions using video-based ethnomethodology. Findings show that parents help facilitate the development of situational interest and further sustained involvement by bringing in new information and encouraging participation through connecting interests to the workshop.

Youths' exploration of the world around them is supported and influenced by the adults in their lives. Family inquiry practices including jointly orienting to a problem and using sensemaking resources can engage children's learning and interest in inquiry (Keifert & Stevens, 2019). Within informal settings, such as museums, workshops, or homes, parents scaffold children's learning and inquiry through conversational techniques (Benjamin, Haden & Wilkerson, 2010) and explanations (Fender & Crowley, 2007). They also encourage, support, and facilitate children's interest through gesture, conversation connecting to learning activities, scaffolding intake of new information, and engaging in familiar social practices (Zimmerman, Perin & Bell, 2010). Children's interests can be a) continuous interest that the parents build upon both in and outside of specific settings or b) situational interest, which is a spike in interest triggered by the context and the child's engagement. Situational interest is discontinuous and novel for the child, but it is based on previous continuous activities or interests (Azevedo, 2017). The maker movement offers a way to engage in interest-driven learning through the creative production and sharing of artifacts (Halverson & Peppler, 2018). However, parental involvement in encouraging situational interest has not been fully studied in all informal contexts (e.g., facilitated maker workshops). Therefore, this study focuses on analyzing how parent's interactions with their children impact their situational interest and engagement with the project or problem in an engineering maker workshop.

Methods

This study centers on a one hour-long workshop focusing on engaging families with elementary aged children in engineering principles using littleBits in a nature center that took place as the second iteration of a larger Design Based Research project called *STEM Pillars*. The workshop was organized around the guiding question: "How do engineers solve problems?" and the Engineering is Elementary model of Ask-Imagine-Plan-Create-Improve-Share (Cunningham, 2009). The families investigated littleBits (modular electronics) through open-ended exploration, simple problems (i.e., tickler, auto greeter, flashlight, flickering lantern), and a challenge problem (i.e., helping neighbors who could not see well). Throughout the workshop families shared their inventions with the other attendees and the STEM expert facilitator. A team of researchers collected video and audio data (5 hours of video; 4 hours of audio) and field notes. Out of the seven families (10 adults, 8 children: ages 6-10) that attended the workshop, we focus on one focal family, Lawrence (age 6) and his father Jax, because of their strong interactions and engagement throughout the workshop.

We analyzed the recordings using ethnomethodology (Koschmann, Stahl & Zemel, 2007). Through this analysis, we identified key moments for further analysis by focusing on the family interactions that influenced youth engagement in the workshop present within the videos and content logs. The clips were transcribed and analyzed through group and individual viewing sessions.

Findings

Situational interest (Azevedo, 2017) is driven by environmental factors, both by the context and by the interactions between participants. The activities and interactions of Lawrence and his father illustrate how situational interest can be triggered and encouraged by parental involvement—bringing in new information from materials, prompts, or explanations and supporting children's interests through conversation and gesture (Zimmerman et al., 2010). Lawrence's situational interest in engineering practices was triggered by creating an invention with his father to answer the prompt: "Help your neighbors who cannot see well – elderly people, young children or people with disabilities". Jax translated this prompt it into a sample goal connected to Lawrence's interests that he could work toward: bringing in new information (*"They need an alarm, that gives a sound, when someone enters the room"*). Based on this goal Lawrence had the idea to have the lights act as an alarm, animatedly gesturing to his glasses and eyes when explaining how to make the light *"go in their eyes better"*. This, in turn, inspired Jax who used gesture to explain his idea to have the light attached to the person's glasses. As they placed the littleBit light onto Lawrence's glasses, Lawrence's facial expressions and body language indicated excitement, showcasing his triggered situational interest, which was enhanced by his father's interactions.

Situational interest is both discontinuous, sparked by something in the environment, and continuous, based on previous continuous activities and interests (Azevedo, 2017). Lawrence began the workshop interested in inventing, supported by his father's engagement with both the questions the expert posed and with Lawrence's ideas. His continuous interest was encouraged through his father's explanations of the mechanics and electricity behind the functionality of the littleBits as they explored. In one episode, after Jax stated that they invented a fan, Lawrence asked *"How?"*. Throughout Jax's explanation Lawrence followed up, engaging with gesture and touch—pointing to parts of the invention they were discussing to further illustrate the electricity following through it. Jax helped to encourage Lawrence's engagement and interest in inventing while connecting their inventions to the bigger concept of electricity. This continuous engagement helped support Lawrence's later situational interest that was sparked by his and his father's eyeglasses light invention.

After situational interest was sparked, it appeared in future interactions in different forms (Azevedo, 2017). This can be seen in the ways that Lawrence interacts with his invention through engineering processes like sharing and iterating, and how his father influences this interest. When Jax encouraged Lawrence to share his invention with everyone, Lawrence's gestures and facial expressions indicated that he was excited, yet he hesitated several times once standing up to share, even saying that Jax should be the one to explain the invention. Jax reiterated that Lawrence should share the invention, but he comes up with Lawrence and offers his support through the whispered words *"I'm here*" and placing his arm unobtrusively on Lawrence's side to indicate his presense while not undermining his son's authority. This supported Lawrence to share his invention with confidence. After sharing, Lawrence's interests in refining and iterating on his invention continued. He asked questions and posed alternate scenarios to puzzle out how to make the invention better. Later in the workshop, he asked *"But what if they hold it not onto the doorknob? And just opened it up by the door if it opened like back in?"*, troubleshooting the use of a pressure sensor placed on the doorknob. He and his father experimented with a light sensor, exploring its functionality with and without the pressure sensor also attached to the invention to refine their invention. Lawrence's continued engagement with his invention illustrated how situational interests develop after they are triggered and how continued engagement is influenced by parental involvement.

Conclusion

The case study of Lawrence and Jax during an hour-long engineering workshop illustrated how situational interest (Azevedo, 2017) can be supported through parents bringing in new information around workshop activities and guiding participation by connecting interest to the workshop goals (Zimmerman, Perin & Bell, 2010). Lawrence's interest in engineering processes used in creating an invention that allowed people who could not see well to know when someone was coming in the room was aided by his father's support before, during and after the event that triggered this situational interest. The implications of these findings are key in designing environments where parents are supported to encourage children's interest in STEM in various informal learning contexts.

References

Azevedo, F. S. (2017) An inquiry into the structure of situational interests. *Science Education,* (*102*)108-127.

Benjamin, N., Haden, C. A., & Wilkerson, E. (2010). Enhancing building, conversation, and learning through caregiver–child interactions in a children's museum. *Developmental psychology, 46*(2), 502.

Cunningham, C.M. (2009). Engineering is elementary (EIE). *The Bridge*, 30(3): 11-17

Halverson, E., & Peppler, K. (2018). The maker movement and learning. In F. Fisher, C. E. Hmelo-Silver, S. R. Goldman, & P. Reimann (Eds.), *International Handbook of the Learning Sciences* (pp. 285-294). Taylor Francis.

Koschmann, T., Stahl, G., & Zemel, A. (2007). The video analyst's manifesto (or the implications of Garfinkel's policies for studying instructional practice in design-based research). In R. Goldman, B. Barron, S. Derry, & R. Pea (Eds.), *Video Research in the Learning Sciences* (pp. 133-143). Mahwah, NJ: Lawrence Erlbaum Associates.

Keifert, D., & Stevens, R. (2018). Inquiry as a members' phenomenon: Young children as competent inquirers. *Journal of the Learning Sciences, 28*(2), 240-278. doi:10.1080/10508406.2018.1528448

Zimmerman, H., Perin, S., & Bell, P. (2010). Parents, science, and interest. *Museums & Social Issues*, 5(1), 67-86.

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Making Space for Gender Equity in Makerspaces

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Abstract: Maker education stands out as an approach to STEM learning that has several benefits. However, despite the recent rise in its popularity, making in education may be excluding some groups of learners. In this poster, we report partial findings of a mixed-methods research project carried out in two high schools serving blue-collar, working-class families in Southern Brazil. We find that factors associated with shifts in self-reported attitude towards STEM and self-efficacy in engineering differ across genders.

Introduction

Maker education has recently undergone major growth in popularity and has become a global phenomenon in education. Scholars in maker education claim that this approach to STEM learning could lead to empowerment and emancipation (Blikstein, 2008), foster critical thinking (Kafai & Peppler, 2014), and engage kids in powerful learning (Halverson & Sheridan, 2014). Despite the rise in popularity, however, we know that maker education is not evenly distributed across regions, social classes, and demographics. Additionally, the themes explored by maker activities in school settings may not cater to all. Therefore, some groups of students may be excluded from learning environments that promote those practices. It is known, for example, that learners from different genders and social, economic, and racial groups are underrepresented in maker environments, such as maker faires and fabrication labs (Holbert, 2016).

In order to investigate gaps that hinder the achievement of equitable maker education, we conducted an investigation in Southern Brazil. In this paper, we report partial findings of a study conducted in two tuition-free schools serving families of blue-collar workers, run by a non-profit institution. *Since the project is ongoing, and due to the nature of a poster, here we focus on survey data, although the data set also includes in-depth interviews with teachers and students -- we are aware, however, of the limitations of data collected via surveys.* The data analysis reported here seeks to shed light on the differences and similarities between male and female students in terms of their self-efficacy in engineering and attitude towards STEM. Responses were analyzed in search of patterns that help explain variances (and lack thereof) in those attributes across genders in students.

Methods

242 high school students answered an online survey based on validated instruments (Siegel & Ranney, 2003; Wang & Berlin, 2010). It contained open-ended, multiple-choice, and multiple-answer questions, and also collected students' names. 140 respondents were female, 101 were male, and 1 preferred not to say their gender; 90 students were in the 10th grade, 77 in the 11th, and 75 in 12th grade. The questionnaire had 7 sections, of which 3 are relevant in this work:

- Dimensions of interest: ***Self-efficacy (engineering)***: A section containing 10 items. ***Attitude towards STEM***: A section with 16 items. Both were composed of Likert-scale items ("Strongly disagree" -- "Strongly agree"), which were recoded to a 1-4 scale.
- General information: ***Gender***: students were given 4 options: "Female," "Male," "Other," and "Prefer not to Say." ***Frequency of classes at the makerspace***: the frequency ranged from "less than once a week" to "more than 5 times a week." ***Frequency of experiments or hands-on projects in STEM classes***: the frequency ranged from "never or almost never" to "every day or almost every day." Data from this section were used to analyze the dimensions of interest.

Results

We ran factor analyses (Grice, 2001) to model non-observed variables of interest for the dimensions of interest. Due to the ordinal nature of these variables, we used polychoric correlation matrices to predict regression scores for each respondent in each of the factors. Then, we ran statistical tests to compare the predicted scores between genders. For the factors whose distributions did not follow normality, we ran Mann-Whitney-Wilcoxon (MWW) two-sample tests. Otherwise, we ran t-tests. Then, again due to the shapes of distributions, we ran MWW tests to analyze how predicted factor scores differ within each gender according to the two frequency scales.

Factors obtained through factor analysis

Self-efficacy (engineering): 1) SEE: Designing, making, and constructing (range of predicted scores: -3.23 -- 1.79); 2) SEE: Tackling difficult problems (range of predicted scores: -2.91 -- 2.01); SEE: Active invention and fixing (range of predicted scores: 2.37 -- 2.02). ***Attitude towards STEM:*** 1) ATS: Learning through designing, developing, and building (range of predicted scores: 2.79 -- 1.49); ATS: Feeling good at school (range of predicted scores: -3.41 -- 1.21); ATS: Learning with new materials (range of predicted scores: -2.69 -- 2.26).

Comparing the factors across genders

Our analysis shows that there was no statistically significant difference between female and male students in any of the 6 factors that make up "Self-efficacy (Engineering)" and "Attitude Towards STEM."

Comparing factors of self-efficacy (engineering) and attitude towards STEM among male students, according to the frequency of classes at the makerspace

Variation in "active invention and fixing" among boys: A one-sided t-test showed that *there is a statistically significant difference* in the predicted score for this factor between boys with a low and those with a high frequency of classes at the makerspace ($M = -0.17$, $SD = 0.92$; $M = 0.23$, $SD = 0.94$, respectively); $t(80.406) = -2.38$, $p = 0.023$. ***Variation in "feeling good at school" among boys***: A MWW test indicates that *there is a statistically significant difference* in this factor between boys with a low and those with a high frequency of classes at the makerspace (Mdn = -0.74 and Mdn = 0.51, respectively), $U = 655$, $p = 0.007$.

Comparing factors of self-efficacy (engineering) and attitude towards STEM among female students, according to the frequency of experiments or hands-on projects

Variation in "tackling difficult problems" among girls*:* Through the MWW test we found a *statistically significant difference* in this factor between girls with a low and those with a high frequency of experiments or hands-on projects (Mdn = -0.78 and Mdn = 0.34, respectively), $U = 1135$, $p = 0.013$. ***Variation in "feeling good at school" among girls***: The MWW test indicates that there is a *statistically significant difference* between girls with a low and girls with a high frequency of experiments or hands-on projects (Mdn = -0.60 and Mdn = 0.59, respectively), $U = 937.5$, $p = 0.001$.

Discussion and conclusion

In contrast to what is commonly seen in the literature, in this context in Brazil female and male students report similar attitudes towards STEM and self-efficacy in engineering. Nonetheless, a closer look at the components of the school experience for these students reveals that the frequency of classes at the makerspace is associated with differences among male students, and the same is true with the frequency of experiments and hands-on projects among female students. In summary, the data suggest that simply being present in makerspaces is not enough to promote meaningful learning and a sense of belonging in STEM for female students -- a finding that might apply to other minoritized groups. In the future, we plan to further triangulate qualitative data (interviews with students and teachers) to investigate the causes that contributed to the results reported in this paper.

References

Blikstein, P. (2008). Travels in Troy with Freire: Technology as an agent of emancipation. In *Social Justice Education for Teachers* (pp. 205-235). Brill Sense.

Grice, J. W. (2001). Computing and evaluating factor scores. *Psychological methods*, *6*(4), 430.Kafai, Y. B., & Peppler, K. A. (2014). 12 Transparency Reconsidered: Creative, Critical, and Connected Making with E-textiles. *DIY citizenship: Critical making and social media*, 179.

Halverson, E. R., & Sheridan, K. (2014). The maker movement in education. *Harvard educational review,* 84(4), 495-504.

Holbert, N. (2016). Leveraging cultural values and "ways of knowing" to increase diversity in maker activities. *International journal of child-computer interaction*, *9*, 33-39.

Siegel, M. A., & Ranney, M. A. (2003). Developing the changes in attitude about the relevance of science (CARS) questionnaire and assessing two high school science classes. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *40*(8), 757-775.

Wang, T. L., & Berlin, D. (2010). Construction and validation of an instrument to measure Taiwanese elementary students' attitudes toward their science class. *International Journal of Science Education*, *32*(18), 2413-2428.

Abstract: Leveraging Dilemmas as a Pedagogical Tool for Novice Youth Worker Learning

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Introduction

Efforts to professionally develop youth workers, educators who play an essential role in the social, emotional, and academic development of youth in afterschool contexts (Fusco & Gannett, 2012; Pozzoboni & Kirshner, 2016), often depend on explicit skill development. Explicit knowledge and skills include, for example, that youth workers understand the principles of child and youth development and apply them, that they use positive guidance techniques to manage the behavior of youth, and that they build relationships with families and other organizations in the community that encourage support of and involvement in the program. The field's articulation of standards is useful, but a focus on explicit skill development tends to minimize an important and necessary focus of on-the-job professional development and runs the risk of reducing youth worker expertise to a rote and procedural set of requirements. The field's efforts to design youth worker development around a standardized vision of explicit knowledge and skills has met with limited success. The tension is that much of youth worker learning typically occurs on the job as part of a learning process of implicit know-how through practice and reflection (Polanyi, 1966; Taylor, 2007).

The central argument I hope to advance via this poster presentation is that the field would do well to move from youth the focus on explicit skill development to embrace the complex ecosystems in which learning occurs (Gutiérrez & Jurow, 2016). This reasoning builds from the idea that the field's articulation of standards has perpetuated a vision of youth work as uncomplicated, making implicit knowledge and skill development for novice youth workers less transparent and difficult to articulate. As a corollary, robust pedagogical designs for youth worker teaching and learning to prepare practitioners for their on-the-job realities tend to be underdeveloped. While some practitioners may possess the necessary personal and transferable attributes important to the profession, most youth workers learn experientially throughout their time in-service as they gain the skills and knowledge necessary to navigate the complexities of the career. Therefore, explicit professional development frameworks need to be augmented by research that captures how to become a youth worker and novices' process of learning and development.

To begin arguing these points, I consider one locus of youth worker learning that is less articulated and researched: implicit skills (Polanyi, 1966; Taylor, 2007) developed experientially as youth workers navigate complex dilemmas of practice (Walker & Larson, 2012; Ross, 2013). I contend that dilemmas of practice ought to be leveraged at the higher education level in particular to build a pedagogical framework from which to teach novice youth workers implicit skills of the profession. I analyze novice youth workers' experience and reflection on dilemmas of practice that they faced as part of an experiential course called Adolescent Development and Educational Psychology (ADEP).

ADEP course design

ADEP was a higher education course that drew on positive youth development and experiential learning in afterschool youth programs. This course intentionally designed a curricular approach around dilemmas of practice, combining instruction about youth development theory, volunteer experiences in youth programs, and the practice of field noting. The course was organized the course around two driving questions:

1. How can adults build a developmental alliance with a young person that embodies elements of positive relationships identified in research?
2. How should classroom and community settings be designed so that they engage and empower young people?

We aimed to develop students' social justice awareness by attending to how adolescents' experiences in settings vary across lines of race, class, gender, citizenship status, language, and sexual orientation. The course leveraged experiential learning opportunities as students volunteered in local youth programs. The instructor team envisioned that through field experiences the students would develop self-awareness, as well as knowledge about adolescent development, which would enable them to reflect on their own approaches to situations and their narratives about youth and programming.

Sources of data and research questions

I collected the data presented in this poster between 2014-2018. For the broader study, I employed a qualitative analytical approach, collecting novice youth worker field notes, and eventually narrowing to case studies. In this poster, I present what four novice youth workers, Sydney, Connie, Claire, and Michael, learned in their experience with *dilemmas of practice*. They each wrote 3-5 sets of field notes representing what they defined as significant interactions throughout the semester.

Findings

In the poster, I will present the four case studies of Sydney, Connie, Claire, and Michael, four ADEP students. The analysis of the cases advances three claims. First, dilemmas faced in the field draw out tensions that exist for novice youth workers. Second, dilemmas orient and reorient the practitioner, encouraging new mental models to arise for approaching a problem of practice. Third, dilemmas advance the implicit skills of youth worker practice, including flexible and adaptable approaches and recognition of one's own socially and historically constructed stance on a situation. The use of dilemmas as a pedagogical strategy in ADEP revealed the ways in which novice youth workers struggled to resolve how to bring their identities and values, conceptual approaches to youth work, and situational encounters into concert with each other. Experienced youth workers, those who have spent much time in the field and with dilemmas, possess mental models for working these dimensions to approach dilemmas flexibly. These youth workers had to travel a path toward learning those implicit skills as they navigated their dilemma even when they felt ideologically opposed to or challenged by at first. Situating this pedagogical approach in a course, especially through writing field notes and engaging in critical reflection, shaped student learning and enabled students to make sense of situations that professionals in the field face.

I found that these cases offer useful takeaways for a field with few studies of pre-service education for youth workers, including:

1. The case studies illuminate how dilemmas can be used as a key pedagogical tool for novice youth worker learning.
2. Dilemmas illicit conversations about and practice with adaptive problem solving.
3. Dilemmas enabled students to make sense of situations that professionals in the field may face and how to do so while also leveraging equity-oriented approaches to youth work.

References

Fusco, D. & Gannett, E. (2012). A conversation with Ellen Gannett. In D. Fusco (Ed.) *Advancing youth work: Current trends, critical questions*, (pp. 3-12). New York: Routledge.

Gutiérrez, K.D., & Vossoughi, S. (2010). Lifting off the ground to return anew: Mediated praxis, transformative learning, and social design experiments. *Journal of Teacher Education*, *61*(1-2), 100-117

Jurow, A. S., Tracy, R., Hotchkiss, J. S., & Kirshner, B. (2012). Designing for the future: How the Learning Sciences can inform the trajectories of preservice teachers. *Journal of Teacher Education*, *63*(2), 147-160.

Kirshner, B., Pozzoboni, K., & Jones, H. (2011). Learning how to manage bias: A case study of youth participatory action research. *Applied Developmental Science*, *15*(3), 140-155.

Polanyi, M. (1966). *The tacit dimension*. Garden City, NY: Doubleday

Pozzoboni, K. M., & Kirshner, B. (Eds.). (2016). *The changing landscape of youth work: theory and practice for an evolving field.* Charlotte, NC: Information Age Publishing.

Ross, L. (2013). Urban youth workers' use of "personal knowledge" in resolving complex dilemmas of practice. *Child & Youth Services*, *34*(3), 267-289.

Taylor, H. (2007). Tacit knowledge: Conceptualizations and operationalizations. *International Journal of Knowledge Management (IJKM)*, *3*(3), 60-73.

van Es, E.A., & Sherin, M. G. (2002). Learning to notice: Scaffolding new teachers' interpretations of classroom interactions. *Journal of technology and teacher education*, *10*(4), 571-596.

Walker, K., & Larson, R. (2012). Youth worker reasoning about dilemmas encountered in practice: Expert-novice differences. Journal of Youth Development, 7(1), 23.

An Iterative Design Cycle: Using *Productive* and *Unproductive Frustration* to Guide Re-Design

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This work presents two versions of a series of conceptual puzzles situated within a video game for introducing players to the field of cybersecurity. Using players' gameplay experiences, we discuss how players' interaction with the first version of puzzles informed the design of game mechanics in the second version. We present the changes made in the second version and how the revisions helped turn unproductive frustration into productive frustration, which improved the gameplay experience. The findings show poorly designed puzzles create unproductive frustration, which inhibits the gameplay and learning experience; whereas well-designed puzzles create productive frustration, which supports players in learning.

This work builds upon the design of an under-development educational videogame, *Hex of the Turtle Islands* - an adventure game, which mixes explorative gameplay with more traditional puzzles. Our game design goal is to introduce players to the field of cybersecurity and to help them develop an identity of someone who can succeed in the field of cybersecurity. Using a design-based research (DBR) approach with a focus on designing conceptual puzzles (Barab & Squire, 2004), we utilize iterative rounds of development and feedback as a means to understand if and how the game is meeting our goals. In this work, we investigate the different players experiences with two versions of the game and how revisions of in-game puzzles contribute to shifts from unproductive frustration to productive frustration.

Puzzles are a crucial component in a wide variety of game genres as they provide opportunities for players to problem solve, explore, and use their previous experiences as a means of constructing knowledge for their next action (Juul, 2008; Oei & Patterson, 2014; Bonner, M. 2016). Our analysis focuses on learning as a generalizing activity (Ellis, 2007). We specially emphasize failure within learning videogames (Gee, 2003; Litts, & Ramirez, 2014). Failure paired with feedback can result in productive frustration that leads to productive iterative action-reflection cycles for the learner (Shokeen et. al., 2020).

In the data collection, we tested the initial game design ideas with 11 participants to understand how players respond to the game. The findings from the first version of game were used to iterate the design. The updated version of the game was tested with another set of 9 participants. Participants ages ranged from 10 to 15.

Version 1: Initial design of the wire puzzle

The wire puzzle is a logic puzzle that presents the player with a set of rules that must be followed for connecting wires to the appropriate ports. Players must follow a series of rules shown in the Wire Library (Figure 1, Label **A**) to solve the wire puzzles (Figure 1). The player must produce a correct configuration by dragging wires from label **B** to **C**. The interface tells the player how many wire connections are needed (Label **F)** and tracks their progress as the players proceed through the puzzle (Label **D)**. The Error Log (Figure 1 - Label **E**) provides feedback highlighting errors in the connection on failed attempt.

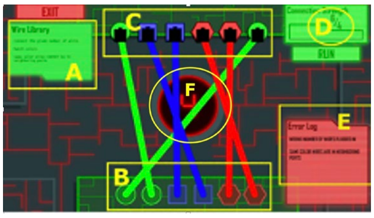

Figure 1. Wire Puzzle

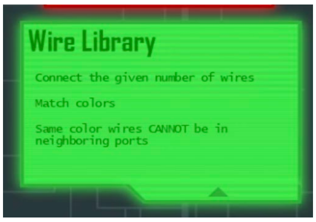

Figure 2. Version 1 Library

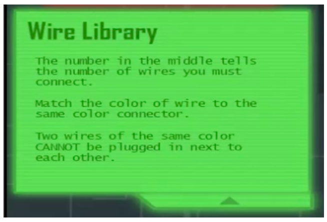

Figure 3. Version 2 Library

During the first puzzle version most of the players in their first attempt connected all the wires but struggled with the information provided in the puzzle interface and reached out to researchers seeking external feedback on their repeated failures i.e. unproductive frustration. These were struggles found mainly due to confusing wording of Wire Library (Figure 2). These findings identified places where design changes were needed, so we addressed these issues in the second design version.

Version 2: Revised design of wire puzzle

The major change to the wire puzzle for the second version was the introduction of 'wire modules', which are in-game representations of the rules associated with the puzzle and the re-wording of Wire Library rules (Figure 3). Players have to find the wire modules scattered around the island that prepare the player to expect a puzzle based on those modules. In the second version, all players were challenged by the wire puzzle. However, they were able to solve the puzzle successfully without seeking external feedback, which shows evidence of a productive frustrating experience.

Determining when the design does not provide accessible feedback to support learners who are failing is a crucial part of DBR. Identifying moments of unproductive frustration can show where modifications of the puzzles in the game are needed to better support iterative action-reflection cycles by players. We found a range of differences between players' experiences during the data analysis of play sessions from the first version of the game. We were then able to use the identified moments of unproductive frustration to design better paired failure-feedback by both communicating rules more clearly up front, and also changing language to be more accessible in both the rules and the feedback mechanism (e.g., the wire library and the error log). These mechanics served to support persistence through productive frustration, which resulted in fewer moments of unproductive frustration by players in the second version of the game. This speaks to one of the challenges of designing learning games: balancing the need for sufficient challenge for the game to be engaging, while ensuring that players are sufficiently supported in learning from and completing those challenges. Informing game design based on productive frustration and unproductive frustration can support designers and researchers in identifying when the challenges and supports are insufficiently balanced. Too many unproductive frustration occurrences indicate that failure and accompanying feedback need to be revised. Through DBR, we found that players experienced an appropriate amount of productive frustration, allowing them to engage in iterative action-reflection cycles.

Feedback and failure play a pivotal role in determining whether a player is experiencing productive or unproductive frustration while solving in-game puzzles. We leveraged moments of unproductive frustration in gameplay sessions of our first game version to guide our redesign and focused particularly on redesigning the feedback and failure mechanics. In developing the idea of productive and unproductive frustration as an analytic lens to be used in the evaluation and design of game-based learning environments, we seek to add another analytic tool to the educational game designers' toolbelt. In doing so, we help equip designers to make engaging and effective game-based learning environments.

References

Barab, S. & Squire, K. (2004). Design-Based Research: Putting a Stake in the Ground. *Journal of the Learning Sciences*, 13, (1). 1–14.

Bonner, M. (2016). Puzzle About The Island – Multi-Perspective Studies on Knowledge in THE WITNESS. 16.

Ellis, A.B. (2007). A taxonomy for categorizing generalizations: Generalizing actions and reflection generalizations. *Journal of the Learning Sciences*, 16, (2). 221–262.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. *Computers in Entertainment (CIE), 1,* (1).

Juul, J. (2008). The magic circle and the puzzle piece. *Proceeding of the Philosophy of Computer Games*. 56-67.

Litts, B. & Ramirez, D. 2014. Making people fail: Failing to learn through games and making. *Proceedings of the Games+Learning+Society (GLS)* 10. 160–166.

Oei, A.C. & Patterson, M.D. (2014). Playing a puzzle video game with changing requirements improves executive functions. *Computers in Human Behavior*, 37. 216–228.

Shokeen, E., Pellicone, A., Weintrop, D., Jass Ketelhut, D., Williams-Pierce, C., Plane, J. D., & Cukier, M. (2020). Designing Failure and Feedback within Puzzles. *Proceedings of Extended Abstracts on Computer-Human Interaction in Play (CHIPLAY)*. 370-374.

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Simulation-Based Learning in Higher Education: A Meta-Analysis on Adapting Instructional Support

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Abstract: This meta-analysis includes 143 empirical studies and investigates the effectiveness of different strategies to adapt and individualize instructional support to learners' prior knowledge and performance within simulation-based learning environments. The review identified strategies effective for learners with lower and higher prior knowledge and contributes to the discussion about effective design of learning with simulations. We conclude that (1) adapted instructional support enhances effects of simulations; (2) different strategies of adapting are effective for learners with different levels of prior knowledge.

Problem statement

Empirical research provides supportive evidence on the effectiveness of learning with simulations in different domains of higher education (e.g. Chernikova et al., 2020, Theelen et al., 2019). However, the research also shows that there is no single solution for effective instructional support which would fit all the learners. This paper contributes to deeper theoretical understanding of instructional support and learning, and provides valuable insights for practitioners and policy makers.

Theoretical background and research questions

The current meta-analysis aims at identifying the added value of adaption strategies for learners with low and high prior professional knowledge. This paper is grounded in skill development theories (e.g. Van Lehn, 1996) and empirical research on scaffolding and other instructional support measures, which were found to be beneficial in early stages of skill development, when learners are exposed to complex problems (e.g. Hmelo-Silver et al, 2006).

To capture adaptivity of learning environments we rely on the framework suggested by Plass & Pawar (2020). Under strategy of adapting we understand decisions made by educators, which were implemented and described in the primary studies.

The following research questions were addressed in the paper. (RQ1) In what ways strategies of adaptation are implemented in simulation-based learning environments in higher education? (RQ2) To what extent can these strategies facilitate learning outcomes in learners with higher and lower levels of prior knowledge within simulation-based learning environments in higher education?

Methods and results

The analysis is based on the collection of primary studies and average effects reported in a meta-analysis by Chernikova et al (2020), and is focusing on the added value of instructional support within simulation-based learning environments. A random-effects model and Hedges g estimation were used (Borenstein et al, 2009).

The average effect of simulations on learning was found to be g=.85, SE =.08 (Chernikova et al., 2020). This effect was used as a reference point to estimate the effectiveness of each adapting strategy.

The following adapting strategies (RQ1) were identified in the studies implementing simulations in higher education: (1) fixed adaptation based on the pre-test, (2) adaptation based on performance during simulation, (3) giving participants control over amount of support. The amount of studies implementing these strategies is reported in Table 1.

In regard to RQ2 we were able to identify one strategy, which was beneficial for all learners, a strategy that had some positive tendency for learners with a high level of prior knowledge, but was rather disadvantageous for students with low levels, and a strategy that had positive effects for learners with low prior knowledge and tended to limit learning gain for learners with high prior knowledge. Number of primary studies, effects sizes and standard errors are presented in Table 1.

Discussion

The findings of the current meta-analysis reveal that in simulation-based learning environments learners benefit from the opportunity to decide on the amount and timing of instructional support they get – this stands in some contrast to effects reported a range of more traditional learning environments (cf. Belland et al., 2017). Our findings suggest that within simulation-based learning environments different strategies of adapting are effective for learners with different levels of prior knowledge.

The limitations of this study include (1) a relatively coarse-grained categorization of strategies to adapt instructional support which might be confounded with some implicit instructional support within the simulation-based learning environments; (2) very scarce the description of learning environment in primary studies and (3) focus on only objective measures of learning outcomes.

In conclusion, as hypothesized, the effects of simulations can be enhanced by instructional support measures and adapting the instruction to match learning needs leads to higher learning gains. More research is needed directly comparing different adapting strategies for instructional support to fully exploit the power of simulations in developing complex skills.

Table 1: Effectiveness of adapting strategies

Strategy		**Low prior knowledge**	**High prior knowledge**
Fixed adaptation (based on pre-test)		*N* , Hedges *g* , (*SE*)	*N* , Hedges *g* , (*SE*)
Treatment	used	*N* =1, na	*N* =0, na
	not used	*N*= 56, .81 (.13)	*N*= 59, 1.08 (.11)
Assignment to groups	used	*N* =1, na	*N* =0, na
	not used	*N*= 32, .94 (.20)	*N*= 59, 1.08 (.11)
Instructional support	used	*N* =0, na	*N* =0, na
	not used	*N*= 57, .77 (.13)	*N*= 61, 1.08 (.11)
Performance-based adaptation			
Individualized scaffolding	used	*N* =0, na	*N* =0, na
	not used	*N*= 53, .74 (.13)	*N*= 55, 1.11 (.13)
Opportunity to adjust behavior during simulation	used	*N*= 12, .94 (.21)	*N*= 18, 0.92 (.20)
	not used	*N*= 39, .72 (.16)	*N*= 38, 1.10 (.14)
Change of complexity during simulation	used	*N*= 5, .77 (.23)	*N*= 6, 1.02 (.22)
	not used	*N*= 49, .75 (.14)	*N*= 50, 1.09 (.10)
Fading of instructional support	used	*N* =0, na	*N*= 3, 0.76 (.34)
	not used	*N*= 53, 0.76 (.13)	*N*= 54, 1.09 (.11)
Decision-making authority			
Amount of support	learner	*N*= 11, .88 (.23)	*N*= 16, 1.33 (.30)
	instructor	*N*= 40, .79 (.16)	*N*= 41, 1.08 (.11)
Assignment to group	learner	*N* =0, na	*N* =1, na
	instructor	*N*= 32, .87 (.21)	*N*= 23, 1.13 (.19)
Task order	learner	*N*= 4, .47 (.14)	*N*= 8, 1.13 (.36)
	instructor	*N*= 46, .82 (.15)	*N*= 42, 1.02 (.10)

Note: *N* - number of primary studies, *SE* - standard error, na - insufficient data for effect size calculation

References

Belland, B. R., Walker, A. E., Kim, N. J., & Lefler, M. (2017). Synthesizing results from empirical research on computer-based scaffolding in STEM education: A meta-analysis. *Review of Educational Research, 87*(2), 309–344. https://doi.org/10.3102/0034654316670999

Borenstein, M., Hedges, L. V., Higgins, J. P., & Rothstein, H. R. (2009). *Introduction to meta-analysis*. Chichester, UK: Wiley.

Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T., & Fischer, F. (2020). Simulation-based learning in higher education: a meta-analysis. *Review of Educational Research. 90*(4), 499-541. https://doi.org/10.3102/0034654320933544

Hmelo-Silver, C. E. (2006). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006), 99–107.

Plass, J. L. & Pawar, S. (2020). Toward a taxonomy of adaptivity for learning, *Journal of Research on Technology in Education, 52* (3), 275-300. https://doi.org/10.1080/15391523.2020.1719943

Theelen, H., Van den Beemt, A., den Brok, P. (2019). Classroom simulations in teacher education to support preservice teachers' interpersonal competence: A systematic literature review. Computers & Education, 129, 14-26. https://doi.org/10.1016/j.compedu.2018.10.015

Van Lehn, K. (1996). Cognitive skill acquisition. *Annual review of psychology. 47*(1), 513–539. https://doi.org/10.1146/annurev.psych.47.1.513

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Investigating Student Engagement through a Virtual Reality Classroom

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Abstract: We present a prototype of a Virtual Reality classroom that is designed to investigate students' engagement as they interact with student- and teacher-avatars, multimedia presentations, and environmental cues. Student engagement is assessed by triangulating multiple measures, including self-reported data, system trace data, electroencephalography (EEG) brain data, and eye tracking.

Keywords: virtual reality, online learning, student engagement

Background

Student engagement is a complex, multidimensional construct that is typically viewed as incorporating affective, cognitive, behavioral, and social components and is thought to be an important pathway between instruction and learning (D'Mello et al., 2017). Due to its multidimensional nature, student engagement is difficult to operationalize and measure. Assessing student engagement is even more challenging in online environments, where information about students' behavior (e.g., nodding, taking notes) is very limited. Advances in virtual reality (VR) technologies now make it possible to examine student engagement in an authentic context with experimental manipulation of the learning environment (Glaser & Schmidt, 2018). Further, VR allows for the study of complex and intricate phenomena (in this case, engagement) within replicable scenarios (Bailenson et al., 2008). VR refers to a three-dimensional, computer simulated environment experienced by users via specialized equipment such as tracking systems and head-mounted displays (HMD) that mediate one's interactions within the digital environment. The use of VR HMDs also provides the additional affordance of promoting a user's sense of telepresence (i.e., feelings of immersion and sense of presence; Bailenson et al., 2008) and enabling users to embody their actions and social interactions to construct an online identity (Dalgarno & Lee, 2010). Users of VR learning systems are represented by avatars that act as the nexus for engagement as they interact with and have their actions mirrored into the world around them and with other users through scripted events that serve as instructional objects and outcomes. An additional affordance of this technology is the benefit of automating data logging (trace data) to provide a holistic snapshot of student–computer, student-student, and student-teacher interaction in the virtual world (Glaser & Schmidt, 2018). These trace data can be further coupled with physiological data, such as eye tracking and Electroencephalography (EEG), to further glean insights into the nature of student behavior within virtual learning environments (Yang et al., 2019).Yet, several challenges should be considered in the context of using VR in learning sciences research. Beyond the more apparent limitations related to the cost and resources required to develop such software, not much is known about the perception of instructional content and multimedia within 3D virtual learning environments (Sutcliffe et al., 2019). There are also concerns related to adverse effects such as cybersickness that some individuals experience while using VR (Davis et al., 2014)

Proposed VR classroom

Here, we present a prototype of a VR classroom, where students control an avatar and receive instructional content delivered by a teacher-agent avatar. The strength of the VR classroom is that it allows simulating real-world learning in the lab, while researchers maintain full control over the learning environment, and can manipulate it to test specific hypotheses. As such, it provides an excellent intermediate tool for bridging between controlled lab-based research and real-world classroom research. Whereas previous attempts to use VR classrooms have focused on attention-deficit/hyperactivity disorder (ADHD) assessment with highly artificial tasks (e.g., identifying a target letter in a sequence of letters) (Parsons et al., 2007), our VR classroom allows investigating student engagement with authentic learning tasks that can evolve in complexity. The system also supports the collection of self-reported data, eye gaze, and EEG brain activity (Fig. 1). In recent years, there has been growing interest in a variety of physiological measures that may supply more direct means for assessing student engagement (D'Mello et al., 2017). Whereas eye tracking can provide important information on how students engage with the virtual classroom environment as they shift their gaze between different elements (e.g., from the teacher to other students), EEG can provide information about *covert* shifts of attention during periods of steady eye-gaze (e.g., students might be staring at the teacher while thinking about their weekend plans).

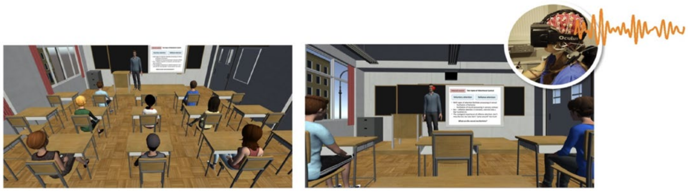

Figure 1. The VR Classroom (inset: a participant wearing an HMD with built-in eye tracker over an EEG cap).

Due to the COVID-19 pandemic, we have not yet been able to collect experimental data with the VR classroom. Instead, we will discuss the type of research areas that can be addressed with the VR classroom environment. For example, using the VR classroom researchers can investigate the interaction between the type of instruction, level of distractors, and student engagement. In other words, at what level of distractors do students become disengaged and does that depend on the type of instruction (e.g., listening to a lecture vs. solving a problem)? Whereas in a real-world classroom, it is hard to manipulate distractors experimentally, in the VR classroom, researchers can introduce and vary the level of distractors, such as a siren of an ambulance passing by and student conversations. Furthermore, the VR classroom offers high fidelity as the learning scenarios are pre-programmed and applied consistently across students. By using this approach, we can seek to examine content and pedagogy types with the goal of identifying how the individualized needs of learners can best be met in online learning spaces. Varying degrees of interaction by the user and within the environment itself can also be designed to examine how the features of the system can promote attention and learning outcomes. The VR classroom also allows to address questions related to how students experience the environment itself, such as to what extent do students experience telepresence, how the features in the environment foster engagement, and whether they experience any adverse feelings (e.g., cybersickness). This line of inquiry has direct implications to the learning sciences as research suggests that these feelings can impact students' sense of presence, cognitive load, usability, flow, engagement, and satisfaction (Servotte et al., 2020). We believe that our findings will have broad implications to the learning sciences, instructional design, and beyond. At the conference, we will seek to engage attendees in discussions related to the feasibility of our approach, methods of collecting data concerning engagement, and the design of different kinds of pedagogy within a VR classroom.

References

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The use of immersive virtual reality in the learning sciences: Digital transformations of teachers, students, and social context. *Journal of the Learning Sciences*, 17(1), 102–141.

Dalgarno, B., & Lee, M. J. W. (2010). What are the learning affordances of 3-D virtual environments? British *Journal of Educational Technology*, 41(1), 10–32.

Davis, S., Nesbitt, K., & Nalivaiko, E. (2014). A Systematic Review of Cybersickness. *Proceedings of the 2014 Conference on Interactive Entertainment - IE2014*, 1–9.

D'Mello, S. K., Dieterle, E., & Duckworth, A. (2017). Advanced, analytic, automated (AAA) measurement of engagement during learning. *Educational psychologist*, 52(2), 104-123.

Glaser, N. J., & Schmidt, M. (2018). Usage considerations of 3D collaborative virtual learning environments to promote development and transfer of knowledge and skills for individuals with autism. *Technology, Knowledge and Learning*, 25, 315-322.

Parsons, T. D., Bowerly, T., Buckwalter, J. G. & Rizzo, A. A. (2007). A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods. *Child Neuropsychology*, 13, 363–381.

Servotte, J. C., Goosse, M., Campbell, S. H., Dardenne, N., Pilote, B., Simoneau, I. L., ... & Ghuysen, A. (2020). Virtual reality experience: Immersion, sense of presence, and cybersickness. *Clinical Simulation in Nursing*, 38, 35-43.

Sutcliffe, A. G., Poullis, C., Gregoriades, A., Katsouri, I., Tzanavari, A., & Herakleous, K. (2019). Reflecting on the design process for virtual reality applications. *International Journal of Human–Computer Interaction*, 35(2), 168–179.

Yang, X., Lin, L., Cheng, P.-Y., Yang, X., & Ren, Y. (2019). Which EEG feedback works better for creativity performance in immersive virtual reality: The reminder or encouraging feedback? *Computers in Human Behavior*, 99, 345–351.

Exploring University Students' Ecologies of Digital Resources in the Context of Disciplinary Learning

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Abstract: This contribution explores university students' use of digital technologies for learning purposes and distinguishes between technologies provided by their institution and external technologies students accessed on their own. Participants were university students, surveyed and interviewed about use of and experiences with various digital technologies. The findings show a pattern in the use of institutionally provided and self-accessed technologies, and that students themselves generate value from their interaction with these technologies.

Introduction

This contribution explores undergraduate students 'use digital technologies for learning, under the assumption that learning involving curricular resources is often combined with activities crossing the boundaries of formal education, especially into online contexts. Students may follow less structured and unorganized pathways as they engage with online resources, such as social media and experience- and resource-sharing tools. Networked digital technologies have undoubtedly transformed the ways in which learning takes place, and the potential to 'support', 'enable', or 'enhance' learning has been associated with every significant development in digital technology (Veletsianos & Navarrete, 2012). New technologies are widely seen to support students in co-creating knowledge with peers, engagement in interest-driven informal learning practices, or personalized engagement with education. Still, concerns remain over the realities of digital technology use within university teaching and learning (Selwyn et al., 2016). Research in this area examined the implementation of different web 2.0 technologies, such as wikis, blogs or Facebook groups, and their effects on student learning and engagement (Heimbuch et al., 2018). Findings are varying and often contradictory, highlighting both opportunities and challenges.

Following Selwyn and colleagues' (2016) argument, this study offers a view of university technology use that is 'state of the actual' rather than 'state of the art' and an exploration of the everyday uses of digital technology by the students in practice. Against this backdrop, the purpose of this study is to contribute to a research agenda that aims at making the students' ecology of resources (Luckin, 2008) explicit, by understanding both use and the distinction between institutionally provided digital tools and digital tools students access and use on their own initiative. With this in mind, the study will answer the following research questions: 1) *What digital technologies are students using for studying and learning?*, 2) *What are the relationship between digital technologies and study programs?*, and 3) *What are the purposes and key drivers for students to adopt different types of technologies for learning within and beyond the university 'ecology'?*

Methodology

The data set was collected at a Norwegian university. A mixed-methods exploratory study was set up to map and interpret students' use of digital technologies related to their study- and learning activities. A survey was applied to 154 students from four study programs [Informatics (INF; n = 35), Philosophy (PHIL; n = 18), Educational Sciences (PED; n = 69) and Humanities/language course (TEd; n = 32)]. The specific items investigated was "What digital channels and tools do you use, and how much?" with responses "Used a lot", "Barely Used" and "Never Used". In addition, a focus-group interview was organized with four students (INF, PHIL, PED, and HUM) focusing on the students' own experiences with use of technology. The (ongoing) analysis consisted of descriptive statistics, independence tests (Cochrane-Armitage test) and an association measure (Freeman's Theta) of the survey data. The qualitative interview data was analyzed following a thematic analysis approach (Braun and Clarke, 2006). We present the quantitative findings in table 1 and the qualitative findings using illustrative data extracts.

Findings

Nearly all student students across all study programs used Canvas (Table 1). There was a low but statistically significant association between Canvas use and the four study programs. Eighty-three percent of students used Instant messaging platforms (IMPs). There were equal proportions of students across all our programs that used IMP, which was indicated by an insignificant association test (Table 1). Finally, a high proportion of students used Wikis with 58% of PHIL and 57% of INF students using Wikis "frequently". The association of use of Wikis by discipline was statistically significant but low (Table 1).

Table 1: Quantitative results

	Whole Sample				Study Programs	
Tools	**Prop. (SD)**	**(3) %**	**(2) %**	**(1) %**	**χ^2 Test (df; p)**	**θ_F (CI_low; CI_high)**
Canvas	0.96 (0.11)	62	34	4	15.94 (3; 0.00)	0.23 (0.13, 0.35)
IMP	0.83 (0.38)	69	15	18	6.19 (3; 0.10)	NA
Wikis	0.84 (0.36)	41	44	16	10.63 (3; 0.01)	0.22 (0.12, 0.36)

Notes. SD = standard deviation; (3) = "Used a lot"; (2) = "Rarely used"; (1) = "Never used";
χ^2 = Chi-square; df = degrees of freedom; p = p-value θ_F = Freeman Theta

Findings from the focus-group interview. **Within the university 'ecology':** ***Canvas***. Students reported that, although Canvas is the official LMS in use at the university, the *usage* is limited. One student explains: *"I mainly [...] look at things my professor says s/he put up there." (PHIL).* Canvas is predominantly experienced as a management tool. However, students also see a potential in Canvas as a tool for supporting learning processes, for example, when *"the teacher puts out a lot of discussion questions" (PHIL)* which have *"been helpful to me" (HUM).* **Beyond the university 'ecology':** ***Instant messaging platforms (IM).*** Facebook/messenger is referred to as the most commonly used communication infrastructure. It is, among others, used for organizing study groups, and for group discussions: "*To get a better idea of what we have learned" (HUM)*. One student (PHIL) explains that social media might be used as the main way to communicate since the students are already using it for social purposes. This makes Facebook "*not that organised"* and *"that's kind of a challenge" (PHIL).* ***Wikis.*** The students frequently use Google Search; however, their experiences with "google-ing" differ. "Google-ing" can, for example, lead to specific Wikis, that: *"Gives, like, a nice summary and then I'll know, I'll recognize it" (HUM).* For other students, just "goole-ing stuff" becomes a time-consuming activity with no useful outcome. As one student explains: *"I am struggling knowing what specifically I should search for" (INF).*

Contribution and further steps

This study explored the use of digital technologies by university students from four disciplinary programs. The findings indicate that students use both institutionally-provided and self-accessed technologies to support their study and learning activities. Overall, we see an effort from students to 'customize' the technologies they access and use. This assemblage effort can be justified by instrumental purposes (which technology provides the best support for a certain activity), discipline-related study needs (support for specific activities), and familiarity with certain technologies due to personal use (Selwyn, 2016). While students seem to use technologies that are not institutionally provided in an emergent way, they appear aware of the fact that their use may be unstructured, and therefore, not always productive for their learning. Overall, this study provides empirical knowledge about how ecologies of digital technologies are being assembled by students in emergent or deliberate manner and how these ecologies, and the process of assembling them, may be discipline-dependent. Further research is bound to examine the way students' non-academic engagement with resources and technologies influences academic engagement, and forms of support and guidance for how such ecologies of resources can be assembled in order to provide the necessary mediating for learning.

References

Braun, V. & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, *3*(2), 77-101.

Heimbuch, S., Ollesch, L., & Bodemer, D. (2018). Comparing effects of two collaboration scripts on learning activities for wiki-based environments. *ijCSCL* , *13*(3), 331–357.

Luckin, R. (2008). The Learner Centric Ecology of Resources: A Framework for Using Technology to scaffold Learning. *Computers and Education, 50*(2), 449-462.

Selwyn, N., Henderson, M., Finger, G., Larkin, K., Smart, V., and Chao, S. (2016). *What works and Why? Understanding successful technology enabled learning within institutional contexts,* Canberra: ACT.

Veletsianos, G. & Navarrete, C. (2012). Online social networks as formal learning environments: Learner experiences and activities. *The International Review of Research in Open and Distance Learning*, *13*(1), 144-166.

Designing an Intervention to Foster Teachers' Contingent Responsiveness during Science Discussions

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Abstract: A teacher's capacity to perceive multiple dimensions of the classroom and to make instructional decisions on the fly is defined as '*Contingent Responsiveness'*. Little is known about how teachers manage the demanding work of moment-to-moment interaction during class discussions and how to prepare science teachers for this challenge. This poster presents the theoretical framework and tentative design features of a professional development (PD) program to foster contingent responsiveness in science teachers.

Introduction

The role of talk in science education has long been established – an essential part of learning science is learning how to engage in scientific discourse (Lemke, 1990). Leading a productive science discussion is challenging - teachers have to respond to the dynamic flow of student talk in the moment, orchestrate different voices towards a collective understanding, support the emergence of new ideas, as well as attend to the complex social relationships among members of the class. Such capacity to attend to multiple dimensions of the classroom situation and the ability to make instructional decisions on the fly in response to student ideas is defined as '*contingent responsiveness*. Despite the breadth of research on dialogic teaching, little is known about how teachers manage the demanding work of moment-to-moment interaction and decision-making on the fly in classroom discourse and how to prepare science teachers for such a challenge. In this study, I co-design a professional development program with teachers in Pakistan to foster contingent responsiveness during dialogic science discussions.

Theoretical framework

Acquiring a repertoire of techniques such as talk moves can help to scaffold a productive dialogue (Kazak et al., 2015). However, research consistently found that whilst teachers are capable of using strategies to elicit student ideas, and to increase students' participation, they often find it difficult in helping students to expand and move their thinking forward (Coffey et al., 2011). Therefore, leading a dialogic science discussion is not simply a superficial elicitation of student ideas, but a sustained interaction for a specific educational goal. Corno(2008) asserted that that teaching responsively is not only technical, but also intellectual as teachers have to simultaneously judge which ideas and questions will be most productive to pursue; attend to the intersection between students' everyday ideas and disciplinary ideas, and channel discussion toward an understanding of disciplinary core (Harris et al., 2012). Nonetheless, what is required of contingent responsiveness is not merely an intellectual exercise with unlimited time for teachers to craft a response, it demands thinking on their feet in a fluctuating array of interactions. The overwhelming pace of a real classroom is illustrated in a one- minute 28-second clip of Professor Deborah Loewenberg Ball, who counted 20 micro-moments when she had to decide how to react (Barshay, 2018). Therefore, responsiveness is not only technical and intellectual, but also improvisational given the fast pace found in a real classroom, which echoes with Sawyer's (2004) metaphor of teaching as an improvisational live performance.

Research aim and method

Given its multifaceted nature and the difficulty in fostering contingent responsiveness, this study aims to understand how science teachers develop such capacity and to design an effective intervention. Using design-based research (DBR) approach, I co-design and iteratively refine a PD program with teachers in Pakistan to foster contingent responsiveness during dialogic science discussions.

Tentative design

The technical, intellectual and improvisational nature of contingent responsiveness is embedded in the design of the intervention. For example, a mixed reality simulator (Mursion: https://www.mursion.com/) is used to address the improvisational nature of contingent responsiveness by approximating the dynamic nature of a classroom and enabling teachers to rehearse teaching in a contextualized environment (Dieker et al., 2014). The talk moves toolkit (Michaels & O'Connor, 2012) addresses the technical nature whilst collaborative inquiry attends to the intellectual nature by promoting conceptual change in teachers, such as the purposes of talk in science. The following conjecture map (Sandoval, 2014) describes the interaction between the design features, mediating process and the intervention outcomes. This poster aims to stimulate a productive discussion around the notion of contingent responsiveness as well as the design features of the intervention.

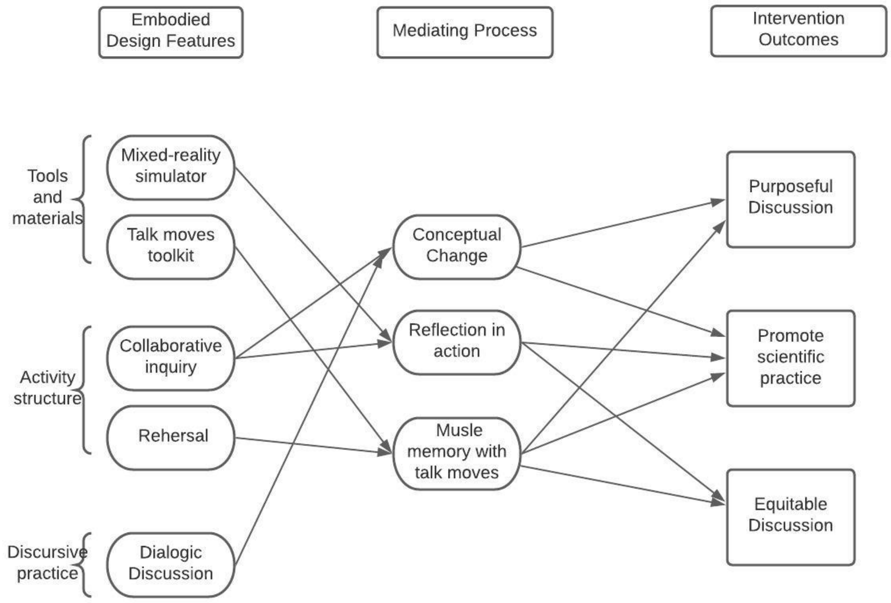

Figure 1. Initial Conjecture Map of the Design to Foster Contingent Responsiveness in Science Teachers.

Referfiences

Barshay, J. (2018). 20 judgments a teacher makes in 1 minute and 28 seconds. *The Hechinger Report*. https://hechingerreport.org/20-judgments-a-teacher-makes-in-1-minute-and-28-seconds/

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching*, *48*(10), 1109–1136. https://doi.org/10.1002/tea.20440

Corno, L. (2008). On Teaching Adaptively. *Educational Psychologist*, *43*(3), 161–173. https://doi.org/10.1080/00461520802178466

Dieker, L. A., Rodriguez, J. A., Lignugaris/Kraft, B., Hynes, M. C., & Hughes, C. E. (2014). The Potential of Simulated Environments in Teacher Education: Current and Future Possibilities. *Teacher Education and Special Education*, *37*(1), 21–33. https://doi.org/10.1177/0888406413512683

Harris, C. J., Phillips, R. S., & Penuel, W. R. (2012). Examining Teachers' Instructional Moves Aimed at Developing Students' Ideas and Questions in Learner-Centered Science Classrooms. *Journal of Science Teacher Education*, *23*(7), 769–788. https://doi.org/10.1007/s10972-011-9237-0

Kazak, S., Wegerif, R., & Fujita, T. (2015). Combining scaffolding for content and scaffolding for dialogue to support conceptual breakthroughs in understanding probability. *ZDM*, *47*(7), 1269–1283. https://doi.org/10.1007/s11858-015-0720-5

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Ablex Pub. Corp.

Michaels, & O'Connor. (2012). *Talk science primer*. TERC.

Sandoval, W. (2014). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences*, *23*(1), 18–36. https://doi.org/10.1080/10508406.2013.778204

Sawyer, R. K. (2004). Creative Teaching: Collaborative Discussion as Disciplined Improvisation. *Educational Researcher*, *33*(2), 12–20. https://doi.org/10.3102/0013189X033002012

Windschitl, M., Thompson, J. J., & Braaten, M. L. (2018). *Ambitious science teaching*. Harvard Education Press.

Linking Talk Types to Socioemotional Formation and Regulation

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Abstract: Social discourse is an important element of collaborative learning. In this study, we qualitatively analyzed the talk types used by groups of graduate pharmacy students during a six-week project-based learning assignment. We found 23 different talk types and linked them to the stages of the Formation and Regulation of Emotions in Collaborative Learning model. The use of different talk types influenced the groups' emotions and overall group functioning.

Introduction

In collaborative learning, students often have difficulty engaging in appropriate discourse with their peers (Bielaczyc et al., 2013), which can result in negative peer interactions and subsequent negative emotions that affect learning and encourage maladaptive collaboration habits (Näykki et al., 2014). The rich literature on discourse includes recommendations on how to engage students in discussions that promote collaboration and learning, as well as how different talk types relate to what and how students discuss (Murphy et al., 2016). Talk types are the different kinds of discourse in which students engage during collaborative learning (Sullivan & Wilson, 2015). More research is needed, though, regarding how different talk types manifest in group interactions and link to the formation and regulation of emotions. A better understanding of these relations would assist educators in helping students engage in positive interactions and overall collaboration. Therefore, in this study, we examined the role of talk types in small group learning.

Our work is derived from the theory of the Formation and Regulation of Emotions in Collaborative Learning (FRECL; Lobczowski, 2020). Per this model, groups are situated within a given *context* shaped by the individuals within the group, interactions between group members, and engagement with various components of small group learning (e.g., the task). Then, a *stimulus event* occurs, followed by an *appraisal* (i.e., cognitive representation of motivational constructs) and ultimately an *emotion* (e.g., happiness) and *response* (e.g., frowning). Upon completion of the formation stages (i.e., context, stimulus event, appraisal, and emotional response), the students may engage in regulation (i.e., the fifth stage). This theory highlights the complex nature of emotions in group settings but does not explicitly consider the role of social discourse within each of the stages. As such, we used an exploratory approach to analyze talk turns from mostly unstructured group discussions to qualitatively investigate: *(1) the different talk types student groups used in a project-based learning course* and *(2) how the talk types linked to the formation and regulation of emotions.*

Methods

Our participants included six groups of four to five second-year graduate pharmacy school students (n = 29) from the southeastern United States. These students were given a project-based task to create innovative solutions for real-world pharmacy problems. This study is part of a larger project in which we recruited the groups to use an app to rate their emotions during biweekly group meetings. These ratings revealed groups with high, medium, or low levels of positive emotional experiences. We analyzed the conversations from three groups (i.e., one high, medium, and low), which occurred during nine two-hour group meetings, totaling 27 group meetings analyzed.

Part of the larger project included deductively and inductively coding talk turns to develop a scheme to highlight the different types of talk used by the student groups (see Table 1). These codes were influenced by context (e.g., conversations before and after utterances) and observable emotional expressions, as evidenced through body language, facial expressions, and tone (Lobczowski, 2020). Coding from the larger project resulted in over 90% agreement and 100% after reconciliation. To connect the talk types to socioemotional formulation and regulation, we identified themes specifically related to the five stages of the FRECL model.

Table 1: Talk Type Codes

Code	Definition	Examples
Apologizing	Saying sorry for social reasons	"I'm sorry, can you repeat it?"
Calling out	Lightly challenging someone about something they said or did	"That's not what you said before."
Challenging	Engaging in argumentation; debating or negotiating ideas	"I disagree."
Comforting	Providing relief to a group member	"Don't be so hard on yourself!"
Complaining	Discussing tensions, positioning as right or others as wrong	"The professor still hasn't replied."

Complaining about group member	Similar to complaining, but focused on a specific member in the group	"I can't believe Mark is skipping our meeting."
Complimenting	Giving compliments to someone (present) in the group	"I like what you did there."
Confronting	Discussing frustrations about a person in the group	"I can't believe you did that."
Correcting	Pointing out and fixing a mistake from someone else	"Well, actually, that's wrong."
Encouraging	Providing support to someone to engage in task or discussion	"Tim, what did you think?
Gossiping	Discussing personal facts about others (typically not present)	"Did you hear about Dr. Smith?"
Gushing	Excitedly sharing positive emotions (or their causes)	"I had so much fun this weekend."
Hear me out	Calling for others to pay attention to what they are saying	"Listen up, I've got an idea…"
Hedging	Presenting ideas without taking a firm stance	"I'm open to other ideas."
Help-seeking	Asking for help	"Can you explain this to me?"
Interrupting	Beginning to speak while others are still talking	A student cut someone off.
Joking	Making jokes about someone or something not currently present	"Did you see what he is wearing?"
Joking/teasing about conflict	Making jokes or teasing about conflict among group members	"Maybe that is why we always seem to be fighting!"
Self-deprecating humor	Making fun of oneself or pointing out one's own flaws	"You know me, always saying the wrong thing!"
Storytelling	Telling a story to the other members of the group	"That reminds me of a time..."
Teasing	Making jokes about a person in the group	"What are you wearing?"
Tension relaxation	Easing group tension by joking or teasing	"Well, now you've confused Jon!"
Venting	Discussing frustrations that are outside of their control	"My car broke down again today."

Results and discussion

We observed 23 different talk types during the student group meetings (see Table 1). Next, we were able to connect the talk types to the different stages of the FRECL model. Although each talk type could occur in different stages, some were more salient in certain stages. First, student discourse (e.g., joking, confronting, correcting) shaped the groups' daily interactions, social norms, and perceptions of others' emotional experiences, thus setting the overall tone for the group (i.e., *context*). Next, the talk types (e.g., teasing, challenging) served as *stimulus events*, with occasional verbalizations (e.g., self-deprecating humor) of *appraisals* of the meanings and intentions for the social discourse. Based on these appraisals, the students then *responded emotionally* to the talk types through visual displays (e.g., facial expressions) and verbalizations (e.g., complaining, gushing). Finally, some talk types (e.g., venting, comforting) were used as *regulation* strategies.

Our findings, framed within the FRECL model, highlight the integral role that social discourse plays in the formation and regulation of emotions within collaborative learning settings. The observed talk types elaborate on the currently available literature and offer a coding scheme for deeper analysis of socioemotional interactions. Our findings regarding how talk types relate to the formation and regulation of emotion have implications for future research and practice. For example, educators can monitor student discourse for maladaptive talk types and intervene when needed. Likewise, researchers can develop interventions to promote productive talk types during collaborative learning.

References

Bielaczyc, K., Kapur, M. & Collins, A. (2013) Cultivating a community of learners in K-12 classrooms. In C. E. Hmelo-Silver, A. M. O'Donnell, C. Chan, & C. A. Chinn (Eds.). *International Handbook of Collaborative Learning,* (pp. 233 – 249). New York, NY: Routledge.

Lobczowski, N. G. (2020). Bridging the gaps and moving forward: Building a new model for socioemotional formation and regulation. *Educational Psychologist, 55*(2), 53-68.

Murphy, P. K., Firetto, C. M., Wei, L., Li, M., & Croninger, R. M. V. (2016). What REALLY works: Optimizing classroom discussions to promote comprehension and critical-analytic thinking. *Policy Insights from the Behavioral and Brain Sciences, 3,* 27–35.

Näykki, P., Järvelä, S., Kirschner, P. A., & Järvenoja, H. (2014). Socio-emotional conflict in collaborative learning—A process-oriented case study in a higher education context. *International Journal of Educational Research*, 68, 1-14.

Sullivan, F. R., & Wilson, N. C. (2015). Playful talk: Negotiating opportunities to learn in collaborative groups. *Journal of the Learning Sciences*, 24(1), 5-52.

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Integrating Data Science Explorations in Science Classrooms

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Abstract: We propose a technology-enriched learning intervention named DataX to engage students in analyzing authentic datasets about societal issues. In a pilot conducted in secondary science, students were first introduced to basic data concepts and then invited to analyze multivariate data about energy and chemical elements. Some students demonstrated sophisticated data skills and playfulness despite initial negative dispositions to data. This study showed early promise of DataX for engaging students in authentic data explorations.

Introduction

Data has been recognized as an important fabric of modern society. It is therefore crucial to seek means to cultivate data-literate citizens so that they are equipped with knowledge, skills, and dispositions important for disciplinary and civic engagement.

Data science as an emerging discipline has garnered significant attention across levels of education (Rosenberg & Chen, 2020; Wilkerson & Polman, 2020). In K-12, a key approach to supporting data science is to interleave it within existing subject areas including statistics, science, engineering, and social sciences. This paper reports on an ongoing design-based research project aiming to develop a technology-enriched learning intervention named *DataX* that positions students as "data analysts" who can build knowledge about important societal issues by collaboratively analyzing authentic datasets in specific disciplinary contexts. In the following sections, we describe the DataX project and report key findings from a pilot study.

The DataX project

We conceptualize student experiences with data as an integral part of their disciplinary and civic engagement. To support this conception, DataX situates data in a larger inquiry process of value to students, aiming to develop "students' identities as agentive data practitioners" who recognize the roles of data in various social contexts and are both capable and willing to use data skills to drive social change (Wilkerson & Polman, 2020, p. 4).

The DataX online environment builds on CODAP (Common Online Data Analysis Platform), an open-source tool designed for Grades 6-14 students to view, transform, analyze, visualize, and interpret data. DataX extends CODAP from an individual-oriented tool to a community-centric, knowledge-building environment that allows learners to collaborate on data investigations. In particular, DataX allows learners to publish data analysis notebooks for others to comment on or remix.

With the designed technology, we conducted a pilot study to examine how students may use support provided by the DataX intervention. We asked: (a) What data experiences and dispositions did students bring into this intervention? (b) To what extent did DataX facilitate students' data explorations and data dispositions?

Methods

This study involved two public schools in a metropolitan area in the midwestern United States. Participants were two science teachers and 81 students from their 11th grade classes.

Before the classroom intervention, we worked closely with the teachers to co-design pedagogical supports responsive to their classes. Through multiple design meetings, we created an overarching plan for their classes to work on the NGSS crosscutting concept of "energy" from different angels.

During the pilot, a pre-survey on students' prior data experiences and data dispositions was first administered in both classes. After the pre-survey, the researchers conducted a mini lesson on several basic ideas about data, discussing "what is data" and exploring real-world examples about data. In the same session, students were introduced to the DataX environment, followed by a warm-up data activity on visualizing a public dataset. After the introductory session, two classes diverged: Class A did a data investigation on energy consumption in the US, whereas Class B investigated the properties of elements in the periodic table. Researchers and teachers provided continuous scaffolding in both classes. Although more DataX sessions were planned, COVID-19 and the emergency transition to remote learning disrupted the pilot, before we could engage students in further investigations.

Multiple sources of data were collected, including the pre-survey, student-generated data artifacts in DataX, videos of classroom activities, researcher field notes, and teacher interviews. To answer research questions, we first analyzed student responses to the pre-survey and identified different data dispositions profiles. Using the profiles, we sampled several students and examined their data artifacts on DataX. Researchers' field notes, video recordings, and teacher interviews were incorporated as secondary data.

Results

Overall, students brought a wide range of data dispositions into the study. Descriptive analysis of the pre-survey showed that nearly 80% of the students found data to be interesting or very interesting; about 78% of students indicated that they like or love data-related activities. Students were approximately normally distributed in their interest in reading graphs, thinking about data, seeking data behind news stories, and exploring complex problems. In terms of experiences with data, about 45% of students indicated they were comfortable working with large amount of data, while the remaining 52% said no.

Starting from students' pre-survey responses, we purposefully sampled four students based on their data dispositions and inspected their DataX notebooks. Overall, we found some students with little data experiences or less positive dispositions ended up doing quite well in their data explorations. For example, Student 1 entered the pilot with an interest in data and data activities. This student' DataX artifacts showed the student was able to read the data and create a simple visualization on the natural state and boiling point of elements in the periodic table, but could not "read beyond the data" to interpret what the graph means. In contrast, Student 2 did not like doing data activities but was able to read "between" and "beyond" the data during the intervention. This student visualized the natural states and boiling points of different elements and was able to interpret that boiling solids would take longer than liquids or gases (see Fig. 1, left). In other cases, students demonstrated a willingness to play or tinker with data. Student 3 from Class B independently created a line graph (see Fig. 1, right) using the energy dataset. Even though the student did not come up with a solid interpretation, this representation is peculiarly novel, and he was looking closely at the graph to make sense of the multivariate relationships.

Teacher interviews indicated that the pilot gave students new opportunities to work on and manipulate data and helped students think more about data in science contexts. One teacher said: "DataX allowed students to connect actual scientific information about the concepts we were studying around energy [and] energy usage and apply that to [we] know not only [about] the world now [but also] the world before." Teachers also highlighted that the activities offered authentic learning experiences for students to connect learning to real life situations. Some students expressed an interest in analyzing energy consumption of countries their families immigrated from.

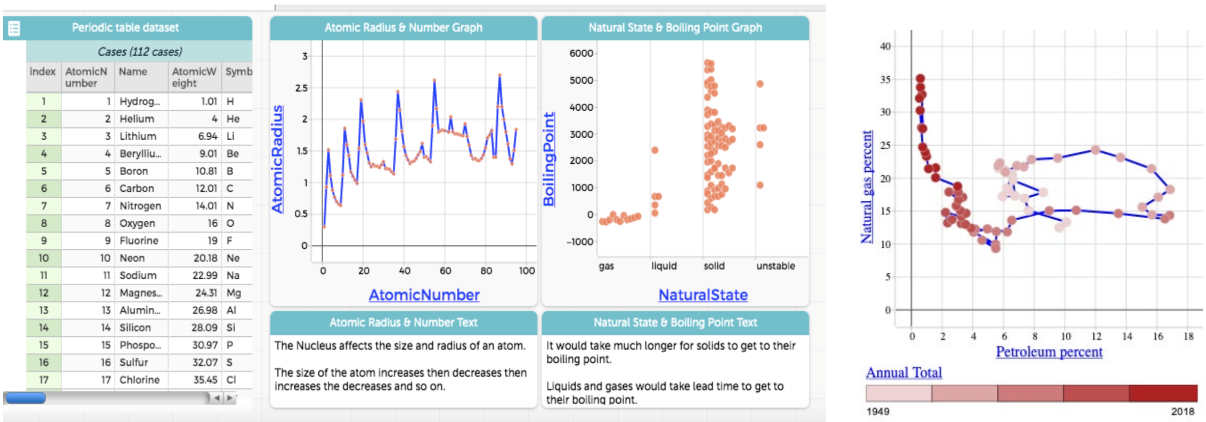

Figure 1. Screenshots of the DataX notebooks created by Student 2 (*left*) and Student 3 (*right*).

Conclusions

The DataX intervention showed early promise for engaging students in authentic data explorations relevant to important disciplinary contexts and societal issues. Future work will continue to revise the technological and pedagogical designs of DataX to facilitate student learning in data science.

References

Rosenberg, J., & Chen, B. (2020). *Exploring data science across the curriculum and across grade levels*. Symposium at the 2020 AERA Annual Meeting, San Francisco, California.

Wilkerson, M. H., & Polman, J. L. (2020). Situating data science: Exploring how relationships to data shape learning. *Journal of the Learning Sciences*, *29*(1), 1–10.

Merging Teacher Professional Development with Designing Curriculum Incorporating Cutting-Edge Science in a Natural History Museum

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Abstract: We brought together high school science teachers, paleoclimate scientists, and museum educators/researchers as a museum-based scientist/teacher inquiry group (or mSTIG) to merge a one-day teacher professional development opportunity at the Smithsonian's National Museum of Natural History with curriculum design ideation to create formal lessons utilizing cutting-edge climate change science. Here we report the first of three benefits. We suggest our mSTIG model can be a powerful way to integrate leading scientific thought into formal curriculum and that natural history museums are compelling places for this type of synergy.

Introduction

It can be difficult for the leading edge of scientific thought to make its way into formal primary or secondary education, in large part because curriculum designers and world-class scientists are rarely in the same spaces. In order to investigate how the unique space of a natural history museum might be leveraged to support scientist, teacher, curriculum designer collaboration we sought to answer the following research question: *What are the affordances when combining teacher professional development and curriculum design using design-based research methodologies in a museum context?* To answer this question our team brought together a museum-based scientist/teacher inquiry group, or mSTIG, composed of teachers, scientists, museum educators, and curriculum designers. This mSTIG developed proto-lesson ideas, termed lesson seeds, which the research team then analyzed for insight on how best to build formal high school curriculum highlighting the science of the Fossil Atmospheres project (Barclay and Wing, 2016; Soul et al., 2019). The Fossil Atmospheres project uses Ginkgo leaf fossils, along with historic herbarium leaf samples and modern leaves collected in nature and grown under experimental CO_2 conditions, to explain ancient and future climate change.

In designing this PD, we were mindful of best practices highlighted by literature involving teacher PD in science (Darling-Hammond et al., 2017) while encouraging, through the mSTIG design, active learning. As curricular designers, the research team approached the mSTIG participants with a Funds of Knowledge mindset (González et al., 2006) and used aspects of design-based research (DBR) methodology. Finally, we grounded our collaborative learning and community building in the Community of Practice tradition (Lave and Wegner, 1991), structuring our PD around the shared goals of understanding complicated scientific knowledge and then designing instructional activities that integrated that knowledge. Specifically, we adapted the STIG inquiry group model Killen et al. (2019) used previously for PD involving integration of computational thinking into lesson design.

Design and data collection

The mSTIG included 14 teachers and took place during 8 hours on a Saturday within an education space at the National Museum of Natural History (NMNH) in Washington DC, USA. The mSTIG was composed of four activities: group brainstorming; a discussion of teacher resources available when teaching climate change; a presentation of the science of the Fossil Atmospheres project, and teachers, in grade-level groupings, thinking specifically about how they might build a lesson using the science of the Fossil Atmospheres project. The lead author qualitatively analyzed teacher surveys, mSTIG artifacts and the notes and recollections of museum personnel. Transcripts of the video underwent two cycles of coding: inductive and axial (Saldaña, 2015).

Findings

Three broad affordances were found: teachers learned from scientists the newest understandings of climate change, scientists were challenged to clearly present their work to teachers, and museum educators/researchers learned from teachers how to best incorporate cutting-edge science into useful, engaging curriculum. We found the mSTIG DBR design was a key difference between mSTIG teacher PD and the more traditional museum-based past teacher PD experiences NMNH had offered and allowed for an important benefit; teachers were able to surface any gaps in their understanding which were then immediately addressed by either fellow teachers or scientists while they were actively involved in the real and meaningful exercise of integrating particular science concepts and practices into science lessons they would find useful and that they thought their students would find engaging. This is seen in following exchange between two teachers.

Celeste: She [one of the project scientists] mentioned that all the textbooks are going to call this the Anthropocene.

Shasta: Well, yeah, that's definitely still something that is still under debate, but yeah.

Celeste: Well, no, they decided to do it, the question is when.

Shasta: Which group is deciding to do it? It's kind of like the Planetary Society says Pluto's a planet, Astronomical Society says it's not. So, what's . . . Which group are you-

Celeste: I don't think the Planetary Society says . . . But that's neither here nor there. My point was only that, is it at the age of harnessing the ability to make fire? Because that changed the environment. They're arguing that . . . should it be with the beginning of the cultural revolution? Should it be with the hunting of the megafauna? Should it be with the first industrial revolution, the second? Should it be the atomic revolution?

Shasta: Yeah, well, some things to more extent than others. Certainly. Gatherers caused huge changes to the environment.

Celeste: Right, right. So, do you want to make that the focal point?

Here, working together to build a lesson seed created an opportunity for Celeste and Shasta to have an interaction that would have been less likely within a more passive teacher PD model. Shasta expressed her hesitancy about the validity of the Anthropocene. Celeste was able to respond with an accurate review of current scientific thinking and then bring the conversation back to the mechanics of their lesson seed without causing tension.

Discussion and conclusion

This work leveraged the multidisciplinary space of a natural history museum to bring scientists working at the leading edge of their field together with U.S. high school teachers, museum educators and curriculum designers/researchers to form a mSTIG community that accrued benefit to every participant group. By combining PD with a DBR opportunity, teachers were able to immediately apply new scientific knowledge to a context they were expert in - teaching science to their students, thereby surfacing gaps in knowledge that could immediately be addressed.

References

Barclay, R.S., & Wing, S.L. (2016). Improving the Ginkgo CO_2 barometer: implications for the early Cenozoic atmosphere. *Earth and Planetary Science Letters*, *439*, 158-171.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development*. Palo Alto, CA.

González, N., Moll, L. C., & Amanti, C. (Eds.). (2006). *Funds of knowledge: Theorizing practices in households, communities, and classrooms*. Routledge.

Killen, H., Coenraad, M., Byrne, V., Cabrera, L., Ketelhut, D. J., & Plane, J. (2020). Reimagining Computational Thinking Professional Development: Benefits of a community of practice model. In Gresalfi, M. and Horn, I. S. (Eds.), *The Interdisciplinarity of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS) 2020, Volume 4* (pp. 2125-2132). Nashville, Tennessee: International Society of the Learning Sciences.

Lave, J. & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Saldaña, J. 2015. *The Coding Manual for Qualitative Researchers* (3rd ed.). Thousand Oaks, CA: Sage.

Soul, L.C., Barclay, R.S., Bolton, A., & Wing, S.L. (2019). Fossil Atmospheres: a case study of citizen science in question-driven palaeontological research. *Philosophical Transactions of the Royal Society B*, *374* (1763), p. 20170388.

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Responding to STEM Students' Gestured Candidate Responses

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Abstract: We demonstrate a way in which teachers can be responsive to students' multimodal contributions in whole-class STEM discussions. To answer teachers' questions, students sometimes use representational gestures to provide unspoken, "off-the-record," tentative responses. By attending to these *gestured candidate responses,* teachers can preview students' potential contributions to the discussion and ratify the contribution. Ratified contributions can be taken up by the teacher and shared with the class. This study contributes to a better understanding of the nuanced roles gesture plays in STEM classroom discourse.

Gesture and responsive teaching in STEM learning

In STEM classrooms, whole-class discussions provide important opportunities for students to co-construct new knowledge (O'Connor & Michaels, 1996). During these discussions, the body is an essential resource for meaning-making: STEM teachers and students regularly use gesture to share and negotiate new understandings together (e.g., Singer, 2017). In particular, students use gesture to make sense of abstract concepts and explain STEM ideas before they have mastered the complex languages of STEM disciplines (e.g., Roth & Lawless, 2002).

STEM educators can take up and be responsive (Coffey et al., 2011) to students' gestures in a variety of ways. These include (1) encouraging students to elaborate their gestures when there are discrepancies between gesture and speech (e.g., Flood et al., 2020), (2) repeating students' gestures to help students connect embodied ideas with rephrased speech (e.g., Alibali et al., 2019; Shein, 2012), and (3) reformulating and extending students' gestures to refine and elaborate the spatio-dynamic imagery available to students (Flood, 2021). A number of embodied responsive teaching techniques have been identified (Flood, et al., 2020; Flood, 2021). By eliciting, attending to, and responding to the ideas students share with their hands and bodies, educators help students make new STEM discoveries, thus enriching opportunities for learning (Flood et al., 2020; Flood, 2021).

Our current study extends previous work on the role of teachers' responsiveness to gestures in whole-classroom discussion (Flood, 2021). We demonstrate how students in physical science class use gestures to make "off-the-record," tentative contributions – *gestured candidate responses* – to answer teachers' questions. By attending to these gestured candidate responses, teachers can take stock of what students could contribute to the ongoing discussion, and then decide to pursue and endorse the contribution, for example by taking up and repeating the gesture publicly. Teachers can also invite students to elaborate on the idea, themselves.

Methodological approach

We draw on a video corpus of two-week long energy units in two eighth-grade science classrooms in the Northeastern U.S. The classrooms feature project-based learning and contain numerous interactive whole-class discussions where students share ideas. We located instances where students used representational gestures to respond to teacher queries. Then, inspired by ethnomethodological conversation analysis, we microanalyzed the embodied communicational practices of teachers and students in these instances to understand how and when gestures were deployed and coordinated with other interactional resources (e.g., gaze, talk).

Findings: Teachers take up gestured candidate responses

We present a representative example from our study to demonstrate how teachers can take up students' gestured candidate responses in classroom discussions. In Excerpt 1, the class is discussing energy and friction (1). Energy cannot be directly perceived and must be studied through the use of indicators that can be measured, like light, heat, and motion. To discuss this problem with students, the teacher reminds the class of another use of indicators they have seen: She asks the class to recall friction indicators, and students offer sound (hearing a door creak) and seeing a model car veer as examples. She asks them to think of more, but no one volunteers. After a pause (E1.02), the teacher asks the class to remember how they explored friction through demonstrations (E1.03-04).

Dan responds, speaking inaudibly (E1.05). It is unclear if the teacher can hear what he says, and students across the room would not be able to make out his words. Dan's response is multimodal, and he looks toward the teacher as he talks and gestures, rubbing his hands together (Figure 1a). Rubbing your hands is a good way to *feel* the presence of friction, since the rubbing generates heat and resistance, both indicators of friction. At this moment, the teacher's head was turned slightly away from Dan, and she was scanning the room. However, she seems to catch Dan's gesture from the corner of her eye. As soon as Dan starts rubbing his hands, she turns her head toward him. By not officially bidding to answer with a raised hand, speaking so as not to be heard by the rest of the class, and gesturing, Dan marks his response as a *candidate* for the teacher to acknowledge or ignore.

Excerpt 1. Friction

```
01 T: Measure see hear is that pretty much–
02    (1.6)
03    Can we thi::nk of how we tried to
04    understand friction in demonstrations↑
05 D: °Like how it feels° ((barely audible,
06    likely inaudible for most of class))
07 T: Feel.
08    (1.7)
09    We did this all:: the time.
```

Figure 1. Taking up a *gestured candidate response* of hand rubbing. Blue highlighted talk corresponds to image (a) and green highlighted talk to image (b). In (c) and (d) other students copy the hand rubbing.

As Dan continues to rub his hands together, the teacher also holds her hands up in view of the whole class and begins to rub them together (Figure 1b), ratifying Dan's response. As she takes up and repeats Dan's gesture, she says loudly out to the class "Feel" (E1.07). She continues to rub her hands together and look around the room. Many students also start rubbing their hands: Of the 15 students in the room, seven repeat the gesture, and the teacher continues to rub her hands together for 16 seconds as other students take up the gesture.

By attending to Dan's gesture, taking it up, and repeating it for the whole class, the teacher shares Dan's embodied knowledge with everyone. Most students would not be able to hear Dan, and in addition, many also likely did not see Dan's hands because of where they were seated. By repeating the hand-rubbing, the teacher provides implicit feedback about Dan's response, endorsing the gesture as a valuable embodied way of knowing about friction. When other students repeat the gesture, they have an opportunity to also experience *feeling* indicators of friction (e.g., heat, roughness). O'Connor and Michaels (1996) argue that one of a teacher's key jobs in orchestrating classroom discussions is to "hold students' ideas in view." By attending to Dan's gestured candidate understanding and repeating it for all to see and feel, the teacher in Excerpt 1 literally does just that.

Conclusion

By attending to *gestured candidate responses,* teachers can take up and broadcast students' tentative ideas to the class. Our study contributes to a growing body of work that demonstrates how responsive teaching is an embodied, multimodal phenomenon, where teachers attend and respond to disciplinary substance (Coffey et al., 2011) not just in what students say, but also in the meanings students convey with their hands and bodies (Alibali et al., 2019; Flood, 2021; Shein, 2012). Our efforts to investigate the ways instructors attend and respond to gestures during whole-class STEM discussions contribute to more systematically characterizing the many forms and functions of embodied communication in STEM learning. Our future work will continue to explore and characterize the different roles gesture can play in organizing whole-class STEM discussions.

Endnotes

(1) We use Jeffersonian Transcript conventions: Degree signs for especially quiet speech (°°); under<u>line</u> for emphasis; up arrows for rising intonation (↑); timed pauses in parentheses (2.5); and colons to denote elongated syllables (::).

References

Alibali, M. W., Nathan, M. J., Boncoddo, R., & Pier, E. (2019). Managing common ground in the classroom: teachers use gestures to support students' contributions to classroom discourse. *ZDM*, *51*(2), 347-360.

Coffey, J. E., Hammer, D., Levin, D. M., & Grant, T. (2011). The missing disciplinary substance of formative assessment. *Journal of Research in Science Teaching*, *48*(10), 1109–1136.

Flood, V. J. (2021). The secret multimodal life of IREs: Looking more closely at representational gestures in a familiar questioning sequence. *Linguistics and Education*, *63*, 100913.

Flood, V. J., Shvarts, A., & Abrahamson, D. (2020). Teaching with embodied learning technologies for mathematics: Responsive teaching for embodied learning. *ZDM*, *52*(7), 1307–1331.

O'Connor, M. C., & Michaels, S. (1996). Shifting participant frameworks: Orchestrating thinking practices in group discussion. In D. Hicks (Ed.), Discourse, learning and schooling (pp. 63–103). CUP.

Roth, W.-M., & Lawless, D. (2002). Scientific investigations, metaphorical gestures, and the emergence of abstract scientific concepts. *Learning and Instruction*, *12*(3), 285–304.

Shein, P. (2012). Seeing with two eyes: A teacher's use of gestures in questioning and revoicing to engage english language learners in the repair of mathematical errors. *JRME*, *43*(2), 182–222.

Singer, M. (2017). The function of gesture in mathematical and scientific discourse in the classroom. In R. B. Church, M. W. Alibali, & S. D. Kelly (Eds.), *Why gesture?* (pp. 317–329). John Benjamins.

Students Doing Ccitizen Science on an Unfolding Pandemic

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Abstract: School-based science inquiry tends to focus on already answered questions. We describe how we used the COVID-19 pandemic in a high school citizen science unit for students to witness and engage in real-time science. High school students developed proposals to study questions about their experiences related to the pandemic. Teacher and student interviews and observations showed that this globally-relevant experience also offered a personally relevant context through which to understand the scientific process.

Introduction and conceptual framework

COVID-19 has brought science to the forefront of public discussion, and highlighted the importance of scientific collaboration and transparency at all levels of its process (Fry, Cai, Zhang & Wagner, 2020; Rempel, 2020). While this global event had serious implications for students' lives (illness, social isolation, shift to online schooling, inaccessibility of public spaces), it also created opportunities for authentic inquiry learning experiences. Whereas traditional science inquiry learning in US schools tends to focus on already answered inquiry questions (Furtak & Penuel, 2019; Linn, Gerard & Matuk, 2016), we saw an opportunity for citizen science (CS) to leverage the global relevance of the pandemic for students to witness and engage in the scientific process unfolding in real-time, and particularly around questions that were personally relevant to their experiences at the time. In classroom-based CS, students and teachers contribute to the work of scientists by generating research questions and participating in data collection and analyses (NRC, 2012). In this study, we ask: How can real-time phenomena, like a pandemic, support students in learning about the scientific inquiry process? We report on initial findings from our implementation of a CS unit on human behavior related to the pandemic.

This work is grounded in participatory science learning, an approach that emphasizes authentic problems, the social negotiation of knowledge, the roles of more knowledgeable others, reflection, and students becoming members of a community (Barab & Hay, 2001). Our design embodies the ideals of participatory science learning by supporting students' collaboration with peers and experts, encouraging them to identify and pursue personally and socially relevant questions, and guiding them through an authentic process of iterative inquiry and reflection. It is through this lens that we both designed the unit, and conducted our analyses.

Methods: Context, participants, and data

We collaborated with a science teacher at a private high school, Ms. C, to implement a 4-week long unit on brain and behavior (B&B) research in her class of 20 juniors and seniors (18 of whom participated in this study). The initial curriculum design focused on the relationship between environmental decision-making and human behavior (e.g. what leads to pro-environmental behavior, psychology of climate change). The unit's learning goals included introducing students to open science, ethics in human subjects research, B&B experimental study design, research proposal writing, and scientific peer review. Students' proposal development also leveraged a beta version of MindHive, a web-based CS platform, that facilitates the proposal, data collection, and analyses of research projects. During the unit, the beta MindHive platform hosted two B&B citizen science research studies (i.e. social influence and climate change, risk-taking in adolescents) designed by partner scientists. Students, via MindHive, participated in these studies and the unit also leveraged the studies as cases to teach experimental design, proposal writing, and introduce basic analysis. When the pandemic shuttered schools and forced us to move online just 2 weeks before implementation, our team opted to use COVID-19 as a relevant context for the aforementioned learning goals. This involved curriculum changes like integrating a lesson on the role of preprints and peer review that utilized active research about COVID-19. We also pivoted to supporting students in developing inquiry questions about the pandemic and recast existing content (e.g., experimental design) in terms of studying pandemic-related behaviors (e.g., social isolation, disrupted routines, mask wearing, online learning). Our data include an interview with Ms. C and an interview with 2 students, asking them to reflect on their experiences implementing and participating in the unit respectively. We also collected draft and final research proposals from all four groups, field notes from synchronous class sessions, post-unit student reflections from 10 of the 17 students, and curriculum materials. Our preliminary analyses used open coding (Charmaz, 2014) to explore the impacts of contextualizing students' CS inquiry within an unfolding pandemic on students' attitudes toward, and understanding of the nature of the scientific process.

Findings

Our initial analyses show 1) how students' proposals gave them opportunities to pursue personally and socially relevant questions 2) how participating in a proposal writing process led to insights about scientific inquiry 3) how students' attitudes toward the scientific research process changed throughout the unit. Students' research questions were at once based in their personal experiences, as well as novel and globally relevant (e.g., "How is zoom school affecting student mental health and morale?"). In addition, students gleaned insight about authentic science as revealed in their culminating reflections like, "the interdisciplinary and cooperative nature of science… was something that I had not thought much about prior to this semester in science." Students also started to understand key facets of scientific inquiry like the iterative nature of scientific discovery and its relationship to experimental design in B&B: "I never really understood just how much research was required before going into an experiment. I always assumed that it was simply looking into something you want to test, but there's a lot of preparation involved for each experiment." Ms. C also underscored the value of a participatory science (Barab & Hay, 2001) explaining, "there is something about going through a process from beginning to end… when we're writing a lab report (in class), we'll often skip procedures. This experience was really thorough… This project brought new members into the class community; professionals with academic credentials; collaborating on a different level who wanted to know what students had to say and what they were thinking." Being in conversation with scientists and exploring authentic phenomena made the curriculum experience compelling and valuable. However, students found it difficult to effectively collaborate remotely, resulting in discordance over research questions, collecting background research, and designing tasks. Ms. C also noted that ideally synchronous class sessions would have been more student-centered, but online learning instead emphasized adult-led lessons.

Significance

This study shows the value of using an unfolding global event as a context for students to learn about the scientific process. It also demonstrates how CS learning can continue amid disruptions caused by the pandemic: By leveraging its global and personal contexts, we can engage students in investigating personally and socially relevant questions that also contribute to emerging knowledge about crises through open and participatory science.

References

Barab, S. A., & Hay, K. E. (2001). Doing science at the elbows of experts: Issues related to the science apprenticeship camp. Journal of Research in Science Teaching, 38(1), 70–102.

Charmaz, K. (2014). Constructing Grounded Theory. Los Angeles: Sage.

Fry, C. V., Cai, X., Zhang, Y., & Wagner, C. S. (2020). Consolidation in a crisis: Patterns of international collaboration in early COVID-19 research. PloS one, 15(7), e0236307.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of "hands-on" and other reform terminology in the era of science as practice. *Science Education*, *103*(1), 167-186.

Linn, M. C., Gerard, L., Matuk, C., & McElhaney, K. W. (2016). Science education: From separation to integration. *Review of Research in Education, 40*(1), 529-587.

National Research Council. (2012). A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas. Washington, DC: The National Academies Press.

Rempel, D. (2020). Scientific Collaboration During the COVID-19 Pandemic: N95DECON.org. *Annals of Work Exposures and Health*.

Acknowledgments

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No Player Left Behind: Exploring the Use of Collaborative Talk in a Playfixing Activity

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Abstract: This study describes an activity in which participants play and fix broken games through the use of collaborative talk (CT). The playfixing activity provides a useful context for examining how participants collectively redesign an incomplete tabletop game. We qualitatively analyzed participants' talk as they playfixed a game, *Pollutaplop*. This study contributes to the design of future learning experiences that invite the use of CT and foster the development of abilities to collaborate on complex tasks.

Introduction

The ability to collaborate within small groups to solve collective problems is crucial for life and work in the 21st century. School-related learning experiences frequently are organized around well-defined tasks or problems, in the sense that learners—often individually—work towards finding one predetermined solution to a problem. While such problem structures offer affordances for learning, they often lack the authenticity of the wicked problems defining the modern world, problems for which definitive answers remain elusive but nonetheless require collaborative approaches to tackle (Kessner et al. 2020). As such, a crucial question becomes apparent: how might activities that foster such collaborative abilities look? In this poster, we describe how an activity in which participants simultaneously play and fix (playfix) "broken" games may offer a useful example to inspire the design and organization of future learning experiences that foster young people's abilities to collaborate on complex tasks that approximate the kinds of wicked problems they will confront in the real world.

This study draws on three notions: collaboration as a learning goal, design as a context, and talk as a meaning-making tool. Collaboration as both a goal and a method for learning has been popular for decades, and there is a robust literature on how to support collaboration in and out of educational settings with participants of all ages (Smith & Mancy, 2018). However, successful collaboration remains a somewhat elusive goal in many contexts, and there is no formula or definitive set of "skills" required for successful collaboration. At minimum, the nature and goals of the task or learning activity must be specified in order to identify the most salient forms of interaction that participants must engage in. The growing interest in design and design-based learning represent important contexts for understanding and cultivating successful collaboration and learning. Design efforts are typically aimed at addressing ill-structured or even wicked problems and thus may depend on forms of collaboration that might differ from, or have different importance than, those required for collaboration around the more well-structured problems typical of many school assignments. From this perspective, collaboration can be viewed and analyzed as a process that gradually leads two or more people to construct shared meanings for conversations, concepts, and experiences (Roschelle, 1992). Talk, from a sociocultural view, remains a central means of building shared understandings, and scholars have proposed various ways to characterize what Newman (2016) and others have called *collaborative talk*—a strategy that participants adopt to jointly work toward the shared goals.

Learning scientists emphasize the importance of understanding learning in context. In the context of our task-participant structure, participants were required to simultaneously play and fix (playfix) broken games—tabletop games intentionally left unfinished, with ambiguous rules and mechanics. That is, they (a) played the broken game in order to fix it, and (b) fixed the broken game in order to play it. In summary, the playfixing activity invites participants to collaborate on solving an ill-structured problem of the broken game. In this study, we ask: *To what extent does playfixing a broken game facilitate the use of collaborative talk among participants?*

Data collection and analysis

The data used in this study were collected as part of a larger investigation of the processes and outcomes of playfixing broken games. This study focused on one 45-minute session in which four adult participants were given a broken game *Pollutaplop*—a tabletop game in which players eliminate waste from biomes of an interconnected water-based ecosystem (see Figure 1)—and asked to identify and "fix" any issues in the game while they play through it. Influenced by previous scholarship on peer dialogue and dialogic talk, Newman (2016) conceptualized CT as a process of *participating* (speakers' active contribution to CT), *understanding* (speakers' attempts to interpret and respond to the contribution of others), and *managing* (speakers adopt their position and monitor their participation). To better understand the enactment of CT in our playfixing case, we retained Newman's (2016) broad categories but modified the definitions and descriptors to more explicitly align with the playfixing activity. Overall, our aim was to create descriptors of talk that could be identified in a transcribed discussion.

Figure 1. Pollutaplop.

Findings and discussion

Here we describe two salient findings. Firstly, the two design episodes consisted of a total of 176 utterances (see Figure 2). Of these, 120 utterances were coded as some form of CT while 56 utterances were uncoded as they were either unfinished utterances or did not contribute to CT. Thus, the majority (68%) of participants' talk during the design episodes consisted of some aspect of CT. Secondly, we found that the strands of CT (i.e., participating, understanding, managing) in the playfixing activity appeared to be interdependent, reflected in how the three elements of CT overlapped and intertwined. The way players participated in CT was influenced by how they understood and managed the talk. Understanding assumed active participation and set the foundation for effective managing—constructing new meanings (e.g., modified game rules). Rather than a unidirectional or step-by-step process of building shared understandings, participants simultaneously offered and clarified suggestions, elaborated different ideas, and interjected to steer the direction of their talk as needed. We also found that some of the players' utterances represented multiple CT strands, revealing participants utilized different CT strands to complete the playfixing activity.

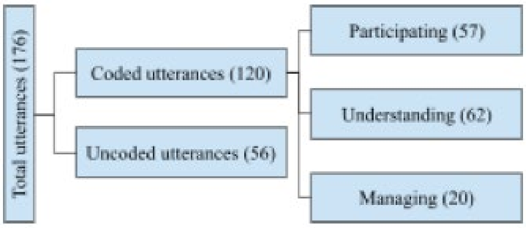

Figure 2. Coded and uncoded utterances.

Conclusion

In this 45-minute playfixing experience, we found considerable evidence of CT, and our analyses also suggest how CT—and collective meaning-making—was interwoven with game play. The common activity of playfixing a board game offered opportunities for shared meaning-making that included even otherwise indifferent participants. We argue that, although broken games are incomplete, they offer participants an engaging opportunity to think about the game that they are fixing and the content they are discussing.

References

Kessner, T. M., Gee, E. R., & Pérez Cortés, L. E. (2020). Wicked play: Wicked problems, designerly citizens, and design games. In M. Gresalfi & I. S. Horn (Eds.) *The interdisciplinarity of the learning sciences, 14th International Conference of the Learning Sciences (ICLS), volume 2*, pp. 1118-1124. International Society of the Learning Sciences.

Newman, R. (2016). Working talk: Developing a framework for the teaching of collaborative talk. *Research Papers in Education*, *31*(1), 107-131.

Roschelle. J. (1992) Learning by collaborating: Convergent conceptual change. *The Journal of the Learning Sciences,* 2(3), 235-276

Smith, J. M., & Mancy, R. (2018). Exploring the relationship between metacognitive and collaborative talk during group mathematical problem-solving – what do we mean by *collaborative* metacognition? *Research in Mathematics Education*, *20*(1), 14–36. https://doi.org/10.1080/14794802.2017.1410215

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Thinking through Representation: Interpreting Representational Fluency across Contexts in Computational Thinking Enhanced Activities

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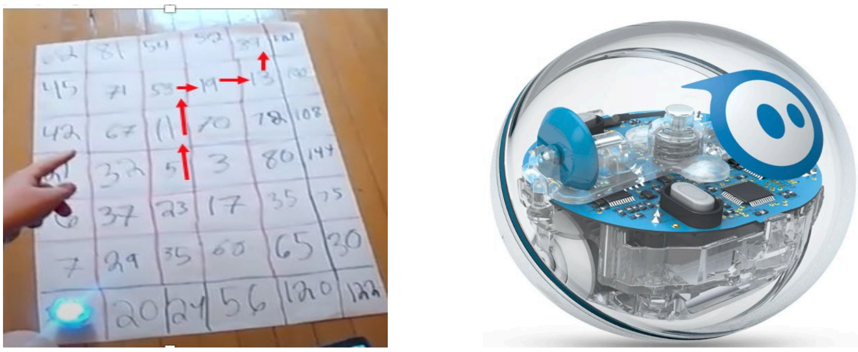
Abstract: In this study, we investigated the emergence of representational fluency in fourth-grade students as they engaged in a robot-mediated task designed to integrate computational thinking (CT) and mathematics. We observed two pairs of students who were engaged in programming a Sphero robot to navigate a maze during a mathematics lesson. We found that the students used language and embodied gestures as forms of representational fluency to mediate the mathematics and CT present in the activity.

Introduction

Representational fluency is crucial to STEM education because learners rely on multiple representations to translate across concepts in problem solving environments. Representations can serve as useful tools to support young learners scaffold abstract concepts as they navigate virtual and physical environments (Brown, Collins, & Duguid, 1989). Technology enhanced computational thinking (CT) environments typically involve software and user interfaces that can empower users to be more innovative in their problem-solving strategies (Resnick et al., 2005).

In this study, we investigate different forms of representational fluency students engaged in as a strategy to program a Sphero robot to navigate a prime number maze (figure 1). Furthermore, we inquired about specific symbolic features, arrangements and relationships within and across the learning environment and how the design of the environment gave room for multiple forms of representations to emerge.



(a) (b)

Figure 1. The prime number activity board (a) the Sphero robot (b)

Theoretical orientation and methodological approach

We review research on representational fluency, and other theoretical perspectives that draw on a situative approach to learning (Brown, Collins, & Duguid, 1989). The situative approach foregrounds learning and understanding in terms of the inquiry of interactions made between people and the material, symbolic and technological resources of the environment. This theory, alongside frameworks on representational fluency (Alibali & Nathan, 2012; Korzma 2003) guides our understanding of how young learners navigate representations in a CT enhanced learning environment. Our study investigates how younger learners can engage in different modalities of representations such as speech, gesture and writing to support their cognitive strategies in a Sphero robot and prime number maze problem solving activity.

Two pairs of students were selected from one of the public schools involved in a District of Columbia Public Schools (DCPS) Research Practice Partnership (RPP), focused on integrating CT in elementary math classrooms. Three cameras per group were used to capture the students' actions. In addition, both students in each group wore head-mounted cameras. We use a case study approach in order to provide detailed understanding of how students engage with Sphero robots to problem solve in a math classroom. For example; program the Sphero robot to navigate a prime number maze. We watched the clips as a team and discussed our observations to come to a consensus whether our claims had enough evidence from the videos. We clipped video instances where students engaged in representational fluency practices, and transcribed for analysis. The transcript was analyzed for representational fluency evidence through a holistic coding process where two team members memoed observations on an excel spreadsheet, highlighting evidence of representational fluency.

Findings

Analysis identified instances during which the participants either engaged in representations through gesturing, used metaphors or described their programming strategies to ground their understanding of concepts or as ways to actively *build cohesion* across representations. We noticed that the students had to align all the cues provided by the environment, each with a different representation, in order to make the robot navigate the maze. Such translations between concrete and abstract concepts, and virtual and physical interactions, required fluency across these representations in which each context could be equal in meaning but represented differently. In some instances, students used speech and gesture representations to map out the prime number maze. Deictic (pointing) gestures were heavily used to distinguish what counted as prime numbers and figuratively tracing out the maze at the same time.

Computational thinking enhanced environments can be generative environments for students to develop representational fluency in order to navigate complex multimodal physical and virtual environments. The current study observed representational fluency can be a useful strategy for problem solving. It is possible that our data could highlight more representations within the virtual programming space if we had access to the programs the students wrote on their iPad using the Sphero application. Although the current study is part of a larger project involving the introduction of CT in fourth grade classrooms, we aspire to demonstrate sufficient evidence about the physical, virtual and embodied representations. Such evidence aligns with the situative approach to learning and understanding in terms of the inquiry of interactions made between people and the material, symbolic and technological resources of the environment as posited by (Brown, Collins, & Duguid, 1989). We therefore consider these strategies to be useful for educators and curriculum designers who wish to integrate CT activities into their lessons, to think about the scaffolds that will allow for representational fluency to emerge and support translations across concepts, representations, and even disciplines (Nathan et al., 2017).

References.

Alibali, M. W., & Nathan, M. J. (2012). Embodiment in mathematics teaching and learning: Evidence from learners' and teachers' gestures. *Journal of the learning sciences*, *21*(2), 247-286.

Brown, J. S., Collins, A., Duguid, P., Díaz, F., Arceo, B., Luque, M. L., … Ausubel, P. D. (2003). Teoria del Aprendizaje. *Education Researcher*, *3*(1), 105–117.

Mitchell J. Nathan, Matthew Wolfgram, Rachaya Srisurichan, Candace Walkington & Martha W. Alibali (2017) Threading mathematics through symbols, sketches, software, silicon, and wood: Teachers produce and maintain cohesion to support STEM integration, The Journal of Educational Research, 110:3, 272-293.

Nathan, M. J., Srisurichan, R., Walkington, C., Wolfgram, M., Williams, C., & Alibali, M. W. (2013). Building cohesion across representations: A mechanism for STEM integration. Journal of Engineering Education, 102(1), 77-116.

Resnick, M., Myers, B., Nakakoji, K., Shneiderman, B., Pausch, R., Selker, T., & Eisenberg, M. (2005). Design Principles for Tools to Support Creative Thinking. *Workshop on Creativity Support Tools*, 1–16.

“Do I hear buzzing?” Emergent Bilinguals Engaging in Science

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Abstract: This study investigated emergent bilinguals’ engagement in a technology enhanced, embodied modeling curriculum about bees. By combining Rodriguez’s (2015) and Engle & Conant’s (2002) definitions of engagement, this paper analyzed moments when students exercised agency in nontraditional ways, shared authority to revise their collective strategies, and formed novel accountability structures as a result of directing their own activities.

Significance and research approach

Emergent bilinguals (EBs) are often excluded from science due to assumptions that English language proficiency must precede content knowledge (Lee & Stephens, 2020). To combat these deficit views of EBs, the current study takes Rodriguez’s (2015) equity-minded definition of engagement and synthesizes it with research on Productive Disciplinary Engagement (PDE; Engle & Conant, 2002) to study elementary EBs’ interactions within an immersive, mixed reality (MR) technology enhanced science curriculum about bees. This study contributes a novel application of existing engagement frameworks to an innovative science learning environment, with a population of students that are often marginalized in traditional classrooms.

This study’s theoretical framework draws on Rodriguez (2015), who provided many examples of practices for promoting engagement that foregrounded student *agency*. For example, “students are provided with some choices for conducting activities and/or projects; Students have choices for representing knowledge” (Rodriguez, 2015). This definition helped us identify student’s agency being exercised in diverse, non-traditional ways. I also draw on Engle and Conant’s (2002) PDE framework, which was developed with monolingual students, for this study to expand researchers’ understanding of engagement to include multilingual learners. The framework provided two components, *authority* (learners share what they really think) and *accountability* (learners explain how their ideas make sense), which require learners to work together, making both concepts particularly useful lenses for studying the current study’s collaborative learning context. With these asset-based lenses—agency, authority, and accountability—in mind, I investigated the research question: What aspects of the learning environment helped support students’ engagement?

The data from this study comes from the larger Science through Technology Enhanced Play (STEP) project, which investigated how elementary school students’ socio-dramatic play can be enhanced by MR software to help them understand complex scientific phenomena. Given my own background from an immigrant, bilingual household, I was drawn to the focal class of this study: a mixed-grades (1st and 2nd), dual language classroom with Spanish-speaking students whose English was limited, as well as English-speaking students who wanted to learn a second language. Although not every child in this class was classified as EB, I analyze interactions of all the children in this study to make claims about how EBs’ engagement in this context differ from traditional science classrooms. The data collection process involved video and audio recordings of eight days of the technology enhanced curriculum about bees and pollination. This study used interaction analysis (Jordan & Henderson, 1995) to select and analyze video data that, based on Rodriguez’s (2015) and Engle’s (2011) definitions, showed students exercising agency, authority, and accountability to engage in scientific learning.

Major findings

This section reports on how the concepts of agency, authority, and accountability helped us investigate how EBs’ engage in scientific practices in diverse and creative ways. Students drove the activities for Day 2 by choosing which strategies of bee foraging to test. Maria (pink shirt in Figure 1), asked the teacher to go into the MR space by herself and have the student-bees follow; this contribution demonstrated Maria’s agency as a learner in this environment. Students also exercised agency over their mode of participation—not only verbal communication and gestures, but also an invented “bee” language—in this environment. On Day 2, Kayley expressed her agency and engagement with the scientific phenomenon in this playful way. Then on Days 3 and 4, other students joined in and a researcher asked, “Do I hear buzzing?” to acknowledge students’ creative form of participation. Maria and Zara on Day 2, and Zara and Hector on Day 4 shared authority over their ideas (collecting strategies and “bee language”) so that their collective understanding of scientific phenomena and communicative tools could deepen to a point they may not have been able to reach individually. On Days 2 and 4, we saw that playful accountability norms allowed for students to persevere despite failures (Dylan celebrating “we almost got full”) to the point that they developed new rules for their invented language system (Hector and Zara sharing what they added to bee language to help them collect nectar more efficiently).

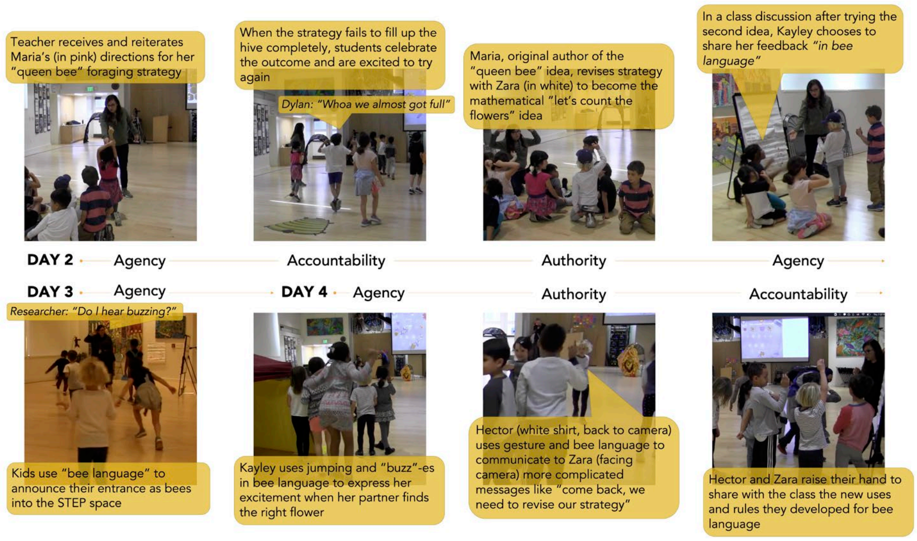

Figure 1. Overview of Days 2-4 with examples of agency, authority, and accountability

Across these three days, we saw examples of how agency, authority, and accountability deepened student engagement. Children led the development of strategies, and invented an imaginary language when they felt English was not sufficient for expressing their (or a bee's) understanding of foraging flowers. This learning environment also valued collaboration and sharing authority, which centered as many student voices as possible, thereby minimizing the chances of marginalizing emergent bilinguals. Because this learning environment normalized "mistakes" and encouraged students to revise their ideas in as many different and creative ways as they want, accountability was redefined as something fun and iterative. Children loved testing new ideas so much that they often ran out of class time to try all their strategies.

Conclusions and implications

The findings showed that this learning environment supported EB students to engage in both traditional and nontraditional ways. The teacher allowed children to direct the activities and to exercise *agency* over how to participate. Contrary to individualistic views on *authority*, the collaborative environment encouraged students to share ownership of ideas with the classroom community in order to co-create and revise their scientific theories. Finally, *accountability* and presenting ideas to one another was framed as something playful and iterative, rather than an arbitrary standard to meet. These opportunities were especially beneficial to EBs who often feel invisible, silenced, or marginalized in science settings. Future research should show how other learning environments can allow for these creative agency, authority, and accountability practices to lead to more equitable, productive disciplinary engagement.

References

Engle, R. A., & Conant, F. R. (2002). Guiding Principles for Fostering Productive Disciplinary Engagement : Explaining an Emergent Argument in a Community of Learners Classroom. *Cognition and Instruction*, *20*(4), 399–483. https://doi.org/10.1207/S1532690XCI2004

Jordan, B., & Henderson, A. (1995). Interaction Analysis: Foundations and Practice. *Journal of the Learning Sciences*, *4*(1), 39–103. https://doi.org/10.1207/s15327809jls0401_2

Lee, O., & Stephens, A. (2020). English Learners in STEM Subjects: Contemporary Views on STEM Subjects and Language With English Learners. *Educational Researcher*, *XX*(X). https://doi.org/10.3102/0013189X20923708

Rodriguez, A. J. (2015). What about a dimension of engagement, equity, and diversity practices? A critique of the next generation science standards. *Journal of Research in Science Teaching*, *52*(7), 1031–1051. https://doi.org/10.1002/tea.21232

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Becoming a STEAM-Teacher: Co-Construction of a Zone of Proximal Identity Development to Support Program Implementation

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Abstract: Exploring the role of teachers' *identities* in their appropriation of the goals, strategies, and materials of STEAM programs, we argue that teachers' "practice-linked" identities (Nasir & Hand, 2008) are consequential for implementation of STEAM programming. We analyze a STEAM program implementation that has shown promise for developing students' interests in STEAM-related futures. We explore how variation in implementation depends upon a *zone of proximal identity development* between program support staff and teachers.

Major issues

Just as they are important for student learning in disciplines, teachers' "practice-linked" identities (Nasir & Hand, 2008), we argue, are important in teaching diverse groups of students to develop STEAM interests and skills. In this paper, we explore how implementation success in MAKE depends upon the construction of teachers' *zone of proximal identity development* (ZPID). We ask the following questions: 1) How do teachers who express using the MAKE program successfully describe their identities with regard to STEAM? and 2) How do STEAM teachers work with program partners to develop a ZPID with regard to STEAM programming?

Perspectives

We approached this study with sociocultural perspectives that suggest teachers' identifications impact their pedagogical approaches (Luehmann, 2016). We see teachers as learners developing new "trajectories of identification" (Polman, 2010) as they engage in new experiences and work to appropriate new pedagogical tools. In order to build understandings around the trajectories that lead to feelings of success with STEAM programming, we draw upon Polman's (2010) notion of the zone of proximal identity development (ZPID). Polman (2010), citing Vygotsky (1978), suggests that identities develop socially in conjunction with cultural tools and practices. ZPID includes the trajectories of identity that an individual can see as possibilities for themselves given the ways they currently identify. We see teachers as potentially embodying trajectories of identity as a "STEAM teacher" in which they describe themselves as experts, learners, or novices in STEAM skills and programs.

Methods and data collection

MAKE (pseudonym) is an interest-driven approach to STEAM learning that can be implemented with students across grades. As the program expanded, the project team has sought to engage and support teachers with a variety of backgrounds in successful facilitation. Our evaluation focused on the conditions and processes that might explain variation in whether and how MAKE was taken up by educators. Our participants included 31 teachers who facilitated the MAKE program during the 2019-2020 school year. We drew upon qualitative methods to conduct semi-structured interviews, including questions around enactment, shifts in teaching, and feelings of support from administration and project teams. We then used a process of interpretive thematic analysis that began with topic coding and proceeded to thematic analysis coding (Braun & Clarke, 2006). As themes of teachers' identifications emerged, we refined our coding scheme and performed a second round of coding to examine teachers' articulations of their identities with regard to the MAKE program and to STEAM generally.

Findings

Throughout our analysis, we noted that teachers of the MAKE program identified within one of three broad categories, (1) those who were confident about their implementation of the program (2) those who were frustrated by the program constraints, and (3) those who expressed feeling insecure about their implementation.

Identifying as an expert with MAKE

Andrea was a STEAM teacher at a STEM magnet school. Andrea described herself as an expert who offered STEAM training at the district level and was "always looking for new resources." Andrea saw herself as both a STEAM *and* a MAKE specialist. Andrea explained that the program filled a gap in curriculum for her students. Because of her expertise, Andrea's administration positioned her as an instructional coach, supporting other teachers co-teaching with a variety of STEAM resources across disciplines. For Andrea, the MAKE program was essential because it allowed her to support other teachers in developing the identities they needed to successfully integrate STEAM skills in their classrooms. Although Andrea had already positioned herself as an expert, she also identified within our interview as a learner and coach and was therefore able to envision a trajectory of identity that could change to incorporate MAKE as part of her identification as a STEAM teacher.

Identifying as an enthusiastic learner of MAKE

Fred's perspective was the common in our interviews. He described himself as a content area teacher who had become the "tech teacher." He went on to explain that he felt "definitely isolated" as the only STEAM teacher in his school. While time constraints meant that Fred did not engage much with the online communities that the MAKE team has established, he expressed feeling confident knowing that a community of practitioners were using the same materials. He also noticed differences in his students' learning that he attributed to MAKE. "They're capable of doing things they didn't think they were before…I can mess up, but I can also learn how to do something in the long run." Fred could see himself becoming a stronger teacher by using the program and hoped he would get to continue to incorporate MAKE program in the future. While not yet expert, Fred was able to co-construct with a community of practice supporting his learning how to engage students with MAKE a ZPID that allowed for feelings of success with the program, even during the pandemic.

Identifying as unsuccessful with MAKE

Mia explained that the MAKE program was new to her advisory classroom. When asked about her context, Mia described the MAKE program as an administrative mandate. Mia explained that she did not feel she had time to develop expertise with the program because the advisory period was intended to introduce students to so many concepts including the MAKE program. Mia acknowledged that although the training she attended had been "really helpful," she did not feel the support she wanted from her school community. "I think that's a real challenge for kids...Because it feels just like something extra that they're doing." She explained she did not have time to engage her students with the program and therefore struggled to identify with its principles and mission. For Mia--in contrast to Fred--the community of practice and support from program partners in how to implement the program was not sufficient as a means to develop a ZPID as a successful MAKE teacher.

Discussion and implications

These cases are representative of the broader themes across our data. Throughout our data analysis we noted that teachers who positioned themselves as "expert" with STEAM were less likely to adopt identities as MAKE teachers, unless they were supporting others. Teachers who had little experience with STEAM or whose settings did not provide support, struggled to position themselves as successful with the program. Teachers who expressed feeling most successful were those who had enough background in STEAM to develop trajectories of identity that allowed them to first imagine themselves as successful, but whose knowledge was also extended with the content in the MAKE program. Our data analysis illustrates the ways that teachers may need support in fostering a ZPID in order to successfully see themselves as knowledgeable in and capable of teaching STEAM. The degree to which they are able to do so is highly contingent on both their own goals and on their ability to co-construct with partners and communities of practice a means to learn to use STEAM tools to support student engagement and learning.

References

Braun, V. & Clarke, V. (2014). What can "thematic analysis" offer health and wellbeing researchers? *International journal of qualitative studies on health and well-being, 9.*

Luehmann, A. L. (2016). Practice-linked identity development in science teacher education: GET REAL! In L. Avraamidou (Ed.), Studying science teacher identity (pp. 15-47). Sense Publishers.

Nasir, N. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. Journal of the Learning Sciences, 17(2), 143-179.

Polman, J.L. (2010). The zone of proximal identity development in apprenticeship learning. *Revista de Educación,* 353, 129-155.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge: Harvard University Press.

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Design-Centered Research-Practice Partnerships as a Means to Promote Multidimensional Transfer among In-Service Teachers

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Abstract: One of the important outcomes of Research-Practice-Partnerships (RPPs) is the development of an infrastructure that enables professional learning communities to sustain their designed innovations over time. Using a design-centric model of RPPs, this research uses ethnographic methods to characterize such partnerships, and assesses the level of transfer on various dimensions in pedagogical field application, as well as changes in participants' perceptions and sociocultural changes to indicate how they apply their new knowledge in different domains.

Research rational

This research examines a special model of Research-Practice-Partnerships (RPPs) between schools and academia, with the goal of promoting pedagogical change and sustaining these innovations over time. Although there is emerging scientific knowledge about the use of RPPs in education, there is scarce knowledge about the impact and outcomes of these collaborations (Fishman et al., 2013; Kali et al., 2018). One of the important outcomes of RPPs is the development of an infrastructure that enables the school to sustain the designed innovation over time. To understand the impact of these RPPs, this research is organized into two stages. The first stage focuses on deepening the understanding of the nature of the RPPs, by characterizing them by means of interactions within each partnership, participants' considerations, dynamics, and their ongoing and changing perceptions of the partnership. This stage is based on Kali et al.s' (2018) model of a design-centric RPP (DC-RPP) approach, which identifies two lenses: one lens which focuses on RPPs in the context of full-school pedagogical change; and the second lens which focuses on a specific discipline, evolving and progressing into innovative course designs. The second stage of this research examines the way educators develop knowledge during RPPs and apply it in different contexts. This stage is based on Dori and Sasson's (2013) transfer model, which evaluates whether and how innovative knowledge is assimilated by educators so it can sustain over time. Therefore, assessment at this stage involves levels of transfer on various dimensions, in pedagogical field application, as well as changes in participants' perceptions and possible sociocultural changes to indicate how they apply their new knowledge in different domains. Understanding similarities and differences of DC-RPPs between the two lenses and then assessing for sustainability of the innovative knowledge acquired during the DC-RPP is vital to better understand the mechanisms underlying effective RPPs, which is the aim of this research.

Background

Professional learning communities and RPP models

Pedagogical changes within schools can be incredibly complex, and there is a need to adjust to the specific needs found within the local context of the school itself (Fishman et al., 2013). One common model for leading school pedagogical change is by building professional learning communities (PLCs). Teachers in PLCs seek continuous improvement as they tentatively explore new ideas and concepts to build shared knowledge (Hod, Bielaczyc, & Ben-Zvi, 2018). In recent years, RPPs have emerged alongside PLCs to promote pedagogical changes in schools and advance research (Coburn & Penuel, 2016). Since partnerships between educational researchers and educators involves participants from varied professional backgrounds with different vocabularies, work practices, and communication structures, developing productive partnerships requires special attention (McKenney & Brand-Gruwel, 2018). Structuring the partnership with clear roles and norms is important to forge trusting relationships, a process which involves effective communication and shared meaning making between the participants (Kali et al., 2018). Scholars have identified different research traditions relevant to RPPs, one of which is the design-based implementation research approach, which examines how interventions are effectively implemented in a broader environment by doing research *with* the teachers rather than *for* the teachers (Fishman et al., 2013). Drawing on this idea, Kali et al's (2018) notion of DC-RPPs focuses on the development of the RPP design, with an emphasis on a recognized theory or approach and by paying attention to the dynamics of the partnership, along with the intention that the school staff to sustain the innovation over time (Kali et al., 2018). This model relies on a theory-practice matrix which produces design principles to guide a productive and innovative process, by overlapping theory lenses with practical constructs. This model can be assimilated in either of the RPP lenses, whether it involves an entire school vying to make a wide-ranging pedagogical transformation, or in the case of designing specific courses in a particular discipline. A powerful tool for assessing continuous improvement and successful assimilation of pedagogical changes within school is to measure transfer skills multidimensionality among practitioners (Dori & Sasson, 2013), as well as to accompany the course of the pedagogical change by ongoing assessment and evaluation processes (Sasson & Dori, 2012).

Measuring sustainability of DC-RPPs through transfer skills

The acquisition of knowledge in one context, internalized through practice and finally applied to a new context, is defined as the transfer of learning (Dori & Sasson, 2013). According to Dori and Sasson (2013), transfer has various dimensions within the categories such as task distance, interdisciplinarity, and skill set. It is therefore of great importance to measure the level of transfer multidimensionally to evaluate educational success. Hence, an assessment process based on transfer that follows the formation and activity of PLCs during pedagogical changes within schools can be of great value to determine the outcomes of DC-RPPs (Akkerman & Bruining, 2016).

Research questions and method

The questions motivating this research include: (a) What are the characteristics of the ways that DC-RPP-based PLCs develop? (b) To what degree and in what ways do the DC-RPPs enhance and contribute to transfer skills among participating teachers so they will be sustainable over time? To answer these questions, I am examining similarities and differences in a multi-dimensional comparison between two settings of RPPs: i) a structured whole-school pedagogical change; and ii) a specific innovative design within a school framework. Each RPP setting is composed of 3-5 schools, of whom the participants are educators and researchers from academic institutions. This research uses an evidence-based, mixed-methods research and analysis approach, integrating both qualitative and quantitative data from interviews, questionnaires, and observations.

Expected contribution

Most research on RPPs emphasizes the interventions developed during the partnerships rather than investigating the impact of the partnership outcomes over time (Coburn & Penuel, 2016). The overall goal at the end of the partnership process is to reach the continuation of the school's generative process independently and in accordance with its vision. Since intra-school and regulatory characteristics create a dynamic school agenda, examining pedagogical changes over time and measuring their sustainability is possible by assessing transfer skills among teachers. Therefore, this research could shed light on this vital facet of RPPs, adding new knowledge to the ways they play out as well as how to measure the effectiveness of different approaches.

References

Akkerman, S., & Bruining, T. (2016). Multilevel boundary crossing in a professional development school partnership. *Journal of the Learning Sciences*, *25*(2), 240-284.

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher*, *45*(1), 48-54.

Dori, Y. J., & Sasson, I. (2013). A three-attribute transfer skills framework–part I: Establishing the model and its relation to chemical education. *Chemistry Education Research and Practice*, *14*(4), 363-375.

Fishman, B. J., Penuel, W. R., Allen, A. R., Cheng, B. H., & Sabelli, N. O. R. A. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *National Society for the Study of Education*, *112*(2), 136-156.

Hod, Y., Bielaczyc, K., & Ben-Zvi, D. (2018). Revisiting learning communities: Innovations in theory and practice. *Instructional Science*, *46*(4), 489-506.

Kali, Y., Eylon, B. S., McKenney, S., & Kidron, A. (2018). Design-centric research-practice partnerships: Three key lenses for building productive bridges between theory and practice. In J. M. Spector, B. Lockee, & M. Childress (Eds.), *Learning, design, and technology* (pp.1-30). Cham: Springer.

McKenney, S., & Brand-Gruwel, S. (2018). Roles and competencies of educational design researchers: one framework and seven guidelines. In: Spector, M., Lockee, B., & Childress, M. (Eds.). *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy*, 1-26. Springer, Cham.

Sasson, I., & Dori, Y. J. (2012). Transfer skills and their case-based assessment. In *Second international handbook of science education* (pp. 691-709). Springer, Dordrecht.

Learners' Adjustment Strategies Following Impasses in Medical Simulations - Effects of Prior Knowledge

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Abstract: In this study we analyze how learners with different prior knowledge use different adjustment strategies (reflective or evidence generation) after impasses and how that affects their learning in a simulation in medical education. We found that learners with medium and low prior knowledge used evidence generation more often. Only learners with medium prior knowledge benefited from further evidence generation. Therefore, adjustment strategies seem to have differential effects depending on learners's prior knowledge.
Keywords: simulations, medical education, impasse, adjustment strategy, prior knowledge

Problem statement

Simulations are a very effective form of learning (Chernikova et al., 2020). However, it is unclear what makes simulations to one of the most effective learning environments in higher education. An open question is if learners with different prior knowledge make use of the additional adjust strategies a simulation offers after the experience of an impasse and if that kind of adjustment improves their learning.

Theoretical background

In different approaches learning from impasses is an important element (e.g. Kolodner, 1983). The experience of an impasse can lead to reflections and therefore triggers a deeper understanding (VanLehn, 1999). In more recent approaches, the experience of an impasse is considered a productive failure, preparing learners for future learning (e.g. Kapur, 2014).

Possible adjustment strategies in simulations are re-inspecting previously presented information and generating further relevant evidence, trial and error, or taking time to reflect without or with less time-pressure. In connection with simulations and the experience of impasses these strategies are not systematically investigated yet. It seems likely that learners with different prior knowledge at a different stage in their expertise development use different adjustment strategies during learning with simulations. However, it is unclear what kind of adjustment strategies learners with different prior knowledge show after they experience an impasse in a simulation and subsequently what kind of scaffolding they would need to improve the quality of their learning process.

Research questions

H1: Learners with high prior knowledge are more likely to use a reflective adjustment strategy after they experience an impasse whereas learners with low and medium prior knowledge are more likely to use a strategy of further evidence generation in a simulation.
H2: Learners with high prior knowledge use more time to reflect after they experience an impasse in a simulation.
H3: What can be learned from the adjustment strategy of evidence generation following an impasse depends on a learner's prior knowledge in a simulation.

Method

For the purpose of our study we used a simulation in medical education in which participants diagnosed fictitious patients (see Radkowitsch et al., 2020). In the simulation learners get access to five patient files. Learners are asked to formulate a request for a radiological diagnostic procedure for each patient to a fictitious radiologist. Learners who justify their diagnostic request appropriately receive a report of the radiological findings. Other learners get a feedback in which the fictitious radiologist asks for further justification. Afterwards learners can either decide to go back to the patient files and generate further evidence or getting the examination without generating further evidence only using internal resources to solve their impasse. We counted both reactions and logged the time between the feedback and the subsequent reaction of the learner. Depending on the correctness of the final diagnosis learners received 0, 0.5, or 1 point. We used a quasi-experimental one-factorial design with learners on three levels of prior knowledge (low (N=45) -medium (N=28). -high (N=25)).

Results

Relative to the absolute number of impasses, learners with high prior knowledge used approximately to the same amount an adjustment strategy of evidence generation (48.1%) and a reflective strategy. Both learners with intermediate (70.1%) and with low prior knowledge (66.1%) used an adjustment strategy with further evidence generation more often. This partially confirms Hypothesis 1.

Regardless of whether a strategy of further evidence generation was used ($F_{2,179} = 4.24$; $p = .016$; $\eta^2 = .045$) or a reflective strategy was used ($F_{2,139} = 2.88$; $p = .030$; $\eta^2 = .040$), learners with high prior knowledge took the most time before taking their next action after they encounter an impasse. This is in support of Hypothesis 2.

To test Hypothesis 3, we defined a step-wise logistic regression model with both frequency of evidence generation strategy and the level of prior knowledge predicting the likelihood of an accurate diagnosis. Both the main effect for the frequency of evidence generation strategy ($b = -.99$; $p = .013$; $OR = 0.37$) and the difference between learners with intermediate and high prior knowledge ($b = -1.86$; $p = .008$; $OR = 0.16$) as well as the difference between low and high prior knowledge ($b = -1.41$; $p = .024$; $OR = 0.25$) were significant. In line with Hypothesis 3, though, there was a significant interaction between the both predictors. The likelihood of an accurate diagnosis decreased with a higher frequency of the adjustment strategy of evidence generation for learners with high and with low prior knowledge whereas it increased for learners with intermediate prior knowledge.

Discussion

In simulations different adjustment strategies after the experience of impasses than in real-life practice are feasible. The findings of the present study can be interpreted in a way that the same adjustment strategy following an impasse can be helpful for specific learners but have negative consequences for learners with other learning prerequisites.

Similar to other approaches (e.g. Kolodner, 1983; VanLehn, 1999) also in simulations reflective adjustment strategies seem important, at least for learners with high prior knowledge. Learners with low and intermediate prior knowledge, however, do benefit to a much lesser extent. Learners with low prior knowledge also were not able to benefit from the adjustment strategy of generating further evidence. Maybe instead of generating meaningful evidence they fell back to a trial and error strategy.

For learners with a medium level of prior knowledge an adjustment strategy of evidence generation following an impasse seems helpful for an accurate diagnosis during their learning process. Maybe only with an intermediate knowledge structure, learners are to identify knowledge gaps and to close that gaps with the additionally generated evidence.

To conclude, simulations can provide learning opportunities not sufficiently present in real life professional situations. They, for example, leave phases for reflection and enable to re-inspect and retry repeatedly. This study found that most of the learners make use of these additional opportunities. However, the taken opportunities have differential effects on learning, depending on the learners' prior knowledge.

References

Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T., & Fischer, F. (2020). Simulation-Based Learning in Higher Education: A Meta-Analysis. *Review of Educational Research*, *90*(4), 499–541. https://doi.org/10.3102/0034654320933544

Kapur, M. (2011). A further study of productive failure in mathematical problem solving: Unpacking the design components. *Instructional Science*, *39*(4), 561–579. https://doi.org/10.1007/s11251-010-9144-3

Kolodner, J. L. (1983). Towards an understanding of the role of experience in the evolution from novice to expert. *International Journal of Man-Machine Studies*, *19*(5), 497–518. https://doi.org/16/S0020-7373(83)80068-6

Radkowitsch, A., Fischer, M. R., Schmidmaier, R., & Fischer, F. (2020). Learning to diagnose collaboratively: Validating a simulation for medical students. *GMS Journal for Medical Education*, *37*(5), Doc51. https://doi.org/10.3205/zma001344

VanLehn, K. (1999). Rule-learning events in the acquisition of a complex skill: An evaluation of cascade. *Journal of the Learning Sciences*, *8*(1), 71–125. https://doi.org/10.1207/s15327809jls0801_3

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Exploring Teachers’ Perspectives on Epistemic Growth

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Abstract: In this study, we used the Apt-AIR framework (Barzilai & Chinn, 2018) to explore the nature of teachers’ epistemic growth through the eyes of practicing teachers. We analyzed teachers' learning journals throughout a course on digital literacy and identified reflections on epistemic growth. Teachers reflected on growth in all aspects of epistemic performance described by the Apt-AIR framework. We also found that teachers reflected on growth in both epistemic performance for learning and in teaching.

Introduction

Recent research on epistemic thinking in the learning sciences has argued that conceptualizations of epistemic thinking should encompass a more diverse range of epistemic practices and attend more to the practical and social nature of epistemic thinking. In light of these observations, Barzilai and Chinn (2018) proposed the Apt-AIR framework which foregrounds learners’ epistemic competence to successfully achieve epistemic aims across diverse situations and contexts. This framework is based on the AIR model which posits that epistemic thinking includes *epistemic **A**ims and value, epistemic **I**deals* and ***R**eliable epistemic processes*. The Apt-AIR framework further identifies five interweaving aspects of competent engagement with epistemic aims, ideals, and processes: (1) cognitive engagement in epistemic performance; (2) adapting epistemic performance to diverse situations and contexts; (3) metacognitively regulating and understanding epistemic performance; (4) caring about and enjoying epistemic performance; and (5) participating in epistemic performance together with others. Promoting epistemic growth, according to the Apt-AIR framework, requires attending to all of these aspects. However, the implications of this approach to understanding teachers' epistemic growth have not yet been examined.

Buehl and Fives (2016) argued that teachers' epistemic thinking relates both to learning and to teaching. In *epistemic thinking for learning*, teachers focus on their *own* ways of knowing and on achieving their own epistemic aims. In *epistemic thinking in teaching*, teachers primarily focus on helping students achieve epistemic aims. In this study, we wished to examine whether Buehl and Fives' (2016) distinction between epistemic thinking for learning and in teaching might apply to teachers' epistemic growth. We examined the following questions: (1) Which aspects of epistemic performance are described in teachers’ reflections on epistemic growth? (2) Do teachers reflect on growth in epistemic performance for learning as well as in teaching in each of these aspects?

Method

The context of the study was an online course on digital information literacy. Participants were a heterogeneous group of 27 practicing teachers with 2 to 18 years of teaching experience in various grade levels and subject areas.

The course included four components that were collectively intended to promote epistemic performance: (a) *Reading and reading discussions* - Teachers read articles and participated in asynchronous discussions about them; (b) *Reflective experience tasks* - Teachers engaged in various tasks that involved searching, evaluating, and integrating online information sources. Teachers then evaluated their strategies and criteria for performing these tasks, individually and in small groups; (c) *Reflective journals* - Teachers wrote four journal entries in which they considered their beliefs regarding epistemic issues and their learning experiences; (d) *Design task* - Teachers collaboratively designed instructional units fostering digital literacy criteria and strategies in disciplinary contexts.

We used teachers' journals as our primary source of data. To validate and triangulate our findings, we conducted retrospective interviews with nine teachers. We developed a coding scheme to capture descriptions of growth within each of the Apt-AIR aspects. These descriptions were coded as growth in epistemic performance *for learning* when teachers reflected on changes in competence to achieve their own aims, and as growth in epistemic performance *for teaching* when teachers described growth in teaching plans or practices that were intended to foster learners' competence to achieve aims. The interrater reliability was Cohen's Kappa 0.77-1.00.

Results

Teachers described growth in epistemic performance for learning and in teaching in all five aspects (see Table 1). Growth in cognitive, metacognitive, and caring about epistemic performance was described by all or most of the teachers. Growth in adaptivity of and participation in epistemic performance was mentioned less often than other aspects, all *ps* < .001-.005. Additionally, growth in cognitive performance was described more in the context of teaching than of learning, $p = .012$; whereas growth in metacognitive performance and in participation in epistemic performance was described less in the context of teaching than of learning, $p = .001$ and .021, respectively.

Table 1: Percentages of Teachers Who Described Growth in Each Aspect in the Reflective Journals

Aspects of Epistemic Performance	Growth in Epistemic Performance for Learning	Growth in Epistemic Performance in Teaching	All Mentions
Cognitive engagement	55.6%	88.9%	92.6%
Adapting epistemic performance	18.5%	14.8%	25.9%
Metacognitively understanding and regulating epistemic performance	100.0%	59.3%	100.0%
Caring about epistemic performance	74.1%	77.8%	92.6%
Participating in epistemic performance	44.4%	14.8%	48.1%

(1) Growth in cognitive engagement in epistemic performance. Teachers expressed growth *for learning* when they described changes in their own abilities to apply strategies or criteria to achieve epistemic aims, e.g., "I pay attention to the writer's expertise, the websites' background, accuracy and credibility" (Loren, J(=Journal)3). Expressions of growth *in teaching* included descriptions of changes in plans to support students' use of epistemic criteria or strategies, e.g., "I will try to lead students to use criteria as a tool for evaluation" (Carly, J4).
(2) Growth in adaptivity of epistemic performance. Growth in adaptivity *for learning* was expressed in awareness that application of criteria and strategies depends on various factors, e.g., "[the tasks] illustrated different circumstances and approaches to the same strategy depending on the information we locate" (Bella, J4). Growth *in teaching* involved awareness that learners need to perform in diverse contexts, e.g., "I will intertwine the strategies in many disciplines to allow learners to transfer the strategy to different contexts" (Mika, J4).
(3) Growth in metacognitive understanding and regulation of epistemic performance. Growth *for learning* was reflected in changes in understanding of epistemic criteria and strategies, e.g., "I learned that every information search starts with inquiry into and sorting of information sources" (Carly, J2), as well as growth in regulation, e.g., "I learned… to metacognitively observe how I investigate and construct knowledge" (David, J3). Growth *in teaching* was evident when teachers referred to supporting students' metacognitive understanding or regulation, e.g., "I want to assist them to develop their control skill" (Lisa, J4).
(4) Growth in caring about epistemic performance. Growth in caring *for learning* was evident in appreciation of the value of using ideals and processes to achieve epistemic aims, e.g., "I now believe in the importance of evaluating knowledge sources in all areas of my life" (Julia, J3). Growth *in teaching* was reflected in references to the importance of promoting students' performance and of fostering students' motivation to engage in epistemic performance, e.g., "Raising awareness of the possible dangers is the first step in my opinion…" (Annabeth, J4).
(5) Growth in participation in epistemic performance with others. Mentions of growth *for learning* involved reflections on the social nature of epistemic performance, e.g., "I am learning to see online information from different perspectives" (Marisa, J2). Reflections on growth *in teaching* included description of how teachers would foster their students' social participation in epistemic performance, e.g., "We will create together criteria for searching for information on the Internet" (Rachel, J4).

Discussion
This study demonstrates that teachers' epistemic growth is multi-faceted and involves co-evolving changes in capabilities and tendencies to actively use epistemic ideals and processes in the pursuit of epistemic aims, to adapt epistemic performance, to metacognitively understand and regulate this performance, to care about it, and to participate in epistemic performance together with others. Further, teachers' epistemic growth was found to involve intertwined changes in epistemic performance for learning as well as in teaching. Nonetheless, growth in adaptivity of epistemic performance and in social participation in epistemic performance were described by relatively few teachers. These aspects may be more challenging to grasp and might require focused attention. Despite these challenges, this study suggests that promoting teachers' epistemic growth along all aspects of the Apt-AIR framework is feasible in teacher education.

References
Barzilai, S., & Chinn, C. A. (2018). On the goals of epistemic education: Promoting apt epistemic performance. *Journal of the Learning Sciences, 27*(3), 353-389.
Buehl, M. M., & Fives, H. (2016). The role of epistemic cognition in teacher learning and praxis. In J. A. Greene, W. A. Sandoval & I. Bråten (Eds.), *Handbook of epistemic cognition* (pp. 247-264). Routledge.

Epistemological Understanding of History in Lower Secondary Education, and its Influence on Historical Reasoning Skills

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Abstract: Although epistemological understanding plays a major role in students' reasoning, limited research is conducted on this topic. Hence, we examined the epistemological understanding of history of 942 students in lower secondary education using a pencil-and-paper test, and its influence on their historical reasoning skills. Results show that only half of the students have an advanced epistemological understanding and that epistemological understanding has a significant influence on a number of core historical reasoning skills.

Keywords: historical reasoning skills, epistemological understanding of history

Theoretical background

Students' epistemological understanding of history can be defined as their insight into the nature and construction of historical knowledge (Kuhn et al., 2000). Studies generally distinguish between three levels of epistemological understanding; the absolutist, multiplist, and evaluativist level (see, Voet & De Wever, 2016). At the *absolutist* level, students associate history with a search for an absolute truth. At the *multiplist* level, students understand that there may exist different interpretations about a historical event but perceive those interpretations as equally correct. At the *evaluativist* level, students also acknowledge the existence of different interpretations in history, but in addition, they are aware that some have stronger evidentiary support than others. This kind of nuanced epistemological understanding is an essential prerequisite for students' historical reasoning skills, as different studies have shown that epistemological beliefs influence students' academic performances (Stoel et al., 2017).

Although the comparison of historical sources and the way argumentation is constructed, depends on students' epistemological understanding (Kuhn et al., 2000; Voet & De Wever, 2016), there is a lack of research that investigates students' epistemological understanding and how it affects the different core historical reasoning skills of students. Historical reasoning can be seen as the act of reasoning with historical information (van Drie & van Boxtel, 2008) and consists of different components. In this contribution, we will use the framework of Voet and De Wever (2017) which outlines five core historical reasoning skills that are required to draw conclusions on historical information: (1) sourcing, (2) appraising, (3) specifying, (4) constructing, and (5) arguing. Here, we will focus on sourcing, appraising and arguing as those historical reasoning skills can be measured using a pencil-and-paper test. *Sourcing* is checking the nature of a source, by considering the author's background and credentials, period of the source production and type of the source. *Appraising* requires assessing the content of a source, by evaluating the author's perspective, reasoning and evidence, and requires comparing information across sources. *Arguing* means to formulate and weigh arguments in support of different conclusions (Voet & De Wever, 2017).

The main aim of this study is to investigate students' epistemological understanding of history and its influence on the core historical reasoning skills sourcing, appraising, and arguing.

Method

Participants

This contribution is situated within a larger research project that aims to investigate the impact of an inquiry lesson unit for history in the second year of Flemish (Belgium) secondary education. 942 students from 52 classes in 23 schools participated. This sample consisted of 525 boys and 417 girls. Their average age was 14 (SD = 0.45).

Instruments

Data were collected through a pen-and-paper test during the history-lesson, under the supervision of the teacher. Prior to the data collection, the teacher received a training about how to collect the data. Students had 50 minutes to complete the pen-and-paper test and they completed the test anonymously.

The first part of the test contained three authentic historical sources about the death of Emperor Claudius. In each source, information about the author and the context was given. After reading the sources, students had to assess the value of each source (*sourcing* and *appraising*) and had to give a substantiated answer to the question "Was emperor Claudius murdered by order of his wife? Explain why you think he was or wasn't." (*arguing*).

For the second part, a paper-and-pencil instrument that Kuhn et al. (2000) used to measure epistemological understanding, was adapted. This original instrument presents students with two contrasting claims about the nature of knowledge across different domains. After reading the claims, students are asked to judge whether only one claim could be right, or both could be correct. Students who opt for the latter, are asked whether they believe that one judgment might be regarded as having more merit than the other or both claims are equally correct. To fit the original instrument in the context of history, students were presented with two claims that were firmly embedded in a research on Emperor Claudius (see above). First, students were asked to read the sources. Then, they read the two opposing claims based on the authentic sources. Finally, students judged the claims and argued what the existence of such different claims meant for decision-making in historical research.

Data-analysis
To answer the research question, frequencies of all variables were calculated, and a multivariate regression was carried out with sourcing, appraising, and arguing as dependent variables and epistemological understanding as fixed factor. Dependent variables were scored from 0 to 2, using a rubric and this data was blind double-coded.

Results and discussion
Looking at students' epistemological understanding of history, most students (51.70%) are evaluativists (n = 487), 35.90% are absolutists (n = 338) and 12.40% are multiplists (n = 117). This suggests that only half of the students in lower secondary education acknowledge the existence of different interpretations in history, and are at the same time aware that some interpretations have stronger evidentiary support than others. This is in line with other research that shows that students often see history as fixed and equate history with the past (Stoel et al., 2017).

Looking to *sourcing,* students' epistemological understanding seems to have a significant effect ($F_{(2, 939)}$ = 4.73, p=.009) on their sourcing competencies. More specifically, *absolutists* (M=0.14, t_{939}=-2.20, p=.028) and *multiplists* (M=0.10, t_{939}=-2.68, p=.008) seem to score significantly lower on sourcing competencies compared to evaluativists (M=0.19) who have a more nuanced epistemological understanding.

On appraising, only *absolutists* (M=0.19) have significant lower results (t_{939}=-2.01, p=.038) compared to evaluativists (M=0.23). Being a *multiplist* (M=0.21) showed a non-significant negative relation with the appraising capabilities (t_{939}=-0.86, p=.39) compared to evaluativists. This means that only students who associate history with a search for an absolute truth (absolutists) assess the content of a source significantly worse, compared to students who acknowledge the existence of different interpretations in history (evaluativists).

As to *arguing*, only *multiplists* (M=0.21) have significant lower results (t_{939}=-2.16, p=.031) compared to evaluativists (M=0.25). Being an *absolutist* (M=0.23) showed a non-significant negative relation with arguing capabilities (t_{939}=-1.33, p=.18) compared to evaluativists.

In sum, students' epistemological understanding of history seems to have mainly a significant effect on the core historical reasoning skill *sourcing* and a differentiated effect on *appraising* and *arguing.*

Theoretical and educational significance
Only half of the students in lower secondary education are evaluativists and therefore only 52% probably possess an essential prerequisite for historical reasoning. Moreover, differences in epistemological understanding can partially explain the differences in students' core historical reasoning skills. So altogether, it can be argued that more explicit attention for students' epistemological understanding in history is needed (Stoel et al., 2017).

References

Kuhn, D., Cheney, R., & Weinstock, M. (2000). The development of epistemological understanding. *Cognitive Development*, *15*(3), 309–328.

Stoel, G., Logtenberg, A., Wansink, B., Huijgen, T., van Boxtel, C., & van Drie, J. (2017). Measuring epistemological beliefs in history education: An exploration of naïve and nuanced beliefs. *International Journal of Educational Research*, *83*(1), 120–134.

van Drie, J., & van Boxtel, C. (2008). Historical reasoning: Towards a framework for analyzing students' reasoning about the past. *Educational Psychology Review*, *20*(2), 87–110.

Voet, M., & De Wever, B. (2016). History teachers' conceptions of inquiry-based learning, beliefs about the nature of history, and their relation to the classroom context. *Teaching and Teacher Education*, *55*, 57–67.

Voet, Michiel, & De Wever, B. (2017). History Teachers' Knowledge of Inquiry Methods: An Analysis of Cognitive Processes Used During a Historical Inquiry. *Journal of Teacher Education*. 63(8), 312-329.

Searching for Instruction: Practices and Trajectories in the Selection of Online Video Tutorials

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Abstract: The search for digital resources is a central starting point for many learning processes. Building on previous research on search queries, this study maps the trajectories of users searching for online video tutorials. The data consists of video recordings of 61 sessions that included a laptop with a web browser along with the materials needed to complete an instructed activity. The study focuses on the activity that took place between the initiation of the first search query and the actual instruction following. The results demonstrate a) the practices of selecting online instructional videos, and b) how these practices form trajectories of activity. The selection process was often extended involving several steps after the initial search term had been formulated. The study concludes with a discussion of how technical developments might support the search and selection of online videos produced for the learning and achievement of practical tasks.

Introduction

Online video tutorials have become a massively prevalent social and pedagogical phenomenon. The popularity of these tutorials can be partly understood in terms of innovations in the production, distribution, and consumption of video. Whether someone wants to find instructions for how to bake a particular cake, cut their dogs hair, or change the oil filter on their car, there is almost certainly several videos that show them how. Given the enormous number of videos that are available, a central concern is finding a tutorial that matches the skills of the user and the requirements of the task. Instead of having an instructor adapting to the needs and competence of the novice, the use of video tutorials necessitates that the user finds the appropriate instructions themselves. In the context of self-directed learning, search engines are not only used to find news sites, encyclopedias and journals. Instead, video-sharing platforms like YouTube are often a key resource that in contrast to sites like Wikipedia, with its library of information, act as massive libraries of skills and practices.

The literature on online search tasks testifies to the important relationship between what is searched for and how it is searched (e.g., Gerjets, Kammerer, & Werner, 2011; Zhang & Capra, 2019). Widely used search technologies are often designed for a specific media type or platform, but not developed to meet the specific needs of a user searching for a particular type of content in a given type of media. The aim of this paper is to map the practices of people selecting online instructional videos and to examine how technical features might be better adapted to or developed for supporting the selection process. To do this, the study addresses the following empirical questions:

- What are the practices of selecting online instructional videos?
- How do the practices of selection form trajectories of activity?

Methods

To map the trajectories of users selecting online instructional videos, this study draws on a corpus of 61 video-recorded sessions. These sessions were collected as part of two different data collection initiatives where the majority (54) were conducted during a science festival. Participants had a laptop with a web browser at their disposal along with the material needed to complete the instructed activity they had chosen. They had free choice of which instructions they followed and where they looked for them. The screen of the laptop was captured along with video-recordings from the laptop's webcam and video cameras arranged so that the practical accomplishment of the instructed activity could be recorded.

Analysis of the video corpus involved several steps intended to map the instructional video selection processes of participants and focused on the activity that took place between the moment participants started writing their first search query either directly on YouTube or through Google search and the moment when they started playing the video during which they completed the task. Each selection sequence was subdivided into selection moments with start-time, end-time, number of search queries entered, number of rollover previews triggered, and number of videos played recorded. Relationships within this data were then examined in terms of selection process features using an exploratory data analysis approach (Morgenthaler, 2009) to identify recurring patterns and significant features of relevance.

Results

With the aim to map the trajectories of people looking for instructional videos and to examine how technical features might be better adapted to or developed for supporting the selection process, the findings of this study examine the selection process features engaged in by participants and the time taken to make selections.

Of the selection process features examined, the number of selection moments, search queries produced, and videos played correlate with each other, indicating that the more selection moments a user has the more search queries they produce, and the more videos they play. It is also clear that participants whose selection process included more than one moment tended to select from their earlier search results or from recommended video lists before returning to producing new search queries in later moments. One selection process feature that did not correlate strongly with the others was number rollover previews. This feature involves a user pausing the cursor over the thumbnail image for a video in the search results or recommended video lists. While the cursor is paused, a preview plays in the thumbnail indicating that the user is evaluating that video. The data shows that users tend to activate more rollover previews the more selection moments they engage in and that when a selection moment included the production of a new search term, it tended to include less triggering of rollover previews than a moment that did not.

A major factor in the variability in amount of time that was dedicated to assessing videos at each selection moment was the type of task for which instructions were being sought with participants seeking instructions for *crafting* a basic origami figure or balloon animal taking less time to find the video they would follow than those looking for instructions for how to *repair* something. For the crafting tasks it was relatively simple for participants to relate the material conditions they had with a piece of paper or balloon to those shown in instructional videos. For the repair tasks that included bicycle repair, picking locks, and tying knots, there was significantly more complexity and variability in the material conditions participants had in front of them in relation to those shown in videos.

Discussion

This study has traced the activity of users from the start of their selection process until their choice of a video instruction to follow is made. The results show how the selection and playing/scrolling of videos are two separate but integrated moments in searching for an online video. When participants did not select their final video from the results of their first search query, most individuals or collaborating groups selected their final video from subsequent search query results and only a few from the recommended video lists. This suggests that the recommendations made by the platform for related videos may not have been particularly useful to participants. By increasing content awareness for instructed activities, recommendations could present alternative takes on the same task, rather than other videos by the same producer or other videos other people have looked at.

For a video platform like YouTube, there is often a substantial number of videos available for every task, but very little in the way of help for delineating the differences in specific characteristics that would allow the matching of a users' material situation to those shown in a video (see also Torrey et al., 2009). This issue is more critical in some cases than in others. In relation to the material investigated here, for instance, it was more difficult for participants undertaking *Setup/use/repair* tasks to find a suitable instructional video because it was more difficult to match their material conditions for completing the task. To assist the user in finding the right video, a focus on search queries may be less productive than features designed to summarize or inform about the content of videos. In relation to this, the study shows that rollover previews are important, and it would be relevant to explore the possibility of summarizing the steps of the tasks shown by relying on the segmentation immanent in the video (through verbal description, pausing, cuts, etc.).

References

Gerjets, P., Kammerer, Y., & Werner, B. (2011). Measuring spontaneous and instructed evaluation processes during Web search: Integrating concurrent thinking-aloud protocols and eye-tracking data. *Learning and Instruction*, *21*(2), 220-231.

Morgenthaler, S. (2009). Exploratory Data Analysis. *Wiley Interdisciplinary Reviews: Computational Statistics* 1(1): 33–44.

Torrey, C., Churchill, E. F., & McDonald, D. W. (2009). Learning how: the search for craft knowledge on the internet. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1371-1380). ACM.

Zhang, Y., & Capra, R. (2019). Understanding How People use Search to Support their Everyday Creative Tasks. In *Proceedings of the 2019 Conference on Human Information Interaction and Retrieval* (pp. 153-162). ACM.

Evaluating a Historical Video Game: Roles of Gaming Expertise and History Expertise

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Abstract: We invited gamers with various levels of gaming and history expertise to play a historical game, *Civilization,* in order to explore how players evaluate the game. Expert players tended to view the game as half-reliable; whereas history mid-experts tended to view it as unreliable. Players employed diverse epistemic ideals to evaluate the game. This suggests that *Civilization* could be used to engage students in critical reflection and discourse about representations of history in popular culture.

Introduction
Historical games are a highly popular genre of digital games. These games incorporate historical representations that have varied degrees of reliability and accuracy (Chapman, 2016). Because players can spend substantial amounts of time interacting with semi-accurate historical representations in historical games, it is important to understand how they perceive and evaluate the reliability of such games. However, the ways in which players think about the epistemic aspects of historical games have rarely been examined.

This study is part of a larger study in which we examine the epistemic aims, ideals, and reliable processes (Chinn et al., 2014) that players of *Civilization V (Civ)*, a popular historical simulation game, engage with in three layers of knowing: knowing in the game, knowing about playing the game, and knowing about the game as a representation (Barzilai, 2017). Because history expertise has been found to affect how people process, interpret, and evaluate historical sources (Gottlieb & Wineburg, 2012), we wished to examine whether and how history expertise might shape players' epistemic thinking. We also examined whether expertise in playing the game might also influence evaluations of the game. In this contribution, we focus on the following questions: (1) How do players with different levels of gaming expertise and history expertise perceive the reliability of *Civ*? (2) Which epistemic ideals do players use to evaluate the reliability of *Civ*?

Method
We used a 2X2 design that crossed gaming expertise and history expertise. The participants included 23 adult gamers who were purposefully selected so that approximately half had no *Civ* experience, and the other half were experienced *Civ* players. Additionally, approximately half of the participants did not study history beyond mandatory high-school studies, and the other half had an academic degree in history or were studying towards such a degree. We considered this latter group as mid-level history experts because they were not professional historians and yet had developing academic expertise in this discipline. This resulted in four groups of players with: (1) no expertise, (2) *Civ* expertise, (3) history expertise, and (4) both *Civ* and history expertise.

To expose players' thinking, they were asked to think aloud while playing *Civ* for one hour. After playing the game, we conducted retrospective semi-structured interviews about the game. The data were qualitatively analyzed using thematic analysis. The analysis was informed by the AIR model, but the specific aims, ideals, and processes employed by the players were inductively inferred from the data. The first author and a research assistant independently coded a third of the quotes. The Kappa score for interrater agreement ranged from 0.64 to 0.85 (M = 0.73, SD = 0.08). Disagreements were resolved by discussion.

Findings

Views of CIV's reliability
We identified three main views of the game's reliability: About half of the players (47.8%) viewed the game as *half-reliable* (i.e., as partly accurate or credible), some players (39.1%) viewed the game as *unreliable (*i.e., as entirely inaccurate or not credible), and a few (13.0%) said that they found it *difficult to judge* its reliability.

Civ experts tended to describe the game as half-reliable (75.0%) more often than *Civ* novices (18.2%). Civ experts often said that the game can meaningfully represent history despite its unreliable characteristics, e.g., "Even if this game does not represent history in the most reliable way, in my opinion it can be a good tool for teaching history." *Civ* novices often expressed difficulties judging the game's reliability (27.3%), e.g., "I saw only a little, so it's really hard for me to say." Gaming expertise appeared to support complex reliability judgements because of expert players' deep familiarity with various features of the game. This helped expert players know which features were more or less reliable and make nuanced judgments.

Historical expertise appeared to play a different role. History mid-experts viewed the game as unreliable (60.0%) somewhat more than history novices (23.1%). History mid-experts used their knowledge of historical processes, events, and phenomena to criticize the game, e.g., "*It's not just ideologies*, but also the geographical area. It's an imaginary scenario, *there's no historical context.*" In contrast, history novices often described the game as half-reliable (61.5%) and seemed more accepting of its semi-accurate features.

Players with both *Civ* and history expertise coordinated their domains of expertise in different ways. One player viewed the game as pure a-historical fun, e.g., "*The game has no historical truth*." Other players interpreted the game, in light of their understanding of the nature of historical knowledge and of video games, as representing a particular historical perspective or abstraction, e.g., "Everything in history is about processes. So if you simplify it, it's down to what happened and who was the leader, so really *it's very fitting to represent it this way*."

Epistemic ideals for evaluating the reliability of CIV

Participants mentioned two main categories of ideals for evaluating the reliability of *Civ*: (a) *Correspondence* to real-world history based on evaluation of *consistency* with their own historical knowledge, e.g., "I know something isn't reliable when it contradicts something I know"; and (b) the *creators' trustworthiness*, which was mostly evaluated according to intent *to entertain vs. inform,* e.g., "they focus more on entertainment than historical reliability", *expertise,* e.g., "if [the creator] is a famous historian it will add some credit to the [game's] reliability", and *commercial interests,* e.g., "the game's main goal is not teaching history but selling as many copies to as many players possible." Interestingly, all player groups engaged with these ideals in a similar manner and frequency.

Discussion

Experienced *Civ* players viewed the game as half-reliable, acknowledging that some features of the game can represent history, while being critical of other features. This complex view allowed them to perceive the game as meaningful while remaining vigilant regarding its inaccuracies. In contrast, greater historical knowledge led players to be more critical of the reliability of the game. Players with both *Civ* and history expertise navigated this tension in different ways: either by rejecting the historicity of *Civ* or by accepting *Civ* as a type of historical representation that can be "read" as a historical text that reflects a particular historical perspective or abstraction.

To evaluate the game, players engaged with multiple epistemic criteria, relating both to the content of the game and to the trustworthiness of its creators. There were no differences in the criteria used by novices and experts, in contrast to prior studies. It is possible that the tension created by the game's semi-accurate nature prompted players to critically evaluate it.

These findings suggest that historical games can have a twofold contribution: They can inform learners, to some extent, about historical processes, events, leaders, etc., and they can also enable players to engage in critical reflection and discourse about the nature and reliability of historical representations. Learning to critique historical representations in games, and to consider creators' intentions and biases, might help raise learners' awareness of how history is represented in popular culture. More generally, we suggest that because learners are frequently exposed to representations (and misrepresentations) of history, science, and more in popular culture and media, learning to navigate and critique such half-reliable spaces is an important 21st century skill.

References

Barzilai, S. (2017). ‘‘Half-reliable": A qualitative analysis of epistemic thinking in and about a digital game. *Contemporary Educational Psychology*, *51*, 51-66.

Chapman, A. (2016). *Digital games as history: How video games represent the past and offer access to historical practice.* New York: Routledge.

Chinn, C. A., Rinehart, R. W., & Buckland, L. A. (2014). Epistemic cognition and evaluating information: Applying the AIR model of epistemic cognition. In D. Rapp, & J. Braasch (Eds.), *Processing Inaccurate Information*. (PP. 425-454). Cambridge, MA: MIT Press.

Gottlieb, E., Wineburg, S. (2012) Between Veritas and Communitas: Epistemic switching in the reading of academic and sacred history. *Journal of the Learning Sciences*, *21*(1), 84-129.

The Impact of Interdisciplinary STEM Innovation on the Role Identity of Science Teachers

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Abstract: The promotion of K-12 STEM education creates new conditions for science teachers to learn new elements in practice. This learning experience would affect teacher role identity development and hence the subsequent innovation process. This study explores how the innovation of STEM education influences the role identity development of science teachers with a focus on how various aspects of practice that teachers experienced in their school contexts impact on their role identity development.

Keywords: Role identity, interdisciplinary STEM, epistemic network analysis

Theoretical perspectives

Teachers learn and negotiate their identities through experience (Sachs, 2005) that teacher role identity is not static but developmental, subject to change in new conditions. Identity change can be regarded as a teacher learning outcome (Garner & Kaplan 2019). The change of teacher role identity affects how teachers engage in the innovation process and where they want to be as well as the scalability of an innovation (Chee, et al., 2015). Integrating both sociocultural and psychological perspectives in conceptualizing teacher identity, the Dynamic Systems Model of Role Identity (DSMRI) acknowledges the influence of school contexts, culture as well as personal disposition and emotion in teacher role identity development (Garner & Kaplan 2019). Extant literature informs us that teacher role identity might be developed in different dimensions such as leadership and pedagogy, depending on their practice experience. We have a question about how teacher learning in practice in STEM innovation affects their role identity development. This question relates to how teachers position themselves in the innovation and their capacity of taking up and scaling up innovation. This study explores the role identity development of four science teachers' after a year of STEM innovation, drawing on the four major components in the DSMRI model: (1) ontological and epistemological beliefs *("Belief" in Figure 1)*; (2) purpose and goals *(Goal)*; (3) self-perceptions and self-definitions *(Self)*; (4) perceived actions possibilities *(Possibility)* (Garner & Kaplan 2019). The following two research questions guide this study:
(1) What changes in the development of role identity among the four teachers in a year?
(2) How do their changes in role identity relate to their practice experience of STEM innovation?

Method

We used the first-year data from a 19-month government-funded University-school partnership programme which supported project network schools to design school-based STEM curriculum topics with self-directed learning pedagogy (Hew, et al., 2016). Four science teachers, Nick, Lily, Craig and Roy from four different schools in the network were selected for this multiple-case study. All STEM topics they implemented adopted self-directed learning pedagogy and required students to integrate learning elements from two or more disciplines.

We examined individual school conditions for teacher learning through innovation with data generated from pre-post teacher and principal interviews, co-planning and debriefing sessions, and school reports prepared by the University research team. We analyzed how various aspects of practice influenced different teacher role identity components with transcriptions of the pre-post teacher interviews in which there were questions letting teachers elicit their identity aspects and experience of practice. Extracted content for each identity component was examined and categorized in terms of their developmental dimensions. An emerging identity component of "challenges" was added in DSMRI for indicating perceived hindrances or difficulties. Five dimensions for identity development in STEM innovation were identified: (a) *pedagogy ("PG" in Figure 1)*, (b) *discipline (DS)*, (c) *interdiscipline (InterD)*, (d) *professional development (PD)*, and (e) *leadership (LD)*.

The five identity components and the five dimensions formed ten categories for coding for the epistemic network analysis (ENA, Shaffer, et al., 2016). The pre and post interviews formed the two timeframes for comparison (Figure 1). The interpretation was done together with the earlier analysis on individual schools' conditions for teacher learning through STEM innovation.

Findings and conclusion

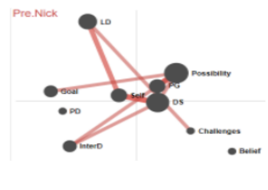
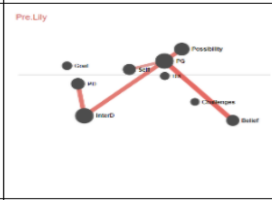
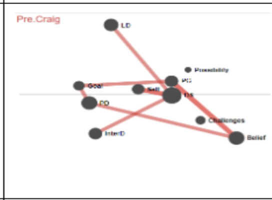
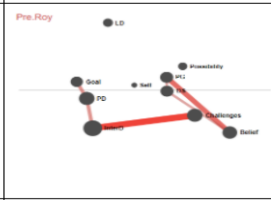
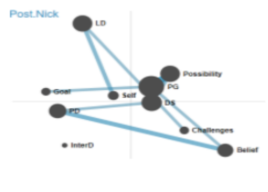
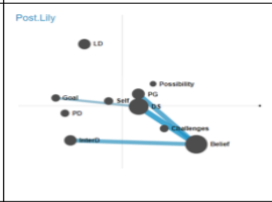
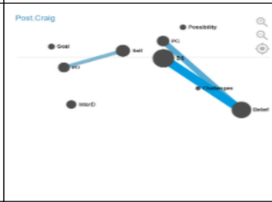
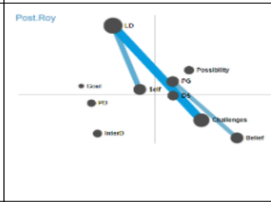
	Nick	Lily	Craig	Roy
Pre timeframe				
Post timeframe				
School Team	Cross-subject Science team	Cross-disciplinary team	Cross-disciplinary team	Cross-subject Science team
Specific School contexts	-Nick held responsible to report to the Principal and the academic department about the STEM innovation -The team decided to experience co-teaching in the process	-Lily focused on science learning with the technology teacher supported the making part -The principal and the technology teacher led the STEM innovation	-Craig worked on his own in science classroom only -The vice-principal in the team was the STEM leader not Craig and gave administrative support to Craig when needed	-Roy held responsible to report to the Principal and the academic department about the STEM innovation -Roy was newly appointed as a leader of Science and Technology

Figure 1. The comparison plot for the four teachers, from left to right Nick, Lily, Craig and Roy

The change in the strength of connection between the dimensions for identity development *(PG, DS, InterD, PD, LD)* and role identity components *(Goal, Belief, Self, Possibility, Challenge)* gives indication for their role identity development after a year (Figure 1). In terms of leadership dimension, Lily and Craig did not show any significant development, while Nick maintained and Roy grew stronger. Unlike Lily and Craig, Nick and Roy experienced more interaction mechanisms of monitoring and reporting. Only Lily showed connection between the interdisciplinary dimension (*InterD*) with a role identity component (belief). Her implementation experience in the cross-disciplinary team let her see that interdisciplinary collaboration could satisfy her interest in science learning. It seems the development on disciplinary dimension grows stronger in a cross-disciplinary team.

This study contributes to exploring teacher learning as role identity change in the context of STEM innovation. There are multiple dimensions for teacher development in STEM innovation. The focus on a single dimension such as pedagogy might not be enough to enhance teacher capacity if they need to steer STEM innovation at school. Further research on more cases are needed for seeking the understanding of how certain patterns of school conditions affect identity development and the scalability of innovation.

References

Chee, Y. S., Mehrotra, S., & Ong, J. C. (2015). Professional development for scaling pedagogical innovation in the context of game-based learning: Teacher identity as cornerstone in "shifting" practice. *Asia-Pacific Journal of Teacher Education, 43*(5), 423-437.

Garner, J. K., & Kaplan, A. (2019). A complex dynamic systems perspective on teacher learning and identity formation: an instrumental case. *Teachers and Teaching*, *25*(1), 7-33.

Hew, K. F., Law, N., Wan, J., Lee, Y., & Kwok, A. (2016). Self-directed learning in science education: Explicating the enabling factors. In C-K. Looi, J. Polman, U. Cress, & P. Reimann. (Eds.). *Transforming Learning, Empowering Learners. ICLS Conference Proceeding* Volume 2, (pp.761-768). Singapore: International Society of the Learning Sciences.

Sachs, J. (2005). Teacher education and the development of professional identity: Learning to be a teacher. In M. Kompf, & P. Denicolo (Eds), *Connecting policy and practice: Challenges for teaching and learning in schools and universities,* (pp. 5-21). Routledge, Taylor and Francis Group.

Shaffer, D. W., Collier, W., & Ruis, A. R. (2016). A tutorial on epistemic network analysis: Analyzing the structure of connections in cognitive, social, and interaction data. *Journal of Learning Analytics*, *3*(3), 9-45.

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From "Playful Activities" to "Knowledge Building": A Case Study about a Teacher's Perceptions on the Role of Experiments

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Abstract: Science education reform initiatives and the integration of maker resources into formal education have the potential to promote new ways of learning. However, well-prepared teachers are central to implement such changes. Using a case study, we describe how the ideas of one teacher about the role of experiments changed as he participated in a PD program. Based on our findings, we suggest strategies for programs aimed at integrating makerspaces resources into science curricula.

Introduction

Significant efforts have been employed to develop and implement new science standards that emphasize not only conceptual knowledge but also the practices of science and engineering. At the same time, makerspaces are becoming increasingly popular in schools, and the new resources they provide can make science learning more aligned with such practices. However, effective makerspace integration into science learning depends not only on the available resources and standards but, most importantly, on teachers prepared to implement new approaches. Student learning and sensemaking come from the productive cognitive effort afforded by well-designed activities, and not solely from the engagement in hands-on experimentations or demonstrations (Duckworth et al, 1990; Furtak & Penuel, 2019). Thus, the integration of makerspaces into school curricula must be accompanied by professional development focused on using maker resources not just as ways to "entertain" or motivate students, but to engage them in meaningful and authentic learning experiences.

As part of a larger effort to reform science education in a medium-sized Brazilian city, we developed a professional development (PD) program for science and makerspace teachers based on two principles: (1) the redesign and implementation of curricular units, as research has shown that changes in teachers beliefs and attitudes usually happen *after* they experiment new teaching approaches and notice the results on students learning (Guskey, 1986), and (2) three iterative cycles where teachers could progressively incorporate new ideas and implement changes based on their experiences in previous cycles, as it has been shown that teachers changes are cyclical and complex processes with interactions between multiple domains (Clarke & Hollingsworth, 2002). Activities in the PD program included workshops, co-design sessions between teachers and researchers, support for classroom implementation, and reflective meetings. Here, we analyze the process of change of one teacher, investigating how his ideas about the role of experiments were transformed as he participated in the program.

Methods

In this study, we analyze the trajectory of one focus-teacher, João (pseudonym), over the four years in which he participated in the PD program, using an in-depth case study methodology. João had a bachelors degree in Biology and 16 years of teaching experience at the beginning of the project. He used to teach science for grades 8 and 9, and during the program (cycle #2) was reassigned as a lab teacher.

Data sources included: audio recordings of interviews (transcribed for analysis), self-assessment reports, and field notes from classroom observation and meeting sessions. Data were analyzed using the Integrated Model of Teacher Professional Growth (Clarke & Hollingsworth, 2002) as a framework for identifying the key elements related to his changing pathways. Although our data analysis process resulted in a series of detailed growth networks describing his changing process, here we present only our main findings.

Findings

Cycle #1

In the beginning of Cycle #1, teachers participated in a 2-day workshop and co-designed a curricular unit with researchers using the backwards design framework. Based on teachers' requests, researchers provided resources and references for the design of the classroom activities aligned with their learning goals. In this initial cycle, João was not expected to introduce constructionist approaches or advanced technology into his classroom, but rather to try out new ways of teaching within his "comfort zone". Before the program, João used the science lab mainly to perform demonstrations of experiments. In his words, “experiments were used for students to see something happening. (...) They just watched me doing it*”.* Students’ roles in these classes were very passive: “they just copied what I put on the blackboard and didn't ask anything”. After participating in the workshop, João mentioned that he started to try out new teaching formats in his lab classes: “My first change was in the way students wrote lab reports. I only asked them two open questions: “what did you learn from the activity?”, and “what were the materials and procedures?”. He also started to incorporate groupwork and more open-ended activities into his classrooms. With this new approach, he saw students more engaged and interested in his classes. However, his perceptions about students’ enjoyment and engagement were the main indicators that the lesson was “good.” As such, in his view, science classes should be more “playful” and “dynamic” as a means to entertain students, which was taken as a direct proxy for learning. In this cycle, he co-designed a unit about genetics, implementing small changes in his teaching, but still mainly relying on traditional, familiar strategies. Since students enjoyed his new way of teaching, he felt confident with these changes to his pedagogical practices.

Cycle #2

In the second co-design cycle, teachers were invited to (1) include science practices as a central part of their units, (2) integrate makerspaces resources for students to engage in deeper inquiry processes, and (3) use formative assessment tools (designed by researchers). For him, experiments and hands-on activities were still seen as the primary way to engage students. However, as he observed students learning in new ways, he was surprised with the results and became interested in collecting and analyzing data about their learning outcomes. Together with the researcher team, João also created a reflection tool to be filled out by him after each classroom implementation.

Cycle #3

In the last cycle, teachers were invited to design, use and analyze formative assessment tools for their lessons. As he said in his last interview, using these tools shifted his evaluation focus to students’ learning processes: “I did not use this type of assessment before - then, what showed me that they learned something was if they knew how to answer a question correctly in the final exam. After we started using these new assessment tools, we were also able to see their performance during the activity, so I started to have a more process-oriented view: the mistakes they make, the questions they ask...”. In this cycle, João designed worksheets for his students and started to video record his classes. After each lesson, he analyzed the worksheets and the video recordings. In a representative utterance during the last cycle, *João stated that the goal of his classes started to be “for them to actually learn”.*

Conclusions and implications

As our findings suggest, at the beginning of the program, João saw *experiments as a way to confirm the theory and to entertain students*, and evaluated his classes based *on the perceived enjoyment and instantaneous engagement* of students. However, as he *incorporated formal assessment tools* to analyze students’ learnings, experiments and “hands-on” activities started to be seen as a *knowledge-building activity*.

One of the implications of our study to the design of PD programs aimed at integrating makerspaces into school curricula is that teachers need *scaffolded and continuous support* to implement changes in their practices: in each co-design cycle, researchers looked carefully at his trajectory to design supporting materials and conduct meetings based on his specific needs. Moreover, special care should be given to the *connections between learning goals and the design of activities*, as well as their *assessment*. In this way, makerspaces’ resources can be used but as a way to engage students in meaningful and authentic learning experiences, and not only to “entertain” them.

References

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, 18(8), 947–967.

Duckworth, E., Easley, J., Hawkins, D., & Henriques, A. (1990). Science education: A minds-on approach for the elementary years. Hillsdale, NJ: Lawrence Erlbaum Associates, Publishers.

Guskey, T. R. (1986). Staff development and the process of teacher change. *Educational Researcher*, 15(5), 5–12.

Furtak, E. M., & Penuel, W. R. (2019). Coming to terms: Addressing the persistence of “hands-on” and other reform terminology in the era of science as practice. *Science Education*, 103(1), 167–186.

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Riddle of the Spirit: Cultivating Children's Ecological Imagination through Multiliteracies Pedagogy

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Abstract: Drawing on the theory of multiliteracies, this study investigated how a pedagogical design called *Riddle of the Spirit* supported children's (N=62, 7–9 years old) ecological imagination about climate change issues. Preliminary findings showed how the children made sense of the story of an unwell thunderstorm spirit Ukko through multimodal resources and how this supported their ecological imagination.

Introduction

Ecological imagination (EI) refers to the capacity to deliberate and become aware of humans' relations with other lives in the ecological system (Kumpulainen et al., 2021). EI is seen as fundamental to empathy, scientific, affective, sensuous and moral thinking, and creating alternative visions of socio-ecologically just futures (Fesmire, 2010). However, little is known about EI in childhood and how designed learning environments can support the imaginative dimensions of children's ecological thinking. Drawing on *multiliteracies pedagogy* (New London Group, 1996), this study investigated a pedagogical design called *Riddle of the Spirit* (https://blogs.helsinki.fi/echoing-project/riddle-of-the-spirit/) that we have developed. The Riddle design aims to enhance children's EI in deliberating climate change issues and considering humans' relations with nature.

Theoretical frameworks

We investigate the potential for using multiliteracies pedagogy (New London Group, 1996) as an approach to stimulating children's EI. The Riddle design (Wong & Kumpulainen, 2020) offers participatory, analytic, and creative learning opportunities realized via holistic approaches across the arts, humanities, and sciences. Its conceptual basis follows the four core components of multiliteracies pedagogy originally framed by the New London Group (1996): *situated practice*, *overt instruction*, *critical framing,* and *transformed practice*. Altogether, the Riddle design provides seven pedagogical activities through cycles of four steps: Wonder, Find, Think, and Make (see Figure 1). The activities are to be applied inside and outside classroom along with a storyline, playful props, and ongoing discussions guided by teacher facilitation. The project begins with a riddle inspired by Finnish myths about a 'thunderstorm spirit' Ukko losing its climate control as the *metalanguage* and core inquiry (*overt instruction*). With the goal of solving this mystery, children are invited to investigate the reasons for the phenomena drawing on their experiences in the world (*situated practice*). The open-ended activities and collective discussions allow children's critical and analytical reflection on their relations with nature and climate issues (*critical framing*), and to create imaginative solutions around climate problems (*transformed practice*).

Figure 1. The Riddle of the Spirit activities are framed by cycles of four steps: Wonder, Find, Think, and Make.

Methods

Our analysis draws on data collected from an ethnographic study of 62 children (38 boys and 24 girls, 7–9 years old) using the Riddle materials in a primary school located in Finland. During a three-month study period in autumn 2019, research sessions comprising learning activities with the materials were conducted once a week for two hours with the children. In total, 51.4 hours of video recordings of in-class and outdoor interactions along with images of artefacts produced by children and two interviews with teachers are analyzed in this study. Our analysis methods build on visual narrative approaches (Bach, 2008) and are informed by our previous works on investigating relational entanglements of children's ecological imagination (Kumpulainen et al., 2021). Our previous research identified six overlapping intensities in children's ecological imagination: affective, embodied, sensuous, cultural and scientific, symbolic, and moral (see Figure 2). Based on our previous findings of EI, our research procedure began by identifying the six intensities of EI from the video data through thematic analysis. Based on the coding, we identified relevant data sets of children's EI for further analysis and interpretation.

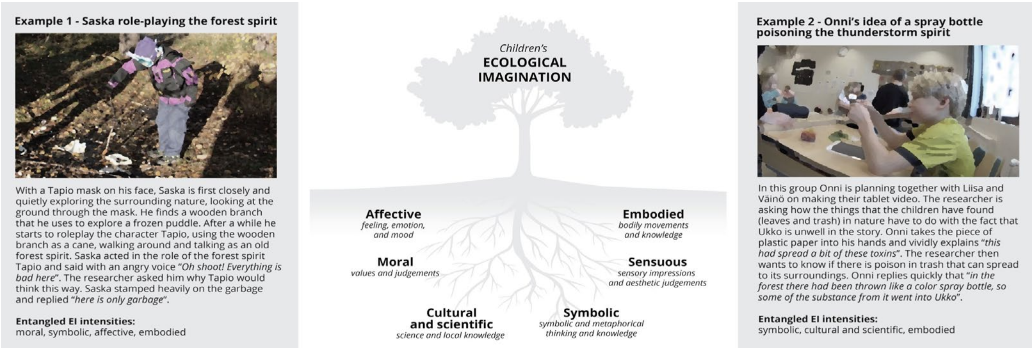

Figure 2. The six intensities of ecological imagination (Kumpulainen et al., 2021) with example 1 (left) and example 2 (right).

Findings and discussion

Our preliminary findings illustrate how the Riddle design supported the imaginative dimensions of children's ecological thinking. Through cycles of meaning-making, the children were found to make intertextual meanings, and to invent new meanings on the relations with the non-human world. In Figure 2, the children expressed new meanings by connecting their sensuous and embodied experiences from the woods and scientific knowledge about climate change with the story of Ukko. Example 1 illustrates how the child Saska's imaginative-moral-embodied-affective experience of 'being an angry forest spirit' was made possible by the activity setup and the multimodal meanings that were constructed into being in the outdoor environment. The role-play mask materially engaged Saska into the imaginative perspective of a forest spirit and Saska responded angrily and critically to garbage in the woods. Moreover, our findings revealed how the Riddle activities allowed the children to creatively and analytically imagine to make sense of the riddle of Ukko. In example 2, replying to the researcher's open-ended question, Onni quickly came up with a story by interpreting a new relation of the spray paint bottle he saw in the woods, his prior knowledge about paint bottles, and the riddle. Onni's narrative manifested his ecological imagination through embodied, symbolic, cultural, and scientific intensities. From the pedagogical perspective, the Riddle design offered the children opportunities to imagine and reflect on humans' relations with nature, as well as to deliberate tensions between the human and non-human worlds. Our results, while preliminary, suggest that the Riddle design potentially supports children's EI by: 1) its mediating material resources that draw upon multiliteracies pedagogy and, 2) fostering holistic and transformative cycles of meaning making.

References

Bach, H. (2008). Visual narrative inquiry. In L. Given (Ed.), *The SAGE encyclopedia of qualitative research methods* (pp. 939–941). SAGE Publications. Cope, B., & Kalantzis, M. (2009). "Multiliteracies": New literacies, new learning. *Pedagogies: An international journal*, 4(3), 164-195.

Fesmire, S. (2010). Ecological imagination. *Environmental Ethics*, *32*(2), 183–203.

Kumpulainen, K., Byman, J., Renlund; J., Wong, C. C., & Vadeboncoeur, J. (2021). Relational entanglements of children's ecological imagination: An investigation into augmented storying. 2021 Annual American Educational Research Association (AERA) Conference.

New London Group (1996). A pedagogy of multiliteracies: Designing social futures. *Harvard Educational Review, 66*(1), 60–92. https://doi.org/10.17763/haer.66.1.17370n67v22j160u.

Wong, C. C., & Kumpulainen, K. (2020). Multiliteracies pedagogy promoting young children's ecological literacy on climate change. In K. Kumpulainen, & J. Sefton-Green (Eds.), *Multiliteracies and early years innovation: Perspectives from Finland and beyond* (95–114). Routledge.

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A Case Study on the Pedagogical Alignment between Science and Makerspace Teachers

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Abstract: Using a case study methodology, this paper presents strategies to foster pedagogical alignments between science teachers and makerspace teachers, including ensuring time to plan and reflect on the results together, defining the role of each teacher both in the planning process as in the classroom, and discussing students' learnings to reflect on opportunities for improvement in future implementations.

Introduction

This paper comes from a very particular place of positionality, emancipation, and inclusion. The first author is a POC middle-school teacher in one of the poorest regions of Brazil, who decided to research his own practice, interview peers (the science teacher), and break the traditional roles and boundaries assigned to teachers in Brazil. This work, thus, is an attempt to systematize rich pedagogical practices in a public school, in which the teacher himself is both the researcher and the one implementing the project.

The recent integration of makerspaces in educational environments draws on constructionist theories, which propose that students build their knowledge better while creating and interacting with physical or technological resources (Papert & Harel, 1991). In the context of Brazil, learning in makerspaces is still little explored and lacks implementation strategies suited to the context of public schools, in which one big challenge is teachers' lack of time for planning and preparing materials (Fernandez et al., 2020). As part of a project to reformulate science teaching in a public network in Brazil that includes the implementation of makerspaces, we propose the establishment of the figure of the "makerspace teacher" (here also called lab teacher), as a viable way for makerspace integration. As research shows, in schoolwide reform initiatives, not only time and material resources are needed to promote instructional change but, more importantly, access to the expertise of others (Penuel et al., 2006). Thus, this new full-time teacher has the technical and pedagogical expertise to assist other teachers in planning and implementing curricular units using makerspaces' resources. However, a sustainable model of collaboration between these teachers is not always easy to achieve. Through a case study, this research seeks to discuss which strategies can be deployed to ensure an adequate pedagogical alignment between the lab teacher and science teachers, increasing their ability to integrate making in classrooms.

Methods

Data were collected over three years with a science teacher and a lab teacher (first author) from a public school in Brazil, and include planning and reflection documents upon curricular units, interviews and classroom observations. Curricular units were applied throughout three cycles of implementation and refinement through the design-based research approach (Barab & Squire, 2004), in which researchers and teachers co-designed lesson plans that gradually integrated resources from the makerspaces into science classes and reflected together about points for improvements. Data were transcribed and coded into dimensions of challenges and solutions, to identify and systematize strategies aimed at ensuring greater alignment between teachers in the planning, implementation, and reflection phases of their designed units.

Findings

In the beginning of the collaboration process, there was no adequate alignment between the lab teachers and science teachers, which led to issues during classroom implementations. Based on the results of each implementation cycle, teachers worked to refine their collaboration strategies to ensure greater alignment between them and, consequently, better learning outcomes for the students. Below, we present the main strategies developed by the teachers, divided into three stages: *planning*, *implementation,* and *reflection*.

Stage 1. Planning

In the beginning of the collaboration process, the lab teacher and the science teacher faced a lack of alignment in the implementation of their co-designed unit. In the first cycle, the design of the lesson plan was led by the lab teacher, and the science teacher only validated it with no deep understanding of the strategies adopted. They also did not plan how they would share responsibilities in the classroom - thus, role conflicts arose between them in the classroom, as this science teacher says: *"There were moments in the unit when the roles got confused"*. According to the lab teacher, *"There must be a good alignment before implementation. If that doesn't happen, the unit ends up not being very effective."* To overcome this issue, throughout the subsequent cycles teachers started to hold several meetings before implementing the unit. In our model, around four 50-minute meetings are held between the lab teacher and the science teacher before the implementation of a given unit, organized in six phases: (1) Meeting #1: teachers meet to select the theme of the curricular unit, the number of classes, and the "big ideas" that will guide its development; (2) the lab teacher searches for resources that can be used during classes, related to the big ideas defined in the first phase; (3) Meeting #2: the resources found are presented to the science teacher, and learning goals are also jointly defined; (4) the lab teacher produces materials and toolkits for the unit; (5) Meeting #3, the resources produced are presented to the science teacher, and formative assessment worksheets are produced; (6) Meeting #4: A test run of the unit implementation is conducted.

Stage 2. Implementation
Our data suggest that the roles each teacher plays during the implementation phase must be well defined in advance. One of the strategies adopted to guarantee this alignment is that the science teacher work is more geared towards the pedagogical orchestration and coordination of the class, while the lab teacher, who produced the resources and toolkits, helps students and the teacher with technical knowledge. However, the lab teacher is also free and invited to make pedagogical interventions during the class, as needed.

Stage 3. Reflection
After the implementation of the curricular units, the lab teacher carries out a detailed analysis of the formative assessment worksheets filled out by students and prepares a report that is presented to the science teacher and to the school coordinators. Teachers can then use the results to redesign the unit for future applications.

As a result of the deployment of such strategies, according to the science teacher, the meeting sessions were more productive, there was a greater diversification of the activities implemented in classrooms, and students' participation and learning were improved: *"We can notice this difference during the classes (participation, commitment, attention), and also afterward when we analyze students' worksheets and the level of knowledge that they achieved."* In addition, the science teacher reported that the results shared by the lab teacher helped her to better "*evaluate herself as a professional*".

Conclusions and implications
Our findings indicate that greater alignment between science and lab teachers guarantees better results with optimization of planning time and students' learning. The strategies developed to ensure this alignment include: ensuring joint times for planning and reflecting on the results, defining the role of each teacher when planning and implementing the curricular units, and discussing the results of each unit implementation as a way to improve the outcomes of future implementations. As new makerspaces are being introduced in schools, such strategies can contribute to help teachers to develop sustainable models of collaboration and to refine their classroom practices.

References
Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *The journal of the learning sciences*, *13*(1), 1-14.

Papert, S., & Harel, I. (1991). Situating constructionism. *Constructionism*, *36*(2), 1-11.

Penuel, W.; Frank, K.; Krause, A. (2006). The distribution of resources and expertise and the implementation of schoolwide reform initiatives. *In* Proc. International Conference of the Learning Sciences, p. 522–528.

Fernandez, C.; Hochgreb-Haegele, T.; Blikstein, P. (2020). Toward a sustainable model for maker education in public education: Teachers as co-designers in an implementation of educational makerspaces. In Proceedings of FabLearn Conference (FabLearn'20). New York, NY, USA.

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Designing Educative Supports for Scientific Argumentation: A Case Study of DBR before and during the Pandemic

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Abstract: Design-based research is uniquely positioned to adapt instructional resources quickly to meet the needs of teachers and students. This paper explores revisions to an educative support that scaffolds (a) scientific argumentation and (b) student task models, in the context of two middle-school science curricula in Chicago. Iterations were informed by: teacher feedback, student work, classroom observations, and teacher and student surveys. Changes supported student task models, NGSS storyline routines, student argumentation, and online instruction.

Introduction

The COVID-19 pandemic has highlighted the ever-present need for research on the design and improvement of educative resources that support teachers and students. In this paper, we share our ongoing design-based research focused on developing an educative support to scaffold student task modeling and scientific argumentation, in the context of NGSS-aligned middle school science curricula. We also discuss how these educative supports were reconceptualized and adapted following the transition to online learning.

Scientific argumentation is a practice that is central to the work of professional scientists and pivotal for the advancement of knowledge in the field. Nevertheless, students often find scientific argumentation to be challenging (Newell et al., 2011; Osborne et al., 2004). One research-based strategy is to explicitly provide students with instruction about the structure of an argument. (Klein et al., 1997). A second research-based strategy is to is to support student notetaking (Greenleaf et al., 2016; Rapanta & Walton, 2016). Drawing from previous research, our educative support, the *Investigation Steps Chart,* helps students track their inquiry activity by asking a set of 5 questions (e.g., How we will use the materials like a scientist to answer investigation question? What have we learned? What do we still need to know?). These monitoring questions incorporate NGSS storyline routines (Reiser, 2017) and are expected to help students develop a task model spanning the entire science unit (Britt et al., 2018). A task model is a learner's representations of the goals (e.g., what do we need to know) and strategies (e.g., how we can use the materials to figure that out) to guide and regulate structuring of the information. The output from this *Investigation Steps Chart* provides the evidence and reasoning that students use for their final argument.

Methods

This design-based research (Cobb et al., 2003) takes place in 7th-grade classrooms in Chicago Public Schools (CPS). It is a collaboration between The Learning Partnership, Northern Illinois University, CPS teachers and the CPS Office of Science. Participants include CPS middle school teachers and their students. Student demographics across schools were: 81% free and reduced lunch, 14% special education, 12% English language learners and 70% African American, 21% Hispanic, 6% White, 0.9% multiracial, 0.6% Asian, and 0.2% Native American/Alaskan. Data sources include: student work, classroom observations, and teacher feedback collected during professional learning workshops. Written parental consent was obtained for all participating students. The educational context of this design work was two different NGSS-aligned curricula. First, Amplify Science, which is the official curriculum adopted by CPS. Second, Journey to El Yunque, a curriculum where students explore and model ecosystem changes in a Puerto Rican rainforest following disturbance events (McGee et al., 2018; McGee & Zimmerman, 2016). Both curricula were structured around units that had a driving question, which students addressed through multiple investigations.

Design and Revision of the Investigation Steps Chart

The *Investigation Steps Chart* consists of a series of questions that students answer before and after the individual science investigations that culminate in a scientific argument. The *Investigation Steps Chart* supports students to develop a task model for each investigation in the science unit, by supporting ongoing and purposeful reflection. Before each investigation, students reflect on: (1) the investigation question, (2) available materials, and (3) how the materials will be used like a scientist. After the investigation, students reflect on: (4) what they have figured out about the investigation question and (5) what they still need to learn. Revisions to the Investigation Steps Chart based on the DBR process included: (a) changing wording to increase emphasis on scientific practices, (b) supporting students to reason about evidence as they collect it, (c) supporting students to collect and organize information about disciplinary core ideas, (d) creating digital versions of the tools, and (e) creating teacher guides for the tools.

Reflection on Engaging in DBR during the Pandemic

As we reflect on our experience engaging in design-based research during a world-changing pandemic, we are struck by the powerfully adaptive nature of the design-based research methodology. Design-based research is inherently oriented towards researchers and practitioners coming together to deepen understanding of learning ecologies, including understanding learning pathways and educative supports, and as such is uniquely positioned to continue seeking solutions, even in the midst of crisis (Cobb et al., 2003). While other types of educational research ground to a halt, our research continued using many of the same techniques as before, adapted to occur digitally instead of face-to-face. As the learning ecology shifted rapidly under our feet, regular conversations with practitioners helped all of us identify obstacles to learning and brainstorm potential solutions. In some ways, the intensity of pandemic conditions had the effect of creating a "window for change" as we began to increase the frequency of our conversations with practitioners and to explore a wider range of potential solutions. In particular, the digital tools we developed during the pandemic will offer a wide range of new possibilities for in-person instruction, as well as online instruction. In other ways, the pandemic slowed our collective endeavor, as technological barriers impeded student participation, student absenteeism skyrocketed, and the pace of science instruction slowed drastically. For better or for worse, this has been a year like no other, and we are committed to carrying its lessons forward as we continue to partner with practitioners to deepen opportunities for student learning. As we continue to test and refine our educative supports, we will build on what we learned by adapting the tools to support remote instruction.

References

Britt, M. A., Rouet, J.-F., & Durik, A. M. (2018). *Literacy beyond text comprehension: A theory of purposeful reading*. Routledge.

Cobb, P., Confrey, J., DiSessa, A., Lehrer, R., & Schauble, L. (2003). Design experiments in educational research. *Educational researcher*, *32*(1), 9-13.

Greenleaf, C., Brown, W., Ko, M., Hale, G., Sexton, U., James, K., & George, M. (2016). *Updated Design Rationale, Learning Goals, and Hypothesized Progressions for Text-Based Investigations in Middle and High School Science Classrooms*.

Klein, P., Olson, D. R., & Stanovich, K. (1997). Structuring reflection: Teaching argument concepts and strategies enhances critical thinking. *Canadian Journal of School Psychology*, *13*(1), 38-47.

McGee, S., Durik, A. M., Zimmerman, J. K., McGee-Tekula, R., & Duck, J. (2018). Engaging Middle School Students in Authentic Scientific Practices Can Enhance Their Understanding of Ecosystem Response to Hurricane Disturbance. *Forests*, *9*(10), 658.

McGee, S., & Zimmerman, J. (2016). Taking students on a Journey to El Yunque. *International Journal of Designs for Learning*, *7*(1).

Newell, G. E., Beach, R., Smith, J., & VanDerHeide, J. (2011). Teaching and learning argumentative reading and writing: A review of research. *Reading Research Quarterly*, *46*(3), 273-304.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of research in science teaching*, *41*(10), 994-1020.

Rapanta, C., & Walton, D. (2016). The use of argument maps as an assessment tool in higher education. *International Journal of Educational Research*, *79*, 211-221.

Reiser, B. J. (2017). Developing coherent storylines to support three-dimensional science learning. Rhode Island Science Teachers Association (RISTA) Conference,

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International Society of the Learning Sciences

Exploring Elementary Science Teacher Identity in a Professional Development Program: Soren's Story

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Abstract: This paper uses a case study approach to explore the science teaching identity of Soren, a participant in a multi-year professional development program (PD). We found that shifts in Soren's identity resulted from the combination of *competence* in rethinking science, *recognition* from others, and *performance* of different ways of teaching.

Keywords: science teacher identity, professional development, elementary teachers

Introduction and overview

Science teacher identity, as conceptualized in this poster, is how one sees themselves within the discourses of science teaching, which is contextually situated and ever-changing. Research on science teacher identity has focused on the importance of: (1) past experiences and (2) reflecting on and participating in science teaching and learning (see Avraamidou 2016; Mensah, 2016). Professional development (PD) offers opportunities for teachers to interpret past science experiences and reflect on new ones in considering science teaching and learning through the lenses of new national science standards. However, although the impact of PD on teacher learning has been explored (Simon & Campbell, 2012) the impact of ongoing PD programs on science teacher identity remains largely unexamined. For this study, we bring together two strands of inquiry as we explore the overlaps and (dis)connections among science and teacher identities by asking the question: How does PD support shifting conceptualizations of science and science teacher identity?. We use Carlone and Johnson's (2007) science identity model as an analytical tool. They conceptualize science identity as lying at the intersection of *competence*, *performance*, and *recognition*. They define *competence* as what one knows about science, *performance* as how one engages in science practices, and *recognition* as how others accept that performance. We expand this model by applying it to science teacher identity. Our case study (Stake, 1995) focused on Soren through her year-long participation in a two-year science teaching PD program. Data sources included recordings of the initial summer PD sessions, lesson observations, interviews, and video clubs (school year PD sessions), and artifacts from science unit plans and student work. We concluded our data collection with a timeline interview (Adriansen, 2012). This interview served as a form of member checking and allowed Soren to reflect on her participation throughout the year. To analyze our research question, we drew on Carlone & Johnson's (2007) framework to identify patterns in performance, recognition, and competence related to science, teacher, and science teacher identities. After identifying these areas, we clustered data (Marshall & Rossman, 2014) into categories to identify overlaps, connections, and disconnections. Next, we present our findings, drawing heavily on Soren's own words to illustrate her identity development throughout her participation in the PD.

Findings

Soren is a kindergarten teacher with 14 years of experience at multiple grade levels. During this study, she taught at an elementary school in a large metropolitan area of the southeastern United States. To address our research question about the impact of PD on science teacher identity, we synthesized Soren's reflections on the different aspects of the first year of the program. Soren initially described herself as both a "lover" and "learner" in relation to science. By the end of her first year of participation, Soren was "very comfortable" saying she is a science teacher; however, she questioned whether or not she would consider herself a "master science teacher." This self-identified question connects to the continued growth and changes teachers experience in their various teacher identities.

In reflecting on her experiences, Soren "starred" four areas from PD that she felt contributed most to her identity changes: (1) the summer PD experience, (2) co-planning a unit, (3) teaching the unit, and (4) using the first unit to plan a second one. Soren described connections between teacher and science competence, performance, and recognition, beginning with experiencing science teaching differently as a learner (*competence*—understanding ways of doing science). Soren discussed her initial experience as a science learner in PD as being "mind-blowing" and connected it to the book she was reading, *Making Thinking Visible*, thereby growing Soren’s science teacher competence as she reimagined what science is. From there, Soren shifted to *performance* by engaging in the practices of teaching (co-planning units, teaching and reflecting). As Soren reflected, and put into practice new ideas, she connected her own prior experiences with current PD experiences to inform her future vision for science learning in her classroom. These experiences linked Soren's *competence* to her *performance*. Soren also attributed change to *recognition* from others in the program. For example, Soren noted that a research team member recognized Soren's competence during the co-planning session when "she just could not stop praising what she’d seen and we were on the floor almost surprised that she was so excited about it.” Although unexpected, this recognition supported Soren’s confidence in her new ideas of what it meant to teach science. For Soren, reflection and practice combined with learning in a community allowed her to continually reconceptualize what it means to be a science teacher.

Conclusion

In response to our research question, we found that for Soren, the *recognition* of her science *competence* in PD meetings, opportunities to *perform* a science teaching identity through PD-supported planning and lesson implementation, and PD activities that created space for reflection were central to (re)negotiating her identity. PD supported conceptualizations of science and science teacher identity for Soren through an immersive experience where she experienced science learning differently from her past. As a result, she reconceptualized what science is, while the community provided recognition from others and a space to plan, enact, and reflect on science teaching practices. Soren's story reflects only one teacher's journey. However, we suggest that by supporting teachers in a PD to reimagine science and science education, they may begin to recognize how they were always-already science teachers and imagine new ways and opportunities to becoming-science teachers (Wallace, 2018).

References

Adriansen, H. K. (2012). Timeline interviews: A tool for conducting life history research. *Qualitative studies*, *3*(1), 40-55.

Avraamidou, L. (2016). Telling stories: Intersections of life histories and science teaching identities. In *Studying Science Teacher Identity* (pp. 153-175). Brill Sense.

Carlone, H. B., & Johnson, A. (2007). Understanding the science experiences of successful women of color: Science identity as an analytic lens. *Journal of Research in Science Teaching: The Official Journal of the National Association for Research in Science Teaching*, *44*(8), 1187-1218.

Mensah, F. M. (2016). Positional identity as a framework to studying science teacher identity. In *Studying science teacher identity* (pp. 49-69). SensePublishers, Rotterdam.

Simon, S., & Campbell, S. (2012). Teacher learning and professional development in science education. In *Second international handbook of science education* (pp. 307-321). Springer, Dordrecht.

Stake, R. E. (1995). *The art of case study research*. Sage.

Wallace, M. F. (2018). The paradox of un/making science people: practicing ethico-political hesitations in science education. *Cultural Studies of Science Education*, *13*(4), 1049-1060.

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The Use of Narrative in the Development of Spatial Sensemaking Practices

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Abstract: Limited research has investigated the affordances of programming that promotes spatial sensemaking for children. We analyzed a program which integrates spatially-rich narrative into the design of a museum-based program for preschool-age audiences. Narrative elements from the storybook guided the educator's facilitation of discursive practices which promoted children's spatial sensemaking practices. Children used spatial sensemaking practices to co-construct evidence-based explanations about a spatial phenomenon.

Early aptitude at spatial thinking influences one's opportunities for careers in science (Wai et al., 2009). Fortunately, spatial thinking can be improved through experience and training (Uttal et al., 2013). We investigated how narrative-based science programs support *spatial sensemaking*: cognitive spatial processes manifest through interactions with people and materials (Ramey & Uttal, 2017). Prior research with middle school students has found spatial sensemaking facilitates science and engineering learning (Ramey & Uttal, 2017; Vaishampayan et al., 2019). However, little research has investigated spatial sensemaking for young children. Thus, we ask:

1. In what way can storybook narrative support children's use of spatial sensemaking practices?
2. How does spatial sensemaking facilitate children constructing explanations in science?

We investigated storybooks because stories can be tools to structure and problematize science (Murmann & Avraamidou, 2013) and can generate interest, help us remember, and improve understanding (Norris et al., 2005).

Using conjecture mapping as a design-based approach

We embody our narrative-based program design in a *conjecture map* (Sandoval, 2014), a tool used by learning scientists to represent the relationships between theoretically-supported designs and learning outcomes. Conjecture mapping begins with a high-level conjecture to represent how elements of the learning design lead to desired outcomes (see Figure 1). Over several iterations, we have focused on designs that led to preschool-age children co-constructing evidence-based explanations (Plummer & Cho, 2020; Plummer & Ricketts, 2018).

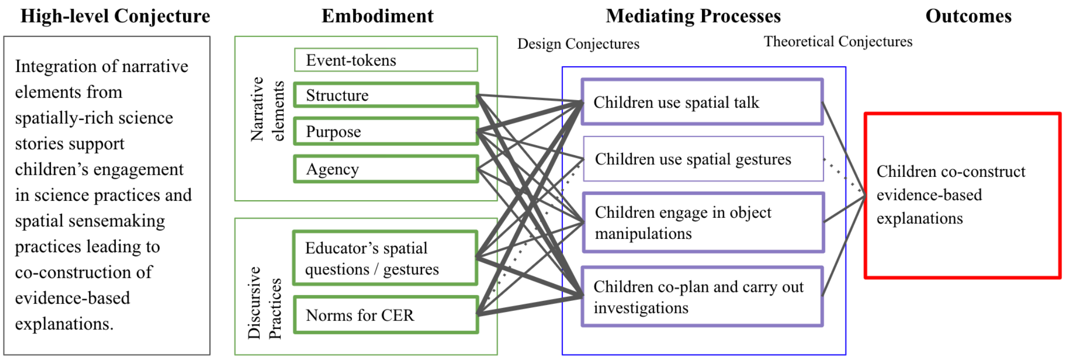

Figure 1. Conjecture map illustrating evidence from analysis of the *Lunar Craters* program.

We conjectured that children's spatial sensemaking practices while carrying out an investigation of a spatially-rich phenomenon would promote their co-construction of evidence-based explanations. Spatial sensemaking practices, particularly spatial talk, gestures, and object manipulation, may be mediators of how children make sense of the spatial nature of science phenomena. We also conjectured that *narrative elements* from the story, introduced through the educator's discursive practices, would prompt the mediating processes of spatial sensemaking and carrying out investigations. These *narrative elements* (see Figure 1), are drawn from Norris et al.'s (2005) theoretical framework for narrative explanations in science (Plummer & Cho, 2020).

Context and methods

We designed a 30-min program to encourage children's use of spatial sensemaking practices. The storybook, *Creating Craters* by Kyungjin Cho, was read by a museum educator ("Anna"). *Creating Craters* is about a brother and sister who go to the Moon, compare the size and depth of craters, and wonder why the craters are different sizes. Anna prompted children to physically explore different sizes of craters, similar to the actions of the characters. Next, children investigated how craters are formed by dropping balls of different masses into a sandbox. Finally, the children made craters using clay to represent their understanding.

We closely analyzed video recordings from one of three iterations implemented at a children's science museum (n=10; average age = 3.9 years, *SD* = 1.22). Using conjecture map elements as codes, multiple authors reviewed the coding to improve validity and reliability. We identified temporal overlap in coded instances which are represented by lines on the conjecture map. The strength of the lines in the conjecture map represents the frequency for which we observed that connection (bold > solid > dotted).

Findings

Findings are drawn from an interpretation of our conjecture map in combination with further interrogation of patterns in coded data revealed by the conjecture map (Figure 1). Program elements (see Embodiment in Figure 1) supported children's use of three spatial sensemaking practices (spatial talk, spatial gestures, and object manipulation), which children used while planning and carrying out investigations to co-construct evidence-based explanations. Our first research question asks how the storybook narrative could be used as a support for children's use of spatial sensemaking practices. Three narrative elements (structure, agency, and purpose) promoted spatial sensemaking practices of spatial talk and object manipulation. The narrative element of purpose also promoted spatial gestures, but less frequently. Further analysis suggests that these narrative elements were embodied in the program design through the discursive practices enacted by the educator: spatial questions & gestures and epistemic norms for evidence-based explanations. Our second research question asks how spatial sensemaking practices facilitate children's engagement in constructing explanations. The most salient conjecture supported by our evidence was that children's use of spatial talk alone or spatial talk plus object manipulation, in conjunction with the investigations they carried out, mediated their co-construction of evidence-based explanations.

Conclusion

Narrative elements from a spatially-rich storybook guided the educator's discursive practices which in turn promoted spatial sensemaking among preschool-age children in the program. Further, children used these spatial sensemaking practices as they carried out investigations to co-construct evidence-based explanations about a spatial phenomenon. In particular, these spatial sensemaking practices were the means by which the children generated evidence and stated their claims as they investigated the spatial phenomenon of crater formation. The use of narrative elements in the program prompted children's spatial sensemaking practices because the educator's questions and prompts drew on the conceptual purpose and engaged the children in similar narrative structures from the storybook. Thus, we recommend selecting science storybooks focused on spatial phenomena for use in planning programs for young children as a mechanism by which educators can engage their spatial sensemaking.

References

Murmann, M., & Avraamidou, L. (2014). Animals, emperors, senses: Exploring a story-based learning design in a museum setting. *International Journal of Science Education 4*(1), 66-91.

Norris, S. P., Guilbert, S. M., Smith, M. L., Hakimelahi, S., & Phillips, L. M. (2005). A theoretical framework for narrative explanation in science. *Science Education, 89*(4), 535-563.

Plummer, J.D. & Cho, K. (2020). Integrating narrative into the design of preschool science programs. In Gresalfi, M. & Horn, I. (Eds.), 14th International Conference of the Learning Sciences (ICLS), Nashville, TN.

Plummer, J.D. & Ricketts, A. (2018). Preschool-age children practicing science: Intersections of explanations, modeling, and gesture use. In Kay, J. & Luckin, R. (Eds.), 13th International Conference of the Learning Sciences, pp. 929-932, London, UK.

Ramey, K. E., & Uttal, D. H. (2017). Making sense of space: Distributed spatial sensemaking in a middle school summer engineering camp. *The Journal of the Learning Sciences, 26*(2), 277-319.

Sandoval, W. (2014). Conjecture mapping: An approach to systematic educational design research. *The Journal of the Learning Sciences, 23*, 18-36.

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin, 139*(2), 352.

Vaishampayan, A., Plummer, J.D., Udomprasert, P., & Sunbury, S. (2019). Use of spatial sensemaking practices in spatial learning. In Lund et al. (Eds.), 13th CSCL, pp. 887-888, Lyon, France.

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains. *Journal of Educational Psychology, 101*(4), 817.

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From Novice to Instructor: Inspiring Educators to Facilitate Maker-Centered Learning

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Abstract: Attaining the benefits of maker-centered learning requires well-trained educators to facilitate complex open-ended projects, a process that begins with teacher education. This study examines how educators experience maker-centered learning, and how they seek to apply these principles to teaching. Ten educator-students were interviewed from a graduate-level makerspace course. Our findings show that educators gained maker skills and a maker mindset along with experiential knowledge, which inspired specific technologies and learning goals for their future students.

Introduction

Makerspaces are environments of learning that encourage students to engage with making through the use of modern digital fabrication tools. Recent interest in makerspaces is fueled by research showing that participation in making encourages engagement with science, technology, engineering, and math (STEM) fields (Vossoughi & Bevan, 2014). Often though, the more salient takeaways from makerspace experiences are not in the form of content-specific knowledge—students come away with skills in collaboration, creativity, problem-solving, and a failure-positive outlook (Clapp et al., 2016; Hsu et al., 2017). Because of this, there is growing advocacy among educators to incorporate aspects of maker principles and activities into K-12 education. Running parallel to these calls is an emphasis on teacher education, since "educators equipped with theory, knowledge, and skills about making are needed to integrate making in formal learning settings" (Hsu, 2017). However, given the nascency of this movement, there is a lack of understanding on how to structure professional development (PD) courses for teachers and the effectiveness of these courses. A national survey on teacher education programs conducted by Cohen (2017) showed the need for an "increase in research on the role of maker principles and technologies in teacher education." While a few emerging studies have researched teacher PD through short-term makerspace workshops (Paganelli et al., 2017) or community-based makerspaces (Jones et al. 2020), there is a lack of research on the effectiveness of a formal makerspace course in shaping future practice and pedagogy for educators. This paper describes an exploratory study of aspiring educators in a semester-long makerspace course situated in a graduate school of education where they learned digital fabrication in the context of educational design.

Methods

The participants of this study were enrolled in a Master's-program level course titled "Making and Digital Fabrication in Education". This semester-long makerspace course had the dual aim of equipping students with the necessary skills to function in a makerspace and also training aspiring educators to become successful facilitators of maker-centered learning in a school-based setting. While the physical classroom was structured like a traditional makerspace equipped with laser cutters, 3D printers, and soldering stations, the course also sought to emulate learning in a school-based setting with more formal and structured learning. The students were trained on how to use the tools through a series of workshops and projects in the first half of the semester and worked collaboratively to design a novel learning tool in the second half of the semester. On a weekly basis, students were also exposed to readings on the makerspace movement, makerspace-related pedagogy, and makerspace research.

The ten interviewees for this study were selected from the eighteen enrollees based on their responses to weekly surveys which captured their self-reported states of learning and emotions. All interviews were conducted by the same member of the research team to ensure the reliability of the results. Questions in the interview protocol were semi-structured and generally categorized into areas that related to the interviewees' background, course experience, course takeaways, and future plans. After several rounds of coding and discussion, the research team derived a common set of codes that would be used to code the transcripts. In total, nine code families were identified with fifty codes created. As a final check on the reliability of the coding process, the researchers reconvened to code the last transcript together and achieved an inter-rater reliability score of 93.2%.

Results

Our findings showed that students acquired both maker skills and a maker mindset, and reflected on how these skills and mindset could be applied in their teaching practice. Another theme throughout the interviews was that students experienced the learning approaches central to makerspaces in new ways and considered incorporating these approaches into their future practice. A sample of the findings is summarized in the table below.

Table 1: Quote-based Findings

Theme	Descriptive Quote	Application to Future Teaching
Maker Skills	"...but without this class, I would not have been doing the electronics stuff, cause I was always kind of scared of working with electricity."	As an example, one prospective history teacher built a dynamic 3D map of evolving landscapes throughout history using the skills he learned in the makerspace. He hoped to share this model with his future students as a teaching tool.
Maker Mindset	"This class was more about learning how to fail. It's the growth mindset thing...and like teaching people to enjoy struggles."	"[my students] never really share their struggles with anybody else...But this mindset from the makerspace is transferable and I want to design a curriculum that can teach them that."
Hands-on learning	"When you're tangibly able to construct something, it just feels a bit more legitimate."	"I'm thankful that I took the course because it's very empowering for me as a teacher to become a designer to think about how you can merge the two worlds...all the tangible stuff. It's very useful in classrooms."
Collaborative learning	"You're always able to achieve more when working with another person than when working independently."	"my experience presented me with a possible way of teaching by building a community"

Discussion and conclusion

The findings showed that students benefited from the structured yet open-ended nature of the class. The formal aspect of the course which incorporated tool demonstrations and scaffolded projects helped make technical activities seem "less intimidating" and more "approachable", particularly for student-teachers from the humanities. At the same time, the informal learning opportunities explicitly built into the course allowed students to experientially study hands-on learning and community-based learning—approaches that they hoped to build into their own teaching. While students experienced benefits of learning in this setting, they expressed interest in more opportunities to consolidate their experiences and brainstorm ways in which they could "incorporate [the takeaways] into [their] own contexts." Some students felt that without the physical environment of the makerspace, they were uncertain about how to "maintain this momentum" for professional applications. Instructors should consider incorporating scaffolded activities that help transition student takeaways and help them maintain these takeaways outside of makerspaces. Overall, these findings provide support for formal makerspace courses geared towards future instructors and provide insights for improvements.

References

Clapp, E. P., Ross, J., Ryan, J. O., & Tishman, S. (2016). *Maker-centered learning: Empowering young people to shape their worlds*. John Wiley & Sons.

Cohen, J. (2017). Maker principles and technologies in teacher education: A national survey. *Journal of Technology and Teacher Education*, *25*(1), 5-30.

Hsu, Y. C., Baldwin, S., & Ching, Y. H. (2017). Learning through making and maker education. *TechTrends*, *61*(6), 589-594.

Jones, W. M., Caratachea, M., Schad, M., & Cohen, J. D. (2020). Examining K–12 teacher learning in a makerspace through the activity–identity–community framework. *Journal of Research on Technology in Education*, 1-16.

Paganelli, A., Cribbs, J. D., 'Silvie' Huang, X., Pereira, N., Huss, J., Chandler, W., & Paganelli, A. (2017). The makerspace experience and teacher professional development. *Professional Development in Education*, *43*(2), 232-235.

Vossoughi, S., & Bevan, B. (2014). Making and tinkering: A review of the literature. *National Research Council Committee on Out of School Time STEM*, 1-55.

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Supporting Students Remotely: Integrating Mathematics and Science in Virtual Labs

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Abstract: Tools that automatically assess and support students are important during remote instruction due to COVID-19 because students do not have direct access to teacher support. We present results of the remote use of virtual labs in an Inquiry Intelligent Tutoring System (Inq-ITS), which captures student performance on practices at the intersection of mathematics and science. Implications are discussed for the development of scaffolding and design of labs to support remote instruction.

Introduction

During the COVID-19 pandemic, teachers faced many challenges with supporting their students' learning in *STEM* classrooms in particular (Reimers & Schleicher, 2020). Specifically, providing support to students remotely requires technologies that can assess students' STEM practice competencies (NGSS, 2013) and difficulties in real time. There are some technologies with this goal for science (i.e., WISE, Vitale et al., 2019) and for mathematics (PAT, Koedinger & Anderson, 1998), but few support the full range of STEM practices. The Inquiry Intelligent Tutoring System (Inq-ITS) is a technology that assesses and supports students on inquiry practices in real time as they complete authentic virtual lab investigations (Gobert et al., 2013). Inq-ITS is currently being expanded to assess and support the practices involved in using math in science (Sao Pedro & Betts, 2019). In this study, we examined data from students who completed Inq-ITS labs with mathematics during remote instruction to address the following research questions: (1) Are math practices more challenging for students relative to other inquiry practices in Inq-ITS?, (2) What influence does the type of math relationship (e.g., inverse square) have on the difficulty of a math practice?, (3) Which specific math sub-practices are most difficult for students?

Methods

Participants in the present study included 4 teachers of eighth grade science courses and their students (N = 74 total students) from middle schools across the United States. Students completed at least one tutorial Inq-ITS lab prior to completing the lab that involved using mathematics in science (i.e., the Gravity and Mass Lab) during remote learning between May to June of 2020. In the Gravity and Mass lab, students use a simulation to investigate how certain variables relate to the force of gravity on a pile of gold on a spaceship. Specifically, students complete three investigations to identify the mathematical relationships between: the amount of gold and force of gravity on the gold (linear), the gold's distance from a planet's center and force of gravity on the gold (inverse square), and the planet's mass and the force of gravity on the gold (linear). Informed by the NGSS (2013) practices, each investigation in the lab consists of six stages: 1) **asking questions**/hypothesizing about the relationship between variables based on a goal; 2) **carrying out an investigation**/collecting data using a simulation; 3) **setting up graphs** by selecting the variables to place on each axis and data to plot; 4) **constructing graphs and equations** by determining the type of mathematical relationship between variables and creating a best fit line/curve; 5) **analyzing and interpreting data** to draw a final conclusion; and 6) **explaining findings** in writing.

To identify the practices that were most challenging for students, we used the validated automated scoring in Inq-ITS (Gobert et al., 2013; Sao Pedro & Betts, 2019) within stages 1–4 (automated scoring for stages 5–6 is in development). Each practice (in bold) is scored according to student performance on sub-practices involved in completing the practices: **asking questions** (identifying the target independent and dependent variable), **carrying out investigations** (running sufficient, controlled trials that target the variables of interest), **setting up graphs** (labeling axes and selecting sufficient data to plot from controlled, targeted trials), and **constructing graphs and equations** (identifying the mathematical relationship in the graph, adjusting the equation to create a best fit curve). The final score for each practice is the average of the sub-practices, scored as binary. We analyzed student performance on practices and sub-practices across the entire lab.

Results

First a Mixed Model ANOVA was conducted to investigate whether there were differences in student performance between teachers and across practices. Results showed that the overall model was significant, $F(3, 68) = 13.46$, $p < .001$, $n^2 = .37$. The between-subjects effect ($F(3, 70) = 1.50$, $p = .223$, $n^2 = .06$) and interaction between teacher and practice was not significant ($F(3, 70) = 1.27$, $p = .290$, $n^2 = .05$), which indicated that there were no significant differences in student performance between teachers. There was, however, a significant within-subjects effect of inquiry practices, $F(1, 70) = 21.44$, $p < .001$, $n^2 = .23$, which means that there were significant differences in student performance on practices. Follow-up analyses using within-subjects t-tests revealed that students performed significantly higher on carrying out investigations ($M = .97$, $SD = .09$) than on asking questions ($M = .92$, $SD = .16$, $t(73) = -2.99$, $p = .004$), students performed well on both asking questions ($M = .92$, $SD = .16$) and setting up graphs ($M = .88$, $SD = .18$, $t(73) = -1.62$, $p = .109$), and students performed significantly higher on setting up graphs ($M = .88$, $SD = .18$) than on constructing graphs/equations ($M = .77$, $SD = .27$, $t(73) = 5.08$, $p < .001$). This suggests that the practice of constructing graphs/equations in science was most difficult for students.

Next, we used a Repeated Measures ANOVA to determine whether there were any differences in student performance on the practice of constructing graphs/equations across the three investigations in the Gravity & Mass lab in relation to the type of mathematical relationship. We found that there was a significant main effect of the investigation, $F(2, 146) = 21.71$, $p < .001$, $n^2 = .23$. Follow-up analyses using within-subjects t-tests revealed that students performed significantly better on the first investigation (linear; $M = .84$, $SD = .33$) relative to the second investigation (inverse square; $M = .61$, $SD = .41$, $t(73) = 5.04$, $p < .001$), and third investigation (linear; $M = .88$, $SD = .28$) relative to the second investigation (inverse square; $M = .61$, $SD = .41$, $t(73) = -5.68$, $p < .001$). There were no significant differences between the first and third investigations (both linear; $t(73) = 1.06$, $p = .292$), but students did perform slightly higher on the third investigation (meaning that students did maintain performance with some improvement from the first to third investigation on this practice). These results support prior findings indicating that students experience challenges with non-linear relationships (De Bock et al., 2017).

Finally, we examined whether there were any significant differences in student performance between the sub-practices involved in constructing graphs/equations using a within-subjects t-test. We found that students performed significantly better on the sub-practice of adjusting an equation to create a best fit line/curve ($M = .83$, $SD = .28$) relative to the sub-practice of identifying the type of mathematical relationship ($M = .73$, $SD = .32$, $t(73) = -3.62$, $p < .001$, $d = .33$). This finding aligns with earlier research findings that students have difficulty determining the type of functional relationships between data (i.e., linear, inverse, etc.; De Bock et al., 2017).

Conclusions and future work

As a result of the fine-grained automated scoring in the Inq-ITS virtual lab, we were able to determine that students had difficulties with the math practice of constructing graphs and equations relative to other inquiry practices, particularly in the context of graphing an inverse square relationship. Additionally, we found that the sub-practice of identifying the type of math relationship in the graph was particularly challenging for students. This level of assessment is critical as we develop auto-scaffolding to ensure students receive support on these difficult practices.

References

De Bock, D., Neyens, D., & Van Dooren, W. (2017). Students' ability to connect function properties to different types of elementary functions: An empirical study on the role of external representations. *International Journal of Science and Mathematics Education, 15*(5), 939-955.

Gobert, J. D., Sao Pedro, M., Raziuddin, J., & Baker, R. S. (2013). From log files to assessment metrics: Measuring students' science inquiry skills using educational data mining. *Journal of LS*, *22*(4), 521-563.

Koedinger, K. R., & Anderson, J. R. (1998). Illustrating principled design: The early evolution of a cognitive tutor for algebra symbolization. *Interactive Learning Environments, 5*(1), 161-179.

NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: NAP.

Reimers, F. M., & Schleicher, A. (2020). *A framework to guide an education response to the COVID-19 Pandemic of 2020*. OECD.

Sao Pedro, M. A., & Betts, C. (2019). *Real-Time formative assessment of NGSS mathematics practices for high school physical science (Report).* Berlin, MA: Apprendis.

Vitale, J. M., Applebaum, L., & Linn, M. C. (2019). Coordinating between graphs and science concepts: Density and buoyancy. *Cognition and Instruction, 37*(1), 38-72.

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Asking Students to Carry out Generative Learning Activities in Text Learning: Exploring the Role of the Quality of the Performed Learning Activities

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Abstract: Tasks such as retrieval practice or self-explaining are expected to trigger generative learning activities necessary for deep understanding. The present study investigated the influence of asking students to either perform re-read, retrieval, or self-explanation activities on text comprehension. Students of two German high schools were randomly assigned to one of three groups when reading expository texts. Subsequently, participants completed a posttest including retention and inference questions. An initial evaluation of the posttest data revealed no significant differences between the groups. This finding raised the question to what extent students actually carried out the requested learning activities and whether the quality of the performed learning activities plays an important role. The results indicate that qualitatively different learning activities are associated to different posttest performance. We conclude that explicitly examining traces of students' learning activities might be a useful supplement in further research on generative learning activities.

Introduction

Learning from a text is an iterative, interactive process in which students process the text information at various levels (e.g., linguistic, text base, situation model level, see for example Kintsch, 1998). The level at which learners process the text information affects how they can later apply it (e.g., reproducing text information verbatim, in terms of paraphrases, or transfer the information to new situations or problems). Deep understanding requires that learners build a situation model by constructing inferences (Kintsch, 1998). Generative learning activities can contribute to deep understanding.

When performing generative learning activities learners infer new knowledge by connecting different information from the learning text and/or by linking this information with prior knowledge (Grabowski, 2004). To elicit generative learning activities, two tasks are very often applied in educational practice and/or examined in empirical research (e.g., Fiorella & Mayer, 2016): retrieval practice and self-explaining. However, research that compares the constraints and outcomes of these two tasks is limited (Roelle & Nückles, 2019). Moreover, research systematically examining not only learners' outcome in terms of comprehension posttest measures, but also if and how the learning activities requested by the task were actually carried out by the learners is almost not existent. The present study compared the effects of different generative tasks in text learning (i.e. re-read, retrieval practice, and self-explaining). Engaging pupils in generative learning activities was expected to foster deep understanding.

Method

The experimental study involved a total of 150 secondary pupils (86 female, *M* age = 15.1 years) at two German high schools. There were no significant differences between the schools for pupils' age and gender.

Data collection was carried out in each school in two sessions (90 and 45 minutes). All materials were provided as booklets. During the first session, all participants read five expository science texts (Hinze, Wiley, & Pellegrino, 2013), and were randomly assigned to one of three groups: The re-read group (n = 51) read each text twice. The retrieval group (n = 54) retrieved after each text the just read information from memory and wrote it in a blank sheet. The self-explanation group (n = 45) self-explained a total of five highlighted target sentences in each text, one paragraph at a time. Three to six days later, students' reading skills and domain-specific prior knowledge were assessed. We included the prior knowledge test at the second session to avoid exposing students to topic-related questions that could influence their learning activities. In addition, the participants completed a posttest on the text information. It contained five multiple-choice retention and five multiple-choice inference questions for each text (50 questions in total, see Hinze et al., 2013).

We assessed the quality of students' generative learning activities by means of a coding scheme. Each student response in the retrieval and self-explanation condition was classified as consisting of either a 1) paraphrase 2) near-bridging inference, 3) far-bridging inference, or 4) knowledge-based inference. In addition, it was examined if a response included a statement on metacognitive monitoring (retrieval group: Krippendorff's Alpha = .75, self-explanation group: Krippendorff's Alpha =.85).

Results

Pupils of the two schools differed with respect to prior knowledge. However, across the randomly assigned groups there were no significant differences for prior knowledge as well as reading skills. Participants of the retrieval group generated more inferences than participants of the self-explanation group. For posttest variables no significant differences between the groups were revealed, either in terms of performance in retention or in inference questions (Table 1).

Table 1: Means and standard deviations of prior knowledge, learning activity and posttest variables (%)

	Re-read group *M* (*SD*)	Retrieval group *M* (*SD*)	Self-explanation group *M* (*SD*)
Prior knowledge	71.18 (15.02)	71.87 (14.45)	73.44 (15.40)
Paraphrases	-	15.67 (8.65)	19.40 (5.06)
Near-bridging inferences	-	7.91 (4.69)	0.87 (1.25)
Far-bridging inferences	-	4.53 (2.77)	2.71 (3.24)
Knowledge-based inferences	-	0.33 (0.64)	1.04 (1.54)
Monitoring statements	-	0.02 (0.14)	21.02 (5.60)
Retention questions post	62.27 (15.16)	63.19 (15.72)	57.24 (17.47)
Inference questions post	59.06 (17.30)	61.19 (19.76)	54.76 (18.43)

Analysis of learning activities in the retrieval and self-explanation groups revealed moderate correlations with both posttest measures for the number of near-bridging, far-bridging, and knowledge-based inferences (r_s between .22* and .36**). In contrast, number of paraphrases and number of monitoring statements were not significantly associated with posttest performance.

Conclusion

The present results indicate that just asking pupils to retrieve or self-explain the text had no benefits for posttest performance compared to a re-read condition. A closer look at pupils' learning activities revealed that students engaged in different kinds of more or less generative learning activities. Some students did so spontaneously, others potentially because the task triggered them to do so. Not all students generated inferences during task completion. Yet, a higher number of inferences was associated with better performance in both posttest measures. It has to be noted that most participants had high prior knowledge, which may have contributed to their engagement in generating inferences (Fiorella & Mayer, 2016; Roelle & Nückles, 2019). Thus, to gain deeper insight into the conditions and effects of providing students with generative tasks, future studies should investigate not only posttest measures but also behavioral traces of students' learning activities.

References

Fiorella, L., & Mayer, R. E. (2016). Eight ways to promote generative learning. *Educational Psychology Review, 28*(4), 717-741. doi:10.1007/s10648-015-9348-9

Grabowski, B. L. (2004). Generative learning contributions to the design of instruction and learning. In D. H. Jonassen (Ed.), *Handbook of Research on Educational Communications and Technology* (2nd ed., pp. 719-743). Mahwah, NJ: Lawrence Erlbaum.

Hinze, S. R., Wiley, J., & Pellegrino, J. W. (2013). The importance of constructive comprehension processes in learning from tests. *Journal of Memory and Language, 69*(2), 151-164. doi:10.1016/j.jml.2013.03.002

Kintsch, W. (1998). *Comprehension: A paradigm for cognition*. New York: Cambridge University Press.

Roelle, J., & Nückles, M. (2019). Generative learning versus retrieval practice in learning from text: The cohesion and elaboration of the text matters. *Journal of Educational Psychology, 111*(8), 1341-1361. doi:10.1037/edu0000345

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Making Students' Ideas Visible through Coding a Scientific Computational Model

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Abstract: This study investigates the ideas of 5th-grade students while creating computational models for diffusion. Results illustrate that translating ideas into code can be a strategy to make them explicit. However, there is tension between designing blocks and learning; limited numbers of blocks interfere with students' expressing their ideas, while an open environment can make it hard to converge into acceptable explanations. We argue that creating domain-specific-blocks for modeling needs to be a thoughtfully designed process.

Introduction

Designing computer models is a promising approach to science learning. It combines the advantages of traditional modeling with computational literacy, opening new possibilities for inquiry-based learning (Weintrop et al., 2017; Wilkerson et al., 2015). Nevertheless, developing a computational scientific model can be a demanding task for teachers and students in elementary and middle school. In the past decade, many new environments have been designed to allow kids to create their own models using block-based programming languages and other innovative user interfaces such as NetTango (Horn et al., 2014), Deltatick (Wilkerson et al., 2015), StarLogo Nova (Klopfer et al., 2009). Drawing on these ideas, this paper introduces the designed nine domain-specific blocks of the scientific phenomenon of diffusion as a Scratch extension.

This study aims to explore what ideas students have about diffusion and how they were translated into code during an activity based on the Bifocal Modeling approach (Blikstein, 2016; Fuhrmann et al., 2018). We use the term "ideas" to refer to the understanding that students have developed about the natural phenomena of diffusion of ink in hot and cold water. Students' ideas are challenging to identify, and many times invisible to teachers. In this sense, designing a model with domain-specific blocks can be a valuable way to disclose students' ideas about the scientific phenomenon of diffusion while students are still in the midst of an inquiry activity.

Methods

The study was conducted with seven students in grade 5 through individual Zoom sessions that lasted approximately one hour. The sessions were based on the Bifocal Modeling approach split into four "mini activities" where students created a program to model the process of diffusion after observing an experiment using the designed domain-specific blocks. Data sources included seven hours of video recording and seven computational models.

Results and Discussion

Data illustrates that students had diverse ideas to explain the process of diffusion. Two main types of ideas were observed: ideas that could be tested with the available blocks - for example, the idea of "speed" - and ideas that could not be expressed with blocks - for example, the idea of "melting". A summary of students' ideas is presented in Table 1, alongside quotes that explain their reasoning.

Table 1: Students' ideas regarding diffusion

Category	Description	Sample quotes	Tested with blocks
Number of particles	There are more particles in hot water than in cold water.	*In hot water, I guess there are more particles.*	Yes
Motion	Water particles move more chaotically than ink particles	*In hot water, water molecules are more chaotic than the food color particles*	Yes
Speed	In hot water, particles are faster than in cold water	*They move faster in hot water probably, because you can see that they spread out more.*	Yes
Collision	When particles collide, they change	*When they touch each other, they don't go over*	Yes

	their direction	*each other, they bounce back.*	
Melting	In hot water, ink particles melt	*In hot water, the food color melts. In the cold water, it stays the same*	No
Density	In hot water, bubbles make the particles lighter, cold water is denser	*Hot water particles are maybe lighter. Maybe the bubbles have something to do with it, and the cold it's just denser*	No
Proximity	Hot water particles are separated from each other, in cold water they are closer.	*In hot water, everything separates. (...) The particles are together in cold water.*	No

Conclusion

Our data illustrates that observing students designing a model can be a good strategy to explore their prior ideas and how they evolve over time. Ideas about diffusion that are usually invisible to both the students and the teacher in a traditional lesson become visible, concrete, and sometimes testable using the blocks. When students designed their diffusion models, they needed to understand many details regarding the phenomenon and to "unpack their thinking" since each step revealed a "piece" of students' prior conceptions (diSessa, 2018), which later can evolve to understanding the broader phenomenon of diffusion. However, a key challenge was that some of the students' ideas were not easily representable using the pre-designed blocks. if the goal of engaging students in the coding of scientific modeling is to allow them to explore their ideas, the ways the blocks are designed might interfere with that goal. Even though blocks make coding easier, they also limit some possibilities. As more and more developers and researchers create domain-specific block-based modeling tools, we warn that the smoother learning curve could come at a price: limiting students' explorations that radically diverge from the "official" explanation. Opportunities to implement domain-specific blocks are numerous, and follow-up research is invited to determine more pedagogical affordances and new areas for improvement.

References

Blikstein, P., Fuhrmann, T., & Salehi, S. (2016). Using the bifocal modeling framework to resolve "discrepant events" between physical experiments and virtual models in biology. *Journal of Science Education and Technology*, *25*(4), 513-526.

diSessa, A. A. (2018). A friendly introduction to "knowledge in pieces": Modeling types of knowledge and their roles in learning. In *Invited lectures from the 13th international congress on mathematical education* (pp. 65-84). Springer International Publishing.

Fuhrmann, T., Schneider, B., & Blikstein, P. (2018). Should students design or interact with models? Using the Bifocal Modelling Framework to investigate model construction in high school science. *International Journal of Science Education,* 40(8), 867-893.

Horn, M. S., Brady, C., Hjorth, A., Wagh, A., & Wilensky, U. (2014). Frog pond: a code first learning environment on evolution and natural selection. In *Proceedings of the 2014 conference on Interaction design and children,* 357-360.

Klopfer, Eric, Hal Scheintaub, Wendy Huang, Daniel Wendel, and Ricarose Roque. (2009) "The simulation cycle: Combining games, simulations, engineering and science using StarLogo TNG." *E-Learning and Digital Media* 6, no. 1: 71-96.

Weintrop, D., & Wilensky, U. (2017). Comparing block-based and text-based programming in high school computer science classrooms. *ACM Transactions on Computing Education (TOCE),* 18(1), 1-25.

Wilkerson-Jerde, M., Wagh, A., & Wilensky, U. (2015). Balancing curricular and pedagogical needs in computational construction kits: Lessons from the DeltaTick project. *Science Education,* 99(3), 465-499.

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International Society of the Learning Sciences

Before the Storm: How Families were Supported for the Transition to Distance Learning

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Abstract: During Covid-19, the amount and quality of preparation for remote instruction has varied greatly across the country. This poster presents findings from a remote diary study that captured a diverse set of families' experiences adapting to remote learning when schools closed in the Spring of 2020. We found that just increasing access to digital resources was not enough; regular, clear, streamlined communication between schools and caregivers was critical to smoothing the transition to distance learning.

Keywords: families, Covid-19, distance learning, diary study, home-school communication

Introduction

The sudden closure of school buildings around the United States due to Covid-19 laid bare the ongoing cost of digital inequities as districts scrambled to finish out the school year remotely. At least 300,000 teachers and fifteen to sixteen million students lack what they need to participate in high quality distance learning (Chandra et al., 2020). These consequential gaps particularly affect lower income, underrepresented minority, and rural families, and must be understood in terms of overlapping, multidimensional sources of inequity in access to learning opportunities (Nasir et al., 2020). How technology is used for teaching and learning has also varied greatly during the pandemic. Pre-pandemic, schools were differentially providing creative and inquiry learning experiences, adding to differences that already occur as a function of family resources (Warschauer & Matuchniak, 2010). Technology in less-affluent schools often features "individualized" progression through workbook-type activities and multiple-choice test practice questions, whereas in affluent schools, technology is frequently used to explore, create, and develop presentations of learning in discussion with peers and teachers (see Darling-Hammond, Zielezinski, & Goldman, 2014). Given the central role of schools in determining access and use of technology, we share preliminary insights into how families were supported by schools to transition to remote learning.

Methods

For two weeks in May 2020 we collected daily documentation from 109 families across the US with children aged 5-10 (grades K-5) using dscout, a smartphone-based remote qualitative research platform (see Barron et al., 2021). Participants were selected from the dscout panel, equally distributed by household income brackets (<$50K, $50-99K, and over $100K). They lived in 28 states, and 55% identified as White, 16% Black, 15% Hispanic/Latinx, 9% Asian, and 4% Middle Eastern/North African. Each selected one child in grades K-5 to focus on in the study (53% were K-2). Caregivers completed 5 mixed methods questionnaires designed to understand the resources and support they received from their child's school before and after the pandemic started, what remote learning looked like for their child, how their family was learning about Covid-19, and the social and emotional impact of the pandemic. We use descriptive quantitative and qualitative grounded theory coding to analyze the responses and gain insights into how families were prepared to handle the transition to distance learning.

Findings

Overall, 44% of participants indicated that they thought they were able to transition well to distance learning, and the results did not differ significantly by income. As displayed in Table 1, the number of digital resources available to families increased after the pandemic. Before the pandemic, higher income families were more likely to report online work required in their child's school (27%) compared to lower income families (5%), suggesting that they may have been better prepared to make the shifts necessary when all learning went remote. After schools closed, higher income families were more likely than lower income families to report having synchronous classes (X^2 = 8.13, p = .017), individualized messages from teachers (X^2 = 8.68, p = .013), and access to teacher-recorded video content (X^2 = 6.78, p = .034).

Table 1: School Provided Supports for Learning Online at Home; Before and During Covid-19 (N=109)

	Before		During	
Reported supports	N	%	N	%
Teacher-led lessons				
Realtime classes or meetings using video	11	10.1%	91	83.5%
Teacher pre-recorded videos of educational content	6	5.5%	64	58.7%
Assignments				
Online assignments (e.g. websites)	36	33.0%	84	77.1%
Ebooks/Audiobooks	16	14.7%	33	30.3%
Pre-recorded videos by teacher	6	5.5%	64	58.7%
YouTube Playlists	13	11.9%	32	29.4%
Paper packets/books	85	78.0%	73	67.0%
Individualized communication				
Individual video or phone check-ins	7	6.4%	53	48.6%
Individualized messages from teachers via email	45	41.3%	87	79.8%
Devices				
Devices to use for learning at home (e.g. iPads, Chromebooks)	53	48.6%	75	68.8%
Hotspots (internet access) to use with devices	25	22.9%	25	22.9%

To understand what preparation made a difference for families, we examined the open-ended text and video responses from contrasting cases. Alma and Cara are mothers of 7 year-old, first grade girls who attend public school. Both mothers involved with their child's schooling before and after the pandemic started, and had markedly different experiences transitioning to distance learning. Through their cases, we see how regular, clear communication between the schools and caregivers was critical for the transition, as were coordinated plans for instruction and sufficient support for caregivers to help their children complete their work. In the poster session, we will go in depth on these cases to illustrate the importance of teacher-caregiver communication and synchronous connections in providing quality remote learning experiences.

Conclusion

Just like a major weather event, the Covid-19 pandemic is forcing families and schools to reckon with their emergency preparations for long-term, traumatic disruptions to student learning. In this poster, we described how understanding the distribution of physical resources is not enough to address equity; the social infrastructure surrounding the resources is critical for a smooth transition between in-person and remote instruction, such as the quality of home-school communication. These results need to be put into the broader context of national conversations about growing inequities, trauma, and an urgent need for reimagining educational environments. The current moment offers challenges and opportunities for growth. As researchers, caregivers, and educators move forward, novel forms of collaboration and interdisciplinary approaches to knowledge creation and design for learning will be needed.

References

Barron, B., Martin, C.K., Lin, V., Lam., C.K., Pozos, R.K., Ngyuen, J., Garcia, S., & Levy, Z. (2021). New views, new roles: How parents supported learning during the transition to remote learning. Annual Meeting of the International Society of the Learning Sciences (ISLS), Bochum, Germany.

Chandra, S., Chang, A., Day, L., Fazlullah, A., Liu, J., McBride, L., Mudalige, T., & Weiss, D., (2020). *Closing the K–12 Digital Divide in the Age of Distance Learning.* San Francisco, CA: Common Sense Media. Boston, Massachusetts, Boston Consulting Group.

Darling-Hammond, L., Zielezinski, M. B., & Goldman, S. (2014). *Using technology to support at-risk students' learning.* Washington, DC: Alliance for Excellent Education.

Nasir, N., de Royston, M. M., Barron, B., Bell, P., Pea, R., Stevens, R., & Goldman, S. (2020). *Learning Pathways: How Learning Is Culturally Organized. In Handbook of the Cultural Foundations of Learning* (pp. 195-211). Routledge.

Warschauer M, & Matuchniak T. (2010). New Technology and Digital Worlds: Analyzing Evidence of Equity in Access, Use, and Outcomes. *Review of Research in Education, 34*(1):179-225.

Two Exploratory Case Studies of Teachers' Adaptive Expertise in teaching Bioinformatics in High School Science Classrooms

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Abstract: In this study, we use an adaptive expertise lens to examine two contrasting cases of how teachers implemented a data-intensive curriculum in environmental science classes. Analysis showed differing levels of teachers' adaptive expertise as well as challenges when working with data representations. We found that teachers' adaptive expertise depends on teachers' awareness of students' context and extensive knowledge of data literacy and suggest that teacher learning experiences should focus on developing these qualities in instruction.

Introduction

Emphasis has been placed by educational researchers on promoting data literacy in science education (NGSS Lead States, 2013). Initiatives have continued to integrate data literacy into science classrooms through curricula that are embedded in students' contexts, tied to real-world problem solving, and focused on creating artifacts related to community issues using collaborative tools (Kjelvik & Schultheis, 2019). Bioinformatics is an ideal topic for this integration because it is a growing field that incorporates science and big data and has real world needs in the STEM workforce (Tractenberg et al., 2019). However, teaching with bioinformatics content is a complex endeavor (Machluf & Yarden, 2013) and science teachers' content knowledge and skills acquired from professional development (PD) often do not transfer to their instruction and result in a weak increase in student learning (Fischer et al., 2018). Thus, research has suggested that teachers must consider the expertise that is required in instruction, becoming not only technically competent working with data, but also responsive to students' diverse contexts and situations (Almerich et al., 2016). Therefore, teachers' decisions about how to be adaptive in their teaching constitute important information for PD researchers to use to understand how to best support the implementation of bioinformatics. In this study, we use an adaptive expertise lens to explore contrasting cases of how teachers were able to implement bioinformatics curricula in their environmental science classes. This study was guided by the following questions: (1) How is a teacher's adaptive expertise enacted?; and (2) How do teachers use resources to enhance their adaptive expertise?

Conceptual framework

Compared to routine expertise which refers to accomplishing familiar procedural tasks efficiently and accurately, adaptive expertise goes beyond the routine and is defined as being able to use knowledge and skills more flexibly to solve problems in new tasks (Corno, 2008). A study by Authors (2015) used an adaptive expertise lens to evaluate how teachers implemented curricula anchored in agent-based computational tools. They defined adaptive expertise through three characteristics. The first characteristics is *flexibility*, involving teachers' ability to change implementation plans and practices according to emerging issues in the classroom. The second characteristic is *deeper level understanding*, which is the ability to demonstrate a deep understanding of content and pedagogical knowledge as they use that knowledge more effectively to keep students engaged and help them advance to next level of learning. The third characteristic is called *deliberate practices*, a process in which teachers reflect on their instruction to improve teaching performance by first analyzing problems and then trying new approaches.

Method

For this early-stage exploratory case study, we selected two environmental science teachers who taught in two different schools in the Northeastern United States. The first teacher was Clara, who had 5 years of teaching experience and taught 10-11th grade environmental science in a school that was comprised of 99% minority or non-White students, all of whom were eligible for a free or reduced-price lunch. Vera, who had 11 years of teaching experience and taught 11-12th grade environmental science in a school that was comprised of 62% minority students and where 98% of the students were eligible for a free or reduced-price lunch. On the state standardized test, students scored as 26% and 35% as proficient in science respectively. A three-week summer PD workshop was designed to help teachers teach problem-based learning (PBL) curricula that included bioinformatics research, data literacy, and mobile learning. We ran the PD for 75 hours in July 2019. During the PD, the teachers learned the bioinformatics content and introduced to student-centered and community-centered approaches. The curriculum required a focus on solving air pollution problems related to asthma in their local area. Teachers also collaborated to revise and pilot tested curricular content that combined using tools for data collection and analysis tailored specifically to their local student context.

We used a multiple case study method (Yin, 2017) to provide a rich description of our participants' adaptive expertise. The three data sources used were: post-implementation semi-structured interviews; classroom observation notes; and the instructional materials used in each lesson. The semi-structured interview was conducted to probe the teacher's specific practices, beliefs, and understanding of implementing the new curricula, as well as the teacher's experience of preparing the class and participating in the project. The observation notes included descriptions of teachers' instructional practices. Instructional materials included the lesson plans and worksheets. With this data source, we gathered detailed information about the design of and reflection on the classroom activities. Transcriptions of the data sources were analyzed through an iterative mining of the data sources by the authors to identify the instances that would highlight the theme of teachers' adaptive approaches.

Findings

Adaptive Expertise: Flexibility

Overall, Clara demonstrated substantive adaptive expertise. For the *flexibility* category, Clara showed an ability to introduce the bioinformatics projects to students in a way that tied in well with the students' context. For instance, when starting the lesson on asthma, air quality, and bioinformatics, Clara was able to anchor the conversation in current events by using news articles on an explosion at [Blinded city] oil refinery that occurred two months before the class. With this example, she prompted students to think of the complex variables that interact with air quality and their impact on health by asking questions such as "what do you think [the event] did to the air quality for people who lived in that area? How did that affect them? What type of people live in that area?" This example shows that Clara could motivate students with topics that resonated with many of them by using real-world examples that were relevant to students' daily lives. On the other hand, Vera demonstrated less prominent adaptive expertise in her classroom implementation. Regarding *flexibility*, the observation notes showed evidence that she incorporated culturally situated approaches to the project activities, however, there were challenges to her content instruction. For example, one observation showed that she introduced asthma and air quality effectively to students by sharing her personal stories related to asthma and healthcare experiences (09/05/19). Vera was also able to encourage students to answer questions without giving them direct answers. However, when it came to the bioinformatics content, the necessary depth of connections between bioinformatics and the factors contributing to asthma was not evident. The observation notes stated that "there was a lot of info presented and I'm not sure the students really absorbed from just reading definitions on the slide" (09/19/19). This example shows that Vera allowed students to draw upon their own experiences and have discussion about asthma, which captured their interests, but the connection with the bioinformatics was not explicit enough and less situated. More details of findings and further discussions will be available in the larger paper.

References

Almerich, G., Orellana, N., Suárez-Rodríguez, J., & Díaz-García, I. (2016). Teachers' information and communication technology competences: A structural approach. *Computers & Education, 100*, 110-125

Corno, L. (2008). On teaching adaptively. *Educational Psychologist*, *43*, 161–173.

Fischer, C., Fishman, B., Dede, C., Eisenkraft, A., Frumin, K., Foster, B., Lawrenz, F., Levy, A, & McCoy, A. (2018). Investigating relationships between school context, teacher professional development, teaching practices, and student achievement in response to a nationwide science reform. *Teaching and Teacher Education*, *72*, 107-121

Kjelvik, M. K., & Schultheis, E. H. (2019). Getting messy with authentic data: Exploring the potential of using data from scientific research to support student data literacy. *CBE—Life Sciences Education*, *18*(2), es2.

Machluf, Y., & Yarden, A. (2013). Integrating bioinformatics into senior high school: design principles and implications. *Briefings in bioinformatics*, *14*(5), 648-660.

NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states.* Washington, D.C.: The National Academies Press.

Tractenberg, R. E., Lindvall, J. M., Attwood, T. K., & Via, A. (2019). The mastery rubric for Bioinformatics: A tool to support design and evaluation of career-spanning education and training. *PloS one*, *14*(11), e0225256.

Yin, R. K. (2017). *Case study research and applications: Design and methods*. Sage publications.

Yoon, S. A., Evans, C., Miller, K., Anderson, E., & Koehler, J. (2019). Validating a model for assessing science teacher's adaptive expertise with computer-supported complex systems curricula and its relationship to student learning outcomes. *Journal of Science Teacher Education, 30*(8), 890-905

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Addressing Students' Needs: Development of a Learning Analytics Tool for Academic Path Level Regulation

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Abstract: Development of learning analytics (LA) tools requires theory-based approach, careful implementation, and user-centred evaluation. In this paper we report on a two-stage user-centred and theory-based development and evaluation of a LA student tool. Results show that LA tool's support for different phases of self-regulation needs to be clearly differentiated and tested with students.

Introduction

Learning analytics (LA) development and implementation lack focus on students as the primary users and grounding in self-regulated learning theory (Tsai, 2020). Design and use of LA tools require careful consideration as LA has been shown to have both positive and negative impact, in some cases diminishing students' motivation and goal orientation (Lonn, et al., 2015) which is argued to be in connection with atheoretical approaches and low participation of users in the design of LA tools (Matcha, 2019).

To develop the LA tool for students we took a user-centred, theoretically grounded approach combining expertise of the multidisciplinary team. We grounded the development and evaluation of the LA tool in theory of self-regulated learning, which is described as consisting of four phases: Planning, monitoring, controlling and reflection (Pintrich, 2005). The aim was to create scientifically grounded, student-centred LA tool supporting self-regulated learning on the level of academic paths, referring to study periods and academic years. This is a novel approach in comparison to previous studies emphasizing LA use in course level. We present the development process, developed visualizations (Fig.1 and Fig.2), and students' feedback.

First, student needs were identified through recorded small-group conversations focusing on higher education academic paths and LA. Addressing self-regulation skills, students' needs for continuous overview of their progress and development on the academic path level and support for time management were the most prominent themes (Silvola et al., 2021). The first LA tool version, consisting of two visualizations, was developed, and tested in the context of academic advising conversations. The visualizations described student progression based on their personal study plans and student success within courses included in the plan. Student experiences showed that the LA tool made students' support needs more explicit and was especially useful for students experiencing difficulties in their studies (Hooli, 2020). The design and implementation of the LA tool was carried out by educational psychology and IT specialists and utilizing legal experts to identify and prevent possible data privacy risks. The second LA student tool version was developed with additional visualization aimed to support self-regulation. As visualizations of grades in the first version of the LA student tool resulted in mixed student experiences (Hooli, 2020), two new visualizations were added to give an overview of the progression on the academic path level, two on planned courses and credit distribution through time (two visualizations in the left upper corner), and one on distribution of attended courses across study fields.

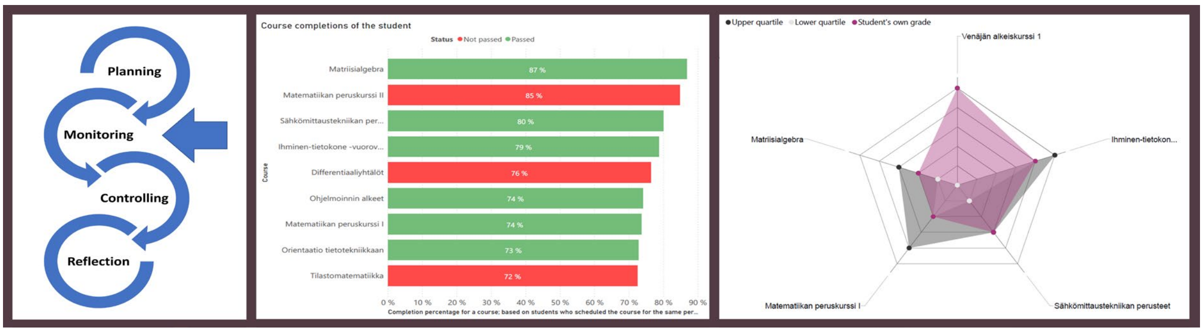

Figure 1. Visualizations in the first version of the LA student tool supporting phases of self-regulated learning.

Results and discussion

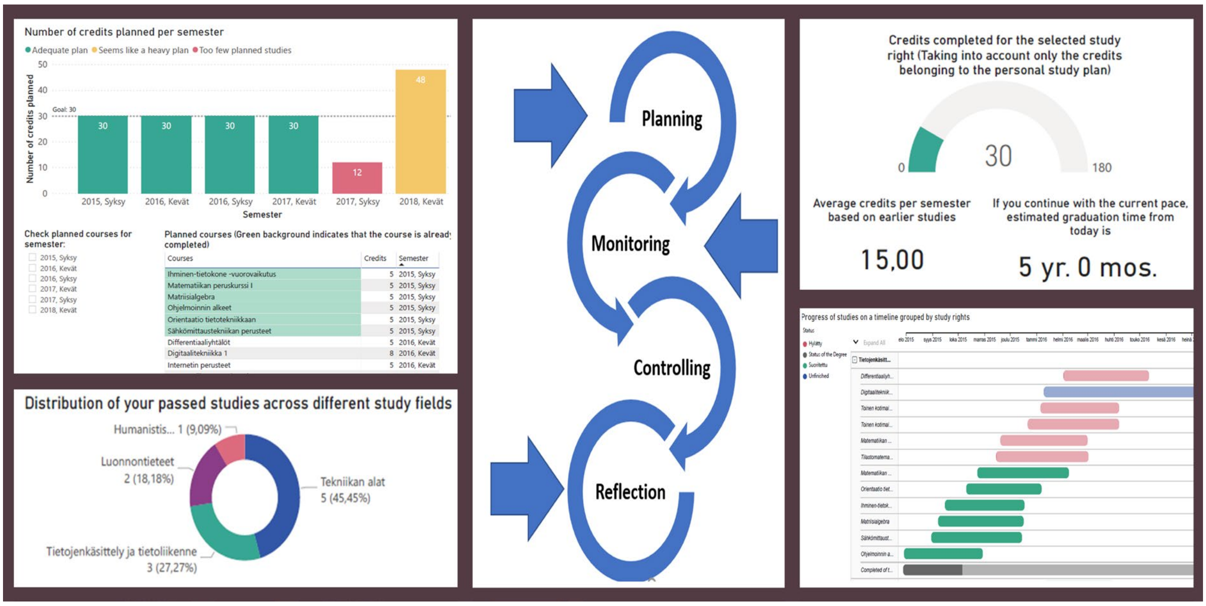

Figure 2. Visualizations in the second version of the LA student tool supporting phases of self-regulated learning.

Preliminary results indicated that students evaluated information about study plans (courses and credit distribution through time) and study progress (completed and not completed courses) as the most useful. Estimated graduation time and own grades were also evaluated positively. Comparative information (grades and course completion percentages of other students) remained controversial. Second version of the tool worked well to support students' study planning (goal setting and creation/revision of the study plan) and monitoring. On the other hand, the tool was less helpful for reflecting over the study behaviours and results or improving study habits.

This study showcases the ongoing research and implementation of theory driven, user-centred LA student tools in a higher education institution. Results show, that created LA tools must be carefully tested to understand if they serve their prescribed aims from the students' perspective. Further research is needed to better understand how the final version of the tool supports phases of self-regulated learning on the academic path level and what functionalities are useful for different students in comparison with regularly used tools.

References

Hooli, H. (2020). Students' experiences of learning analytics in academic advising for supporting self-regulated learning. Master thesis. University of Oulu.

Lonn, S., Aguilar, S. J., & Teasley, S. D. (2015). Investigating student motivation in the context of a learning analytics intervention during a summer bridge program. *Computers in Human Behavior, 47*, 90–97. https://doi.org/10.1016/j.chb.2014.07.013

Matcha, W., Gašević, D., Uzir, N. A., & Pardo, A. (2019). A systematic review of empirical studies on learning analytics dashboards: A self-regulated learning perspective. *IEEE Transactions on learning technologies, 13*, 1–20.

Pintrich, R. P. (2005). The role of goal orientation in self-regulated learning. In M. Boekaerts, et al. (Eds.), *Handbook of Self-Regulation.* (pp.451-502). Elsevier Science.

Silvola, A., Näykki, P., Kaveri, A., Muukkonen, H. (2021). Expectations for supporting student engagement with learning analytics: An academic path perspective. Manuscript submitted for publication.

Tsai, Y. S., Rates, D., Moreno-Marcos, P. M., Muñoz-Merino, P. J., Jivet, I., Scheffel, M., & Gašević, D. (2020). Learning analytics in European higher education—Trends and barriers. *Computers and Education, 155*.

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A Tale of Two PDs: Exploring Teachers' Experiences in Co-designing Computational Activities

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Abstract: At two professional developments (PDs), we position teachers as curriculum co-designers to support the integration of computing into traditional K-12 classrooms. Four case studies of teachers' successes and challenges over a four-week period showed that each teacher required differentiated support to address personal fears and concerns. Results suggest flexibility and team discussions may particularly support teachers in co-design and enhance future PDs focused on developing computational activities for students in the K-12 classroom.

Introduction

Much work advocates for integrating computational activities in traditional K-12 classrooms because such activities can provide students with authentic learning experiences, deepen learning of content, and increase equity in a future increasingly dependent on computing (Grover & Pea, 2013; Weintrop, et al., 2016). However, the integration of computational activities requires substantial support for teachers to adequately learn new skills and technologies (Kali, McKenney, & Sagy, 2015). Recent work addresses this issue by engaging teachers in collaboratively designing computational activities alongside researchers as a means of increasing teacher ownership and technological pedagogical content knowledge (Cober et al., 2015). Co-design positions teachers as subject matter experts, involves them in writing underlying code, and allows them to eventually build computational activities themselves. Given the diversity of co-design, more work is needed to understand how to support teachers as individuals while progressing towards a common goal (Chval et al., 2008; Kali et al., 2015). To this end, we investigate teacher experiences at two different summer institutes that provided PD through engaging teachers in collaborative design of computational activities with researchers. We examine teachers' challenges and successes as they co-designed computational activities over the four-week PDs.

Method

Two universities each conducted a four-week summer institute that positioned teachers as co-designers of computational activities for their students. University 1 paired 11 high school teachers from a large US Midwest city with researchers to co-design computational thinking (CT) activities in PD henceforth referred to as CTSI (CT Summer Institute). University 2 engaged three middle school teachers from the Intermountain West to co-design theory-building (TB) activities with one PI and four graduate students in PD henceforth referred to as TBSI (TB Summer Institute). Both PDs introduced computational activities and tools in the first week by asking teachers to explore models in existing CT or TB units and discuss how the activities in the units supported student engagement. The latter three weeks focused on co-design of new CT or TB units.

At CTSI, teachers worked on their units in small co-design teams by subject area with at least one CT researcher and undergraduate assistant. All 11 CTSI teachers met weekly for CT workshops and feedback sessions. We analyzed teacher responses on a Google Forms survey collected during a Weekly Reflection held on Fridays: "What went well for you or your work this week?" and "What was a challenge for you this week?"

At TBSI, the teachers and researchers met every morning for Scrum team-building sessions, and every Friday afternoon for a Weekly Reflection meeting. During both meetings, teachers responded to the questions: "What did you enjoy?" "What did you find challenging?" "What did you learn?" "What goals do you have?" "Do you have any feedback for improvement?" Meeting discussions were recorded, transcribed, and analyzed.

We identified teachers who developed computational activities each week and completed a unit by the end of the four-week PDs as well as teachers who struggled in one or more weeks in the co-design process.

Results

We highlight one teacher from each summer institute who was "successful" (Brooke and Mary, pseudonyms) or "struggled" (Evan and Rebecca) at our PDs. In Week 1, Brooke from CTSI and Mary from TBSI both felt "excited" about computational activities and integrating them into their classes. Yet, they both struggled in Week 2 when planning their unit. Brooke decided to reverse the sequence of her class activities, which took time. Mary originally felt she had to "know all of the things to make a simulation." Once her co-designer had built her model, her vision shifted to focus on the big ideas: "to build these models means you have to think of all the parameters and all the things that are interacting which can lead to some really big ideas and understanding." By Week 4, Mary was back to feeling "excited about the things I want [students] to pull out when the students do the model." Brooke took on building her own computational models with support from co-designers, making her "really proud of the unit coming together and of how collaborative it was" (Week 4).

In contrast, Evan (CTSI) and Rebecca (TBSI) faced various challenges when developing computational activities during the four-week PD. For Evan, his challenge in Week 2 was "[s]taying focused on working on [his] unit, really beginning to think what [he] want[s] the kids to get out of it." After more regular discussions with his co-design team, he started working on activities in Week 3, noting: "this unit is NOT going to be perfectly polished, finished by next Friday." By Week 4, he was "[w]orking with [his] co-design team to finalize most of [his] unit" which was completed in the fall. Early in Week 1, Rebecca expressed concerns with coding ("What have I gotten myself into? I'm diving in very scared because I don't code."), theory building ("This is the first time I have conceptualized what theory building means in the classroom. I have always thought that theory building is something someone else does and my job is to bring students to understand those theories."), and unfamiliar tools. She started developing activities, but by Week 4, she still did not have an understanding of her computational activities until a researcher developed a graphic novel ebook, which used a storytelling analogy to explain the process of building a computational model. Rebecca stated: "The ebook to explain coding is really good and I think it is helping me a ton! I was able to understand more about what is not right with my own blocks. I went back to the first model and felt way more confident." Her unit was completed shortly after the institute.

Discussion

Results showed that our teachers were able to ultimately integrate computational activities (and even design their own computational models!) through co-design. However, their progress drastically differed due to various challenges, including confusion about computing (Rebecca), staying focused (Evan), and concern over building computational models (Mary). Some teachers, such as Rebecca, face multiple obstacles that require additional resources and support. Such divergence in teacher progress and outcomes align with findings from prior research on co-design PDs, which showed diversity in teacher pathways (Naimipour et al., in press).

Co-design allowed us to address the different needs of teachers through individual adjustments and just-in-time resources during our PDs. Because K-12 teachers are often not trained in computational skills and may face fears about computing, we must address their individual needs, knowledge, skills and beliefs as learners and designers. With such qualitative understanding of individual needs and ways to support them, we can further develop PDs that center on building close relationships with teacher partners and address their challenges through co-design so that they can engage with and integrate computational activities in the K-12 classroom successfully.

References

Chval, K., Abell, S., Pareja, E., Musikul, K., & Ritzka, G. (2008). Science and Mathematics Teachers' Experiences, Needs, and Expectations Regarding Professional Development. *Eurasia Journal of Mathematics, Science and Technology Education, 4*(1), 31-43. https://doi.org/10.12973/ejmste/75304

Cober, R., Tan, E., Slotta, J., So, H. J., & Könings, K. D. (2015). Teachers as participatory designers: Two case studies with technology-enhanced learning environments. *Instructional Science*, *43*(2), 203-228.

Grover, S., & Pea, R. (2013). Computational Thinking in K–12: A Review of the State of the Field. *Educational Researcher, 42*(1), 38-43.

Kali, Y., McKenney, S., & Sagy, O. (2015). Teachers as designers of technology enhanced learning. *Instructional science*, *43*(2), 173-179.

Naimipour, B., Guzdial, M., Shreiner, T., & Allendale, M. I. (in press). Engaging pre-Service teachers in front-end design: Developing technology for a social studies classroom. In 2020 Annual Frontiers in Education Conference. IEEE.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology, 25*(1), 127-147.

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Improving Teacher Noticing of Students' Science Ideas with a Dashboard

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Abstract: We explore how a Teacher Action Planner (TAP) that synthesizes student ideas impacts teacher noticing. The TAP uses Natural Language Processing (NLP) to detect student ideas in written explanations. We compared teacher noticing while using the TAP to noticing when reviewing student explanations. The TAP helped teachers deepen their analysis of student ideas. We did not see any impact on immediate instructional practice. We propose redesigns to the TAP to better connect noticing to instruction.

Keywords: teacher noticing, natural language processing, NGSS, Knowledge Integration.

Introduction

Created in partnership with the Educational Testing Service, the Teacher Action Planner (TAP) uses Natural Language Processing (NLP) to summarize student ideas about science concepts. This summary and the recommended actions based on the student ideas are informed by Knowledge Integration and the NGSS. The TAP was implemented in the WISE Plate Tectonics unit for the first time to support teachers in reflecting on student ideas and planning their instruction (Zhai et al., 2020). This study focuses on investigating how the TAP supports teacher noticing of student's science ideas, as well as how recommendation actions might support teacher planning for distance learning.

The *Knowledge Integration Framework* outlines four processes that support students in developing scientific ideas. They include eliciting initial ideas, discovering new ideas, distinguishing between ideas, and revising their original perspective (Linn & Eylon, 2011). In this study, the TAP pretest report summarizes what ideas students are initially *articulating* at the beginning of the unit, which teachers can use to support their planning. The posttest report summarizes how students *revised* their initial ideas based on what they have learned from the unit and can help teachers to reflect on their teaching and student learning.

Methods

A TAP report was created for the item called Mt. Hood, which calls for students to link ideas about plate interactions and convection currents. We created rubrics to assess each student's explanation along three dimensions: *Knowledge Integration*, the DCI *ESS2.A Earth's Materials and Systems,* and the CCC *Energy and Matter* (Gerard et al, 2020). An NLP model was developed to automatically score student explanations the Mt. Hood Item (Riordan et al, 2020). The resulting model scored student responses with accuracy comparable to human-scorers (quadratic weighted kappa KI=.861, CCC= 0.836, DCI=0.763) and was then embedded into the Mt. Hood item to create a TAP. 'Recommended Actions' in the TAP were designed to help teachers use the summary of Mt. Hood scores to plan instruction and were based on an initial meeting with the lead teacher at the participating school.

We used a cross-case comparison study to examine how teachers used the dashboard. Four 7th grade teachers and their 504 students participated in this study. Two of the 4 teachers had access to TAP reports (Teachers 1 and 2) and two teachers had access to only logged student explanations (Teachers 3 and 4). This was the students' first unit of distance learning for Fall 2020. Teachers used a combination of WISE, Google slides, and Zoom.

Student data included student explanations on the Mt. Hood pre/post item. Each teacher was interviewed twice, after the pretest and again after the posttest. Interviews were analyzed using an emergent coding approach to find themes in teacher's noticing of student thinking, plans to adapt instruction, and their feedback on TAP design. Researchers observed synchronous Zoom classes to see how the teachers used the TAP or student explanations to adapt their instruction. Observation data was examined to discern similarities or differences between the teachers.

Results

The pretest interviews suggest that teachers in the TAP condition noticed more details about their students' ideas than those without the TAP. Teacher 1 noticed that students scored low on both NGSS standards. They wanted to look at the data in more detail, saying "*it would be nice if [the TAP] can figure out student misconceptions or incorrect ideas.*" They wanted more targeted information about individual students to identify which students to assist. Teacher 2 noticed differences in student ideas between their class periods. They noticed that one of their class periods scored low on both NGSS standards and remarked, "*This surprises me, because they talked about it last year.*" They also noticed that the majority of students in this same period were struggling "*in that integrating piece.*" In contrast, their other periods displayed a stronger understanding. Both teachers noted that the TAP's recommended actions affirmed their original plans. Teacher 2 said "*[The TAP] gives me a little bit of confidence to do what I was planning to do.*" Teachers without the TAP did not have these insights from examining the student explanations and did not dive deeply into student ideas during their interviews. For instruction, the teachers followed a similar, agreed-upon plan to implement the unit. The alignment among teachers and with their original plan meant there were few opportunities to adapt instruction.

During the post-interview Teacher 1 identified a key idea that their students had trouble with. Students "*were confused about heat transfer and density*" as it applied to convection currents. The teacher elaborated, "*[Students] moved from level 1 to 2 and 3 in DCI. In CCC they mostly just moved to 2 and not a lot of them moved to 3*." The teacher's observation was reflected in the average student scores in the posttest across all classrooms. Teacher 1 wanted to explore this data more closely by looking at individual student data but was unable to due to the current limitations of the TAP. They suggested this as an important area of improvement. Teacher 2 noted their students' growth from pretest to posttest. "*I see a lot more 2s and 3s as opposed to when we first started*." They again noticed the difference in student understanding between periods. "*It's clear my period B is struggling. They may need a little more structure and a lot more discussion time.*" They found this helpful for planning how they can support their different periods in the future. Teachers 3 and 4 did not mention either of these observations when they looked at their posttest student data. Teacher 3 mentioned that they would take a closer look at the data later when they input grades. Teacher 4 said they noticed an improvement but did not look into student explanations in detail.

Conclusions and implications

While previous studies with the TAP focus on teacher implementation of recommended actions (King Chen, 2020), this study brings to light key insights about how teachers use the dashboard to analyze student data. Teachers who had the TAP were able to deepen their understanding of ideas students were still missing and were able to identify differences in performance between class periods. Though informative, the recommended actions provided by the TAP did not prompt teachers to change their instruction. The next steps for refining the dashboard include adding more specific data on individual student NGSS aligned scores to deepen teacher noticing and more closely aligning recommended actions with the student data to help teachers deepen their analysis of specific student's data.

References

Chen, King J. (2020). Impact of autoscored student data reports on teacher instructional customizations for students' science learning. *international conference of the National Association of Research in Science Teaching (NARST),* National Association for Research in Science Teaching, 2020

Gerard, L., Wiley, K., Bradford, A., King Chen, J., Breitbart, J., & Linn, M. C. (2020). Impact of a Teacher Action Planner that Captures Student Ideas on Instructional Customization Decisions. Paper presented at the Annual Meeting of the International Conference of the Learning Sciences, Nashville, TN.

Linn, M. C., & Eylon, B.-S. (2011). *Science Learning and Instruction: Taking Advantage of Technology to Promote Knowledge Integration.* New York: Routledge.

Riordan, B., Cahill, A., Chen, J. K., Wiley, K., Bradford, A., Gerard, L., & Linn, M. C. (2020). Identifying NGSS-Aligned Ideas in Student Science Explanations. Paper presented at the Thirty-Fourth AAAI Conference on Artificial Intelligence, New York, NY. Awarded (AI4EDU)

Zhai, X, C. Haudek, K, Shi, L, H. Nehm, R, Urban-Lurain, M. From substitution to redefinition: A framework of machine learning-based science assessment. J Res Sci Teach. 2020; 57: 1430– 1459. https://doi.org/10.1002/tea.21658

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Collaboration and Peer Social Relationships: The Role of Friendships in Middle School Inquiry Science

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Abstract: Early adolescent learners in inquiry-based science learning environments must grapple with regulating group activity as well as the socioemotional challenges of collaboration. The current study early adolescents' understandings of the role of peer social relationships and friendships in collaboration in middle school inquiry classrooms. We qualitatively analyzed end-of-semester interviews with 32 seventh grade students who participated in a semester-long series of inquiry units. Results suggest that early adolescents view peer relationships and friendships primarily as beneficial resources to support self-regulated learning and minimize the impact of competence and peer group concerns on learning, while friends were seen as particularly helpful for smoothing group interactions and promoting cohesion. Further, early adolescents distinguished between types of friends, with a focus on friends who would support group functioning. Specific to argumentation and explanation as scientific practices, early adolescents viewed peers as an important source of alternative perspectives and explanations.

Introduction

Reform-oriented science curricula leverage collaboration as an avenue for rich opportunities to learn through productive disciplinary engagement and inquiry. Yet, learners can struggle to effectively regulate group activity in addition to struggling with scientific practices like argumentation and explanation (Berland & Lee, 2012; Kuhn, 2020). Developmental science research has addressed the central role of peer social relationships and friendships during adolescence. This literature distinguishes between peer relationships generally and friendships specifically: friendships are positive, strong bonds between people and friends use their relationship to achieve socioemotional goals. Peer relationships and friendships both are also related to self-processes, as information from these relationships informs academic self-concept and self-esteem through social comparisons and self-evaluations (Bukowski & Raufelder, 2016). Further, research on status problems in the classroom has highlighted how early adolescents rely on peer status orders, or popularity-based hierarchies, which operate alongside academic status orders at the middle school level (Lloyd & Cohen, 1999). Finally, some findings suggest benefits to working with friends over acquaintances for problem-solving accuracy on difficult variable isolation problems (Azmitia & Montgomery, 1993). In sum, mitigating challenges to high-quality collaboration in inquiry-based science classrooms likely will require attention to peer social relationships and friendships. The present study examined the following question: how do early adolescent learners understand the role of existing peer relationships and friendships in collaboration in inquiry-based science?

Method

Participants came from four 7th science grade teachers' classrooms participating in inquiry-based science curricular units over the course of a semester. Curriculum units focused on life science topics such as genetics, evolution, and cells. The units were designed to promote reasoning and argumentation; lessons were collaboration-intensive. Data for the present study were collected from transcribed semi-structured interviews with the 32 student interviewees. Mean interview length was 18 minutes, with some interviews lasting as long as 30 minutes. Students were asked about their perceptions of group processes and inclusivity of interactions within groups. Two interview prompts were identified as relevant to the present research question: 1) "In what ways, if any, do you benefit from learning with your classmates in a group in science class?" (Follow-up: "What have you learned that you might not have learned if you had worked independently?") and 2) "Do friendships contribute to how well the group works together?". The authors developed a coding scheme using 10% of the sample and coded the remaining interviews. Frequencies were calculated for the number of students receiving each code.

Results

Frequencies for the themes identified can be seen in Tables 1. Among all of the themes discussed by students, themes referring to pre-existing peer relationships and friendships as beneficial were typical. A theme that did not reflect a clear benefit or disadvantage of pre-existing peer relationships and friendships was Effortful and Useful Contributions Overriding Role of Friendship (22%).

Table 1: Advantages and Disadvantages of Peers & Friends – Frequencies

Theme	Frequency	Percentage
Exchange of Ideas & Alternative Perspectives from Others	25	78%
Content Knowledge Development & Self-Explanation	14	44%
Social Skill Development & Perspective Taking	12	38%
Group Cohesion	11	34%
Help Receiving	10	31%
Task Distraction	7	22%
Social Anxieties - Peer Group Concerns & Shyness	5	16%
Risk of Exclusion/Unfair Consideration of Ideas	5	16%
Social Anxieties Competence Concerns	2	6%
Too Few Perspectives/Skill Sets	1	3%

Interview excerpts indicated differences in the role of friends versus peers. Peers were seen as valuable resources for learning through the exchange of ideas and receiving explanations, providing support for self-regulated learning processes, and offering opportunities to learn from mistakes. Learning with peers raised concerns about appearing competent and fitting in, but collaboration itself somewhat alleviated those concerns. Friends' presence reduced the burden of managing social interactions during collaboration, partially by alleviating social anxieties and counteracting shyness. Students noted the value of friends for ensuring one's ideas are heard during collaboration.

Discussion and conclusion

Taken together, the results presented here indicate that early adolescent learners view peers as promoting sufficient consideration of counterarguments, supporting self-regulated learning processes such as monitoring, and providing opportunities to learn from mistakes. Further, they see friends in particular as offering socioemotional protections that enhance motivation. Learners valued friends who would make good collaborators; and recognized the importance of friends for helping reduce the negative impact of academic status hierarchies. Further, Exchange of Ideas & Alternative Perspectives from Others was the most referenced benefit of collaboration, with over 75% of students discussing it. Science education researchers note important distinctions between arguments and explanations (Berland & McNeill, 2012; Osborne & Patterson, 2011), but the adolescents in the present study spoke in somewhat generic ways about what exactly was being exchanged. Future research should aim to clarify what observed discursive moves are reflected in learners' conceptualizations of "sharing ideas". Interventions to promote adaptive outcomes considering learners' motivational concerns should aim to preserve beneficial classroom social practices like collaborative argumentation.

References

Azmitia, M., & Montgomery, R. (1993). Friendship, transactive dialogues, and the development of scientific reasoning. *Social Development*, *2*(3), 202–221. https://doi.org/10.1111/j.1467-9507.1993.tb00014.x

Berland, L. K., & Lee, V. R. (2012). In pursuit of consensus: Disagreement and legitimization during small-group argumentation. *International Journal of Science Education*, *34*(12), 1857–1882.

Berland, L. K., & McNeill, K. L. (2012). For whom is argument and explanation a necessary distinction? A response to Osborne and Patterson. *Science Education*, *96*(5), 808–813. https://doi.org/10.1002/sce.21000

Bukowski, W. M., & Raufelder, D. (2018). Peers and the self. In W. M. Bukowski, B. Laursen, & K. H. Rubin (Eds.), *Handbook of Peer Interactions, Relationships, and Groups* (2nd ed., pp. 141–156). Guilford Publications.

Kuhn, D. (2020). Why Is Reconciling Divergent Views a Challenge? *Current Directions in Psychological Science*, *29*(1), 27–32. https://doi.org/10.1177/0963721419885996

Lloyd, P., & Cohen, E. G. (1999). Peer Status in the Middle School: A Natural Treatment for Unequal Participation. *Social Psychology of Education*, *3*(3), 193–214. https://doi.org/10.1023/A:-1009609126635

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction? *Science Education*, *95*(4), 627–638. https://doi.org/10.1002/sce.20438

Curricular Mechanics for Motivation

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Abstract: We propose *curricular mechanics for motivation* as a mechanism by which educators might counteract curriculum violence perpetrated on students at the level of curricular design. We ground our discussion of these curricular mechanics in gameful learning principles and self-determination theory (SDT) (Deci & Ryan, 2002). We outline six examples of such mechanics, drawn from syllabi from courses taught at a large public R1 university.

Introduction

Curriculum violence, when enacted curriculum compromises learners' intellectual or psychological well-being (Ighodaro & Wiggan, 2010), remains under-attended to at the level of curricular design. Curricula are often designed with (well-intended) coercion in mind: how can we get students to comply with our expectations for how they should learn and demonstrate both effort and progress? We contend this violence is often perpetrated along racial and socioeconomic lines in schools typically denied adequate funding and adequately prepared faculty through systemically unjust institutions. One framework for confronting this problem is gameful pedagogy, which proposes that by creating space for learners to have agency within the classroom and designing curricula to support student motivation, we can collectively begin to address the historical structures that have led to curriculum violence. We introduce *curricular mechanics for motivation* as a theoretical framework and design mechanism for attending to these concerns.

Games-inspired learning

Interest in games for learning has remained high across the last two decades among scholars and practitioners. A popular misconception of Gee's (2003) seminal work in the field, however, is that games are the only context in which the principles of engagement he outlined are applicable. This misconception has led to a proliferation of games designed for classroom use, while the empirical evidence for their effectiveness remains mixed (Gee, 2011). *Gameful learning* (Hayward & Fishman, 2020), in contrast, takes up Gee's fundamental proposition: that good games are designed with powerful learning principles at their heart, and that these principles could be applied more to learning environments of all sorts outside of games. We build on this work here by discussing gameful learning design in greater detail through the lens of game mechanics.

Curricular mechanics (for motivation)

Our conception of curricular mechanics relies on a framing of school itself as a game–albeit a poorly designed one. Simply put, game mechanics are the ways players take action within the game world to pursue goals. Players see and make sense of the game world in terms of verbs, or what they can do as part of gameplay (Gee, 2015). *Curricular mechanics*, then, are mechanisms by which learners can take action within the curriculum. Traditional curricular designs typically constrain learners' choices: go to class, or do not; complete and turn in assignments, or do not; study for the midterm and final, or do not. Gameful pedagogy contends that designing more curricular agency for students increases intrinsic motivation, yielding a variety of positive outcomes from increased learning, reduced academic anxiety, more creative work, and more collaborative engagement (Hayward & Fishman, 2020).

When describing curricular mechanics for motivation, we mean the pedagogical structures by which learners are given control to select both their learning goals and the pathways they will travel in pursuit of those goals. For the purposes of this proposal we focus on curricular mechanics through the lens of SDT, which highlights three pillars essential to experiencing intrinsic motivation: autonomy, belongingness, and competence.

Examples of curricular mechanics for motivation

Table 1 outlines six example curricular mechanics designed into undergraduate course syllabi at a large American public R1 university, including the gameful learning principles grounded in SDT they embody.

Table 1: Example curricular mechanics

	Description/Example	Autonomy	Belongingness	Compe tence
Difficulty levels	Assignments descriptions include information about what knowledge is necessary to be successful, and recommendations for alternative assignments are available if students would like to learn/practice necessary skills in advance.	X		X
Multiple paths to success	Students start with zero points and build up, and more points/assignments are available than needed for full credit, meaning poor performance at any point along one pathway does not close other pathways to success.	X		X
Assessment choice	Students are empowered to decide what medium (e.g., essay, blog, vlog, creative effort) they wish to use to show mastery.	X		X
Team competitions	Students are placed in teams, and at strategic points throughout the curriculum these teams compete together in topical challenges.		X	X
Clear and forgiving late work policy	Instructor designs a clear policy on late work that includes latitude, encouraging students to make choices that privilege their own socioemotional health, which communicates that they are valued as a human.	X	X	X
Assessment weighting	Students choose to what degree (%) specific assignments will count towards their grade. This lowers consequences for failure, encouraging risk-taking.	X		X

Discussion

We view the work we have herein in two ways: (a) as a design framework, and (b) an analytic framework. First, we contend curricular mechanics for motivation specifically is a useful tool to aid educators as they design course mechanisms with their learners' humanity front of mind. Second, we envision future work in which curricular mechanics may be leveraged as a broader analytic lens for making sense of the interplay between curricular designs and learners, with interaction forming the catalyst between them.

References

Deci, E. L., & Ryan, R. M. (2002). *Handbook of self-determination research*. University of Rochester Press.

Gee, J. P. (2003). *What video games have to teach us about learning and literacy*. Palgrave MacMillan.

Gee, J. P. (2011). Reflections on empirical evidence on games and learning. In S. Tobias & J. D. Fletcher (Eds.) *Computer games and Instruction* (pp. 223-232). Information Age Publishing.

Gee, J. P. (2015). *Unified discourse analysis*. Routledge.

Hayward, C., & Fishman, B. (2020). Gameful learning: Designing with motivation in mind. In *Interdisciplinary of the Learning Sciences, 14th International Conference of the Learning Sciences (ICLS), Volume 2* (pp. 1007-1014). International Society of the Learning Sciences.

Ighodaro, E., & Wiggan, G. A. (2010). *Curriculum violence: America's new civil rights issue*. Nova Science.

Expanding How We Record and Report Learning: Exploring Employers' Perspectives

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Abstract: This paper presents employers' perspectives on how they make sense of students' cognitive, non-cognitive, and technical ability utilizing data from resumes, academic transcripts, and various interview techniques. Employers' perspectives on a skill-based transcript as a tool for hiring are also reported. The findings inform the design of future assessment and credentialing infrastructures, with the goal of expanding how knowledge and ability are measured and defined in higher education.

Introduction and theoretical framework

This paper reports on the first study within a larger effort to reshape undergraduate education in a U.S. research university around twenty-first century learning outcomes and problem solving, instead of traditional course sequences. The purpose of the study reported here is to understand the broader implications of this larger effort as it relates to the recruitment and hiring practices of companies likely to employ graduates of the proposed program. A key feature of this program is a shift from summative information such as letter grades and grade point averages (GPAs) to mastery-based assessment for learning. This summative information makes up the underlying and often-unquestioned infrastructure of what is considered "normative" in education (Star & Ruhleder, 1996). Additionally, research on skill assessment finds "potentially important non-academic skills" are not well understood through summative information (Stasz, 2001, p. 393) and research on hiring suggests summative information contributes to subjective evaluations of ability through processes of cultural matching (e.g., Rivera, 2012). How would shifting to mastery-based reporting of knowledge and ability affect the ways that companies identify and select potential employees from among college graduates? To address this question we interviewed recruiters and hiring managers (hirers) to understand how they currently make sense of the information they have about students and sought their perspectives on the challenges and opportunities of implementing a mastery-based learner record as an information tool for recruitment and hiring. By exploring new infrastructures for communicating about knowledge and ability, we hope to understand designs for assessment infrastructures that are better able to account for twenty-first century learning outcomes rather than "master narratives" of school success (Penuel, 2019).

Methods

We recruited twelve participants from organizations that employ graduates of an existing pre-professional bachelor's degree program in a U.S. research university. Participants were selected to represent a broad range of organizational types and represented consulting, financial services, manufacturing, and consumer goods and services companies. Recruitment, interviews, and analyses were conducted iteratively, and recruitment proceeded until it was felt that no new information was being gained.

Interviews were conducted via videoconference, lasting roughly one hour. Topics focused on: (1) The participant's position within their organization, (2) The stages of the hiring process in their organization, (3) The factors shaping their approach to recruitment and hiring, and (4) The specific information sought at each hiring stage. At the end of each interview, participants were presented with an example of a comprehensive learner record (CLR) and asked for their reaction and thoughts about what role(s) it could play in their hiring process. In recent years, CLRs have emerged as an information tool for representing mastery-based learning outcomes (Shendy et al., 2019, January 20). The CLR presented to hirers represented learning outcomes in terms of complex cognitive, interpersonal, and intrapersonal skills rather than grades or test scores.

All interviews were transcribed and coded using content analysis and grounded theory to reduce the data to emergent themes and patterns. Interview transcripts were reviewed until no additional themes were found. Findings are represented as participants' experiences with applicant evaluation and educational information within the labor market for entry-level positions.

Findings

Participants indicated hiring is supported by the establishment of talent pipelines – trusted recruitment infrastructures that can include formal partnerships with academic programs and instructors, informal meet-and-greets, and recruitment fairs. Decisions on where to establish pipelines are informed by historical data on current employees, institutional reputation, and curricula. This indicates hirers are looking for scalable ways to develop talent pipelines but may rely on potentially subjective insights into knowledge and ability when deciding where to establish them.

In terms of how summative information is used in hiring, hirers indicate they use summative information as a solution to a data management problem - the sorting and screening of large volumes of applications. The perception that transcripts have poor informational value also often leads to practices of contextualizing information to understand applicants' knowledge and ability; a common example included looking at grade trends to determine if a student was competent in a subject. Interview techniques such as case studies and technical assessments were generally more trusted as a means of understanding knowledge and ability. Case study challenges provide a way of "seeing" cognitive skills in action such as problem solving or critical thinking. A student's reflection on their work portfolio provides an opportunity to demonstrate metacognitive skills and familiarity with a community of practice. While these interview techniques can have a significant impact on a hiring decision, they are not employed until after students have been screened through a review of their resumes or transcripts. Hirers want better representations of students' knowledge and ability as they believe many potentially qualified applicants are screened out of the application process based off of the information contained in their transcripts and resumes.

Reactions to the CLR presented to the participants were generally positive. Participants saw them as useful for presenting verified claims of a student's knowledge and ability and efficiently finding the information they looked for when evaluating applicants. One participant likened them to a LinkedIn page, but with the added benefit of being verified by the college. This demonstrates that new representations of students' abilities are unlikely to be utilized without verification, a key role that colleges can play. Participants who already review portfolios of student work drew parallels between portfolios and CLRs. This is listed as an opportunity because it demonstrates that practices required to review CLRs already exist in some form already. One challenge that emerged in the interviews involves developing representations of complex behavioral skills that are interpretable and believable. For instance, how would evidence about "teamwork" be represented? However, the interview data also reveals that current approaches require hirers to make inferences based on limited information. One solution might be to conceptualize CLRs as a tool for comparing different strengths among applicants rather than as an objective ranking or scoring of twenty-first century learning outcomes.

Implications and conclusion

Innovations in higher education are more likely to succeed if learners perceive them as supportive of their goals; in the case of this work, the goal of finding a desirable first post-graduation job. By studying the explicit and implicit infrastructures that undergird learning and the representation of learning, learning scientists can provide evidence-based guidance for new forms of reporting systems and formats to better align our educational goals with the perceived needs of participants in the system. In the case of the current study, those participants are hiring organizations. The demand for students with twenty-first century knowledge and abilities is hindered by current representations of learning, which in turn hinder the design of educational programs and courses. Expanding the range of ways we describe and document learning also has implications for making educational systems and paths to employment more equitable. This study is a step towards more meaningful assessment and reporting infrastructures.

References

Penuel, W.R. (2019). Infrastructuring as a practice of design-based research for supporting and studying equitable implementation and sustainability of innovations. *Journal of the Learning Sciences, 28,* 659-677.

Rivera, L.A., (2012). Hiring as cultural matching: the case of elite professional service firms. *American Sociological Review, 77*(6), 999-1022.

Shendy, J.E. (2019, January 23). *7 Things you should know about the comprehensive learner record.* EDUCAUSE Learning Initiative (ELI). https://library.educause.edu/resources/2019/1/7-things-you-should-know-about-the-comprehensive-learner-record.

Star, S.L. & Ruhleder, K. (1996). Steps toward an ecology of infrastructure: design and access for large information spaces. *Information Systems Research*, *7*(1), 111-134.

Stasz, C. (2001). Assessing skills for work: two perspectives. *Oxford Economic Papers, 53*(3), 385-405.

International Society of the Learning Sciences

Why Robots?: Historicizing Engineered Imaginaries and Coded Visions of Learning

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Abstract: The inclusion of robots, robotics kits, and other automated tools and apps in educational settings leads us to consider hidden assumptions and implicit theories that robots encode. This paper draws critical attention to advances in automation by examining two current uses of robots in learning designs. Drawing on recent ideas in STS (Suchman, 2011) and Critical Code Studies (Benjamin, 2019), we analyze two categories of automated agents- competitive robots built by youth and coding robots used by young children.

One way of reflecting on the past and recalling the history of the learning sciences is through the field's origins in cognitive science and computing. Learning sciences inherited theories of learning from cognitive science's computational model of the mind as an information processor (Collins et al., 1978). Likewise, computer scientists and engineers have applied models of human intelligence to machines to develop devices that learn or that automate learning (Hayles, 2005). These mutual processes of designing learning and designing technologies have built automation and AI into the mainframe of our field. A consequence of the close relationship between learning sciences and robotics is that automation is accepted, well, automatically. This paper explores the questions: *why robots here, in education?* And *why robots, now at this particular historical moment?* Drawing on STS perspectives (Suchman, 2011) and recent advances in Critical Code Studies (Benjamin, 2019), we focus on two types of robots used in learning environments: *competitive robots*, which are built by students and used in robotics competitions and commercially available *coding robots* used to teach programming to young children.

Engineered imaginaries and coded visions of learning

All technologies encode human values, a point that is not lost on STS scholars (Suchman, 2011), but has yet to make it into the mainstream concerns of critically minded scholars of educational technology. While there have been some attempts to open the black boxes of learning technologies (e.g. Lachney & Foster, 2020), there is still much work to do to make AI more transparent for learners and to make visible how inequity gets encoded. If, as Benjamin (2020) incisively said, "most people have been forced to live in somebody else's imagination", how then are robots implicated in engineering inequitable imaginaries? And how are educational settings reproducing the "default settings", even as we design for learning that disrupts or resets established inequities? Robot designs are based in theories of human learning and behavior and often tested on young children, who have been model organisms for AI (Fox Keller, 2007). As robots and automated tools become regular fixtures in learning environments, it is important to consider what theories of learning and axiological assumptions they import and reproduce. As Firth and Robinson (2020) wrote, "there is also an element of futurology in mapping the field [of robot-human relations] because epistemologies prefigure technology creation" (p.12). Robot imaginaries mobilize future-oriented narratives of science fiction and speculative fantasy and animate utopian dreams of engineering a better future as well as dystopian notions of destruction (Richardson, 2015). We wonder what that means for education. Whose future does this help make?

Case 1: Coding robot toys

Coding robots respond to computer science standards and computational thinking frameworks that support learning to program for children as young as Kindergarten age (e.g. Silvis et al., 2020). Their cute construction and affordable price point make commercially available coding toys common features in today's early learning settings. The progenitor of these tools was Papert's (1980) tangible programming floor turtle, the literal embodiment of his "objects to think with," a "relational artifact" designed to support "epistemological pluralism" (Lachney & Foster, 2020). When such toys are used to teach computational thinking and other "21st century skills," we might wonder just what kinds of human-robot relations they support, what worlds they help to make, and what imaginaries they engineer and reproduce. We get some sense of these relations from Evelyn Fox Keller (2007) in "Booting Up Baby," where she describes the recursive reliance of children on robots and robots on children when it comes to thinking computationally. "For whom" and "to what ends" are good questions to ask about these designs and the futures they inspire (Philip et al., 2018). Designers of learning and technology should also recall "from whom" these designs originate and "on whom" they are modeled. Whose babies are we booting up when we bring robots into early learning environments? Who is now being asked to live in those imaginations?

Case 2: Cooperative-competitive robots

Robotics competitions have dramatically increased over the past 20 years across the K-12 educational landscape. FIRST Robotics is a leader in managing and organizing youth robotics competitions, with divisions that span PreK to high school-aged children (FIRST Robotics, 2020). The logic of these competitions has epistemological foundations in constructivism (Lachney & Foster, 2020). Individual teams cooperate to engineer robots with a weight limit of 120 pounds that compete in the highest division. Robot designs are constrained by competition rules, which are remade and unveiled at the beginning of each year. Starting with the competition in mind means that the robot is always under construction over the course of the season. The final robot is therefore a dynamic collective imaginary of the team of youth, mentors, and coaches. For the majority of youth, the robot itself is not the learning technology; rather the team's iterative use of tools, machines, design software and programming ultimately make the robot operate. The robot is a symbolic vision of the relationships between humans and machines (Richardson (2011). Competitions are enmeshed with complex spatial politics around gender and race (Hennessy Elliott, 2020) and relatedly class, as certain teams obviously spend more money on their operations than others. We wonder what relationships emerge between the under-construction robot and the youth participants. What kinds of futures are robots helping to inhabit?

Discussion and significance

Benjamin's (2019) characterization of "the new Jim Code" cautions us to remain critical of how robots, as social and technological systems, might further encode future injustices. Whereas Suchman (2011) asked what figure of the Human is enacted in the design of humanoid robots, we wonder what futures are prefigured by engaging with robots in educational settings. In the case of coding robots, children are both the basis for and target of human-robot interactions. In the case of competitive robots, the robot is always under construction and the team is imagined as a collaborative community, where team culture is a means and outcome of design. Within each, there is also a hidden intent of educational designs that aligns: contributing to future industrial development as part of a skilled workforce which can program (coding robot and cooperative-competitive robot) and collaboratively design, engineer, and program mechanisms capable of addressing problems. We challenge educators and researchers to make opportunities with children and youth to critically engage with the histories of these educational designs and the futures- and learners- that they engineer and help us imagine.

References

Benjamin, R. (2019). *Race after technology: Abolitionist tools for the new Jim Code.* Polity Press.

Collins, A., Brown, J. S. & Harris, G. (1978) Artificial intelligence and learning strategies. In H. F. O'Neil (Ed.), *Learning Strategies* (pp.107-139). New York: Academic Press.

Hayles, N.K. (2005). Computing the human. *Theory, Culture & Society 22*:131-151.

Hennessy Elliott, C. (2020). "Run it through me:" Positioning, power, and learning on a high school robotics team. *Journal of the Learning Sciences*, *29*(4–5), 598–641.

Firth, R. & Robinson, A. (2020). Robotopias: mapping utopian perspectives on new industrial technology. *International Journal of Sociology and Social Policy,* 0004.

Keller, E.F. (2007). Booting up baby. In J. Riskin (Ed.), *Genesis Redux: Essays in the History and Philosophy of Artificial Life.* University of Chicago Press.

Lachney, M. & Foster, E.K. (2020). Historicizing making and doing: Seymour Papert, Sherry Turkle, and epistemological foundations of the maker movement. *History and Technology, 36*(1), 1-29.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* Basic Books.

Philip, T., Bang, M., Jackson, K. (2018). Articulating the "how," the "for what," the "for whom," and the "withwhom" in concert: A call to broad the benchmarks of our scholarship. *Cognition & Instruction 36*(2).

Richardson, K. (2015). *An anthropology of robots and AI: Annihilation anxiety and machines.* Routledge.

Silvis, D., Lee, V., Clarke-Midura, J., Shumway, J., & Kozlowski, J. (2020). Blending everyday movement andrepresentational infrastructure: An interaction analysis of Kindergarteners coding robot routes. In M.Gresalfi & L. Horn (Eds.), *Proceedings of International Conference of the Learning Sciences.*

Suchman, L. (2011). Subject objects. *Feminist Theory, 12*(2), 119-145.

Gesture-Based Representational Challenges for Learning Science with Mixed Reality Technologies

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Abstract: Studies on gesture-based learning environments show that student science learning is enhanced by gesturing, but few studies describe students' challenges using gesture-augmented technology for learning. I examined students' representational challenges when using a gesture-augmented simulation to learn thermal conduction. Using grounded coding to analyze three middle school students' videos using the simulation, operational and conceptual challenges emerged as pertinent factors impacting their sensemaking. Implications and suggestions for further research follow.

Interest in designing gesture-based digital environments is growing as studies show gesturing shapes students' thinking, learning, and communicating (Church & Goldin-Meadow, 2017). Comprised of a class of embodied Mixed Reality learning environments, gesture-based technology has been shown to enhance student learning (Abrahamson et al., 2020). However, gesturing about scientific concepts in augmented contexts is a novel experience for many students leading to new sensemaking challenges. For gesture-based technology to support student science learning, there is a need to understand what challenges they experience when using gesture-augmented technologies and what instructional supports can support their smooth adoption and engagement with the tool to enhance scientific inquiry.

In this study, I explored students' representational challenges using a gesture-augmented computer simulation to explain thermal conduction to understand how their actions around representing molecules in the computer simulation through gesture impacted their conceptual understanding. The simulation (Figure 1) depicts a molecular model of a spoon with temperature gauges on both ends of the model. A student makes a fist over Leapmotion™ to depict a block of molecules. Wiggling the fist makes one block of molecules (indicated by green color) vibrate faster and the adjacent gauge to show temperature rising. In this way, a student uses a conceptually-congruent gesture (Segal, 2011) to run the simulation and see heat transfer occurring at the molecular level.

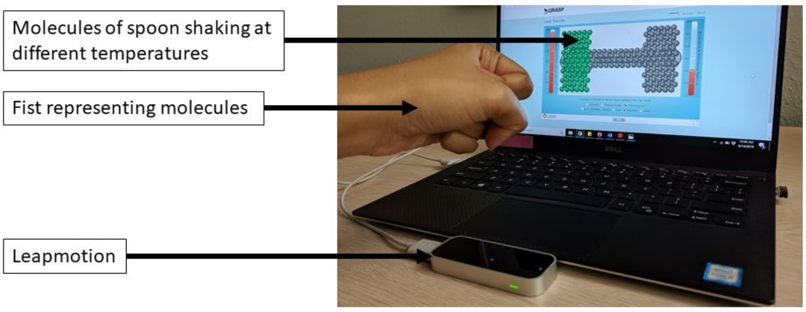

Figure 1. A user shaking their fist to make the left block of molecules shake and the temperature to rise.

Methods

To explore students' interaction with the simulation, I examined video data from a design-research project developing gesture-augmented computer simulations for various physical science topics. In each video, a student was interviewed using the simulation to explain heat transfer through molecular motion. Three eighth-grade students were selected from the data corpus for a case study. These students were selected considering differences in how they made sense of gesture augmentation and the mechanistic nature of their final explanations. Using methods of grounded theory, video was coded for how each student talked about gesture-augmentation. Two kinds of codes emerged, capturing student sensemaking around the *operational* and *conceptual* dimensions of gesturing. These codes were applied to student talk across the length of time of simulation use to explore temporal patterns between codes and the mechanistic nature of their explanations. Preliminary insights from this coding follow.

Findings and discussion

Grounded coding showed two ways students addressed gesture-augmentation while constructing explanations of heat transfer. The first was *operational* and was related to ways they thought gesturing controlled the simulation.

For instance, when Avondre (all names are pseudonyms) used the simulation, he stated, "When I move my fist more, the molecules will move more." This kind of talk showed Avondre establishing the intended understanding of gesture control, but it was also used to capture moments of alternate understandings. For instance, Janine talked about a difference in control between her left hand and her right hand. She explained that "I have more control, I guess, so with this hand [her left hand]. So, it probably was easier for me to shake it and have it go higher instead of this one because it'll lose this one [her right hand]." In this way, this code captured different ways students saw how their gesturing controlled the simulation and it signaled when the gesture became salient to them during their time with the simulation.

The second code addressed the *conceptual* connections students made regarding the representation of gesture in this context. This code indicated when students attended to their hand as representing molecules in the simulation. For instance, Avondre clearly articulated the conceptual connection twice. He first addressed it when introduced to gesture control, and he later stated it again in conjunction with a mechanism for heat transfer by saying, "when I bump my fists together, it represents the green molecules right there, and it bumps into all of them which creates a chain reaction of bumping…" On the other hand, Janine offered a different conceptual connection by saying, "maybe [my fist is] the spoon, like the molecules of the spoon or something. Like, maybe this represents the bowl of it and then like my arm represents the spoon?" In this way, this code indicated when students began appropriating the simulation's gesture as part of a molecular model of heat transfer.

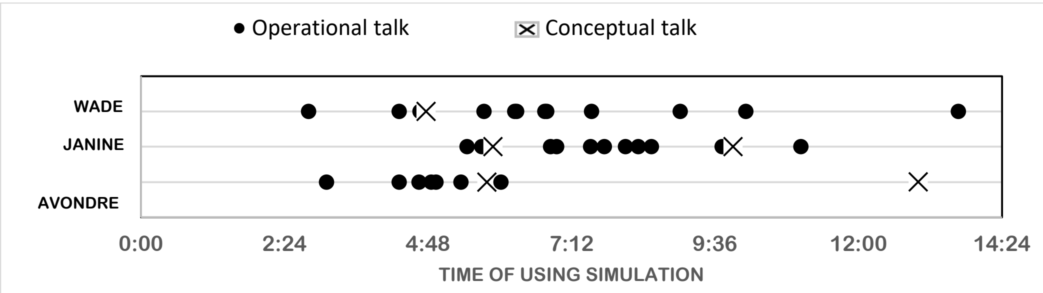

Figure 2. A timeline depicting student talk about gesture while using the simulation.

Finally, for temporal patterns, I plotted each student's code on a timeline and examined the frequency and timing of gesture talk (Figure 2). The plot shows that Wade addressed more operational aspects of gesture while Avondre and Janine addressed a few more conceptual aspects. Given that at the end of the interview, Avondre and Janine described canonically accurate mechanistic models of conduction, whereas Wade's explanation was not canonically accurate, extended talk about operations may indicate a student's difficulty understanding how gesture functions with the simulation. This temporal pattern has implications for simulation design and instruction. While operational talk always occurs with the use of new digital tools, more design research is needed to help reduce students' cognitive load on understanding tool operation. Meanwhile, students are typically unaware of how they can use gestures to support their scientific sensemaking. More research is needed to support students using gestures as tools for modeling and communicating scientific ideas.

References

Abrahamson, D., Nathan, M. J., Williams-Pierce, C., Walkington, C., Ottmar, E. R., Soto, H., & Alibali, M. W. (2020). The future of embodied design for mathematics teaching and learning. *Frontiers in Education, 5*. https://doi.org/10.3389/feduc.2020.00147

Church, R. B., & Goldin-Meadow, S. (2017). So how does gesture function in speaking, communication, and thinking? In R. B. Church, M. W. Alibali, & S. D. Kelly (Eds.), *Why Gesture?: How the hands function in speaking, thinking and communicating* (Vol. 7, pp. 397–412). John Benjamins Publishing Company.

Segal, A. (2011). *Do gestural interfaces promote thinking? Embodied interaction: Congruent gestures and direct touch promote performance in math. (Unpublished doctoral dissertation).* Columbia University.

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Mapping Conceptual Tensions Around Civic Learning

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Abstract: Civic education initiatives often display conceptual tensions that render program design a Herculean endeavor. In this poster, we map key civic learning tensions and discuss how they relate to critical topics in the learning sciences field. We find that learning scientists are already well positioned to further understand such tensions and that our research community might benefit from a new research agenda to organize our efforts around civic learning.

Introduction

Understanding that democracy does not run on autopilot, and that a prepared and informed citizenry is a condition for its existence, is a critical learning challenge. Nevertheless, how one teaches or learns about abstractions such as social justice, representation and equality is prone to a variety of conceptual tensions and misalignments. This poster asks *What needs to be learned to attain civic engagement?* We review research from the education, communication and learning sciences (LS) fields to map conceptual tensions crucial for rethinking civic learning in a digital and polarized age and propose a new LS research agenda to respond to this challenge.

Conceptual tensions around civic learning

We define *civic learning* as the body of experiences a person goes through to acquire the various forms of knowledge to participate in the governance (broadly conceived) of a community. It is precisely this broad range of possibilities that afford and magnify the conceptual misalignments we present in this paper.

Tension 1: What is a "Good Citizen"? - The lack of conceptual agreement around what counts as a "good citizen" might hinder the establishment of civic education programs, deepen the exclusion of particular groups, and result in policies and interventions informed by opinions or subjective moral standards. After studying formal and informal civic education programs across the United States, Kahne and Westheimer (2004) found a broad range of views about the characteristics needed for a participant citizen: from loyalty and full compliance with laws and regulations to the ability to critically analyze society and disobey when needed. This model shows that educators view citizenship as the practice of personal responsibilities, often manifested by notions of "character", and civil obedience. Civic programs that place compliance over critique might be favoring behaviors such as obedience, docility and blind loyalty to governments, and failing to advance critical forms of participation.

Tension 2: What counts as "participation"? - Several scholars have called for new theoretical tools to broaden definitions of civic participation. Under these expanded notions, youth engagement with the civic sphere is seen through their participation in *affinity networks*: groups of individuals who share interests, practices and participatory cultures (Ito et al, 2015; Jenkins, 2009). The forms of civic participation that happen through affinity networks conform to what Jenkins and colleagues (2016) defined as *participatory politics* (PP), which are contrasted by the authors with *institutional politics* (IP). Whereas IP depicts civic participation as a domain separated from institutionalized practices, PP are naturally embedded in our daily lives and incorporated into ordinary social and cultural interactions. This understanding has implications to how scholars might frame the challenges of civic learning. The very notion of civic disengagement seems to be under scrutiny by scholars of various fields. Mihailidis and Gerodimos (2016) posit that "expanded learning cultures remain somewhat removed from spaces of formal education" (p. 379), while informal programs have been widely adopting practices that harness youth's interests and contribute to strengthening affinity networks.

Tension 3: What constitutes civic knowledge? Several studies have measured what and how much learners know about civics. In the U.S., for instance, these studies often take the form of surveys and involve knowing facts about branches of government, citizen rights and elections, among other compatible topics. Knowledge *about* elections, rights, and government is no doubt a requirement for a participatory democratic life. However, a question remains whether factual knowledge is enough or if other epistemologies should be considered when thinking about civic learning. For this reason, LS scholars are invited to investigate what other forms might civic knowledge take and how should it translate into designed learning experiences.

Extant studies in the LS describe new literacies as capable of encompassing both factual and practical knowledge about critical participation in society. Mihailidis and Gerodimos (2016) described such literacies as "fluences" for young people to navigate the civic space and acquire the necessary practical skills to act upon it. Similarly, Jenkins (2006) proposed that such fluences are a bridge between in and out of school realities. Finally, researchers such as Ito et al. (2015) and Westheimer and Kahne (2004) argued that internal motivations or personal dispositions are a fundamental piece in the epistemic puzzle of civic activity. *Civic voice*, a term described by Mihailidis and Gerodimos (2016) is "the dispositions and modalities of expression that young people use to participate in daily life". This metacognitive knowledge about oneself resonates with recent work by Jenkins and his team (2016), who collected cases of civic action based on identity building by asking young people "what is your civic superpower?". The results point to identity, self-awareness, and self-efficacy as elements that might be studied, designed, and promoted under an expanded notion of *civic knowledge*.

Towards a civic learning agenda for the learning sciences

Below, we discuss how notions of civic learning in the LS might disrupt problematic conceptions of education:

1. Avoiding "keychain civics". Engagement with civic knowledge must be deep enough to promote civic learning. Blikstein (2013) describes the *keychain syndrome* in maker education where simple engagements with 3D printers to make a keychain impede meaningful interaction and tokenize learning. Keychain civic learning then is where learners engage with basic facts, symbols and myths of origin of a country but never move on to more complex ways of knowing. To avoid it, learning designers need to shift from focusing on factual knowledge in siloed civics courses or short, highly scripted, and self-contained activities to a more complete civic epistemology, including skills and identities, in all learning designs.

2. Civic learning cannot be devoid of civic pedagogies. As civic media rise to address gaps in formal civic learning (Zuckerman, 2016), learning scientists need to ask what pedagogies are needed to be in place so that civic media fulfils its potential. We suggest that civic learning should be thought of not merely as learning of a particular topic (the school subject Civics) but rather as a framework for understanding how learning and education are *always* contextualized by the civic identity, engagement skills or proclivities, and epistemologies of the learner's context as a member of society. Much as Gutiérrez (2014) seeks to embrace syncretic forms of literacies that "support educational, economic, and sociopolitical opportunity for youth from nondominant communities" (p. 49), we argue that all learning environments, within and beyond school walls, can be thought of as a venue for civic learning.

3. Civic pedagogies must honor the diversity of epistemologies beyond the Global North. Much as Freire (1970) called for *epistemologies of the South*, we argue that civic learning must be understood and designed beyond the constraints and traditions of the Global North. More than a mere geographical issue, scholarly work in Northern countries often instantiate a particular epistemology in which knowledge is "by definition fragmentary, imperfect and socially dispersed" (Krašovec, 2013, p. 66). In this view, the learner "wastes no time dwelling on higher truths or grand narratives but possesses and uses only a tiny socially neccesary (sic) quantity of specialised knowledge, one is no longer required to know why, only how." (p. 69).

References

Blikstein, P. (2013). Digital fabrication and 'making' in education: The democratization of invention. *FabLabs: Of machines, makers and inventors*, *4*(1), 1-21.

Freire, P. (1970). *Pedagogy of the oppressed* (MB Ramos, Trans.). New York: Continuum.

Gordon, E., & Mihailidis, P. (Eds.). (2016). *Civic media: Technology, design, practice.* MIT Press.

Gutiérrez, K. (2014). Integrative research review: Syncretic approaches to literacy learning: Leveraging horizontal knowledge and expertise. In P. J. Dunston, L. B. Gambrell, K. Headley, S. K. Fullerton, & P. M. Stecker (Eds.), *63rd Literacy Research Association Yearbook* (p. 48-60). Altamonte Springs, FL.

Hoadley, C. (2018). A short history of the learning sciences. In *International handbook of the learning sciences* (pp. 11-23). Taylor and Francis.

Ito, M., Soep, E., Kligler-Vilenchik, N., Shresthova, S., Gamber-Thompson, L., & Zimmerman, A. (2015). Learning connected civics: Narratives, practices, infrastructures. *Curriculum Inquiry, 45*(1), 10-29.

Jenkins, H. (2009). *Confronting the challenges of participatory culture: Media education for the 21st century*.

Jenkins, H., Shresthova, S., Gamber-Thompson, L., & Kligler-Vilenchik, N. (2016). Superpowers to the People! How Young Activists Are Tapping the Civic Imagination. *Civic media: Technology, design, practice*, 295-320.

Krašovec, P. (2013). Neoliberal epistemology: from the impossibility of knowing to human capital. *Filozofija I Društvo, 24*(4), 63-83. https://doi.org/10.2298/FID1304063K

Mihailidis, P., & Gerodimos, R. (2016). Connecting pedagogies of civic media: The literacies, connected civics, and engagement in daily life. Civic media: *Technology, design, practice, 371-391*.

Westheimer, J., & Kahne, J. (2004). What kind of citizen? The politics of educating for democracy. *American educational research journal*, *41*(2), 237-269.

Zuckerman, E. (2016). Effective civics. In *Civic media: Technology, design, practice*, 49-76.

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Materials and Participants: A Dialogical Relationship

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Abstract: Materials play an important role in learning. Humans actors use materials in particular ways depending on the context and materials also can shape how human actors use materials. This study explores the dialogical relationship between the participants and materials in suminagashi, a Japanese paper marbling activity. We found that materials that are traditionally thought of as art materials, such as paintbrushes, are used to support practices often considered science practices, such as experimentation.

Introduction

Scholars have long recognized how materials play a role in learning and that they shape learning experiences in important ways (Gibson, 1977). For example, certain materials are often associated with particular disciplines and practices. A paintbrush can be thought of as a tool used in painting and visual arts, while a microscope may be linked to science and science experiments for closely examining specimen. In previous work, we found that 4-7th grade girls saw specialized materials of science being used for almost predetermined ends, limiting the types of activities or practices that the girls engaged in with those materials (Tsurusaki et al., 2017). Fields such as design studies have pushed conceptualizations of the role of materials to explore the active role they play in shaping the learning context and experience. In other words, there is a dialogical relationship between materials and the designer (Schön, 1992) and material agency is contextual, emergent, and contingent (Tholander, Normark, & Rossitto, 2012). Furthermore, both humans and materials possess agency (Shotter, 2006). We build on the idea that materials and designers are in a dialogical relationship by investigating materiality in STEAM activities with adults. We explore the question: *What is the dialogical relationship between the participants and materials in a STEAM activity?*

Theoretical framework and methods

The meanings that material objects take on are situated within the contexts, narratives, and purposes of their use. Harré (2002) argues that material objects take on different meanings depending on the context of their narratives. For example, a needle may have meanings related to sewing, navigating, or removing a splinter depending on the context. Nasir and Cooks (2009) examine the importance of the role of material resources in learning the practices of a discipline, in this case, how athletes use material resources in the sport of track. Humphries and Smith (2014) argue that material objects "…[are] complex, vibrant and interactive agents capable of influencing and shaping the human experience" (p. 482). How material resources are used shape learning experiences.

While some may examine the use of materials in their final form, such as how a paintbrush or microscope is used (e.g., Harré, 2002; Nasir and Cooks, 2009, Humphries and Smith, 2013), some materials can also change form and the reflexive nature of the materials can impact learning in different ways. Ingold (2011) argues that materials are not fixed, but rather their meaning is made as they are used. It is in the process of creating or making that we draw out the potential of materials through our interactions and relations with them (Ingold, 2013). Therefore, it is our experiences and connections to the materials themselves from which we can draw meaning.

The context for this study was a two day, in-person STEAM professional development program for informal educators in the Northwest U.S. We analyzed the interactions of participants and materials in an activity called suminagashi, a process of paper marbling developed in Japan. Suminagashi inks were dropped into a bin of water, where they floated or sank depending on how the ink was added to the water, the surface tension of the water, and the density of the ink (Figure 1).

Figure 1. Participants dropping suminagashi ink into water bin (left) and paper marbling prints (right)

The participants used the ink bottles, various sizes of brushes, and other objects to apply and manipulate the ink and create designs. Once ink was added to the water, the participants used various types of paper to transfer the ink from the water bin to the paper. Two participants shared one set of materials, which included a water bin, suminagashi inks, brushes, and paper. We videotaped the activity and transcribed the video for dialogue and actions. We used interaction analysis (Jordan and Henderson, 1995) to explore the dialogical relationship between the participants and the materials.

Major findings

What could traditionally be considered art materials, such as paint brushes and inks, are used in this activity to support experimenting and observation, which while they are practices in both art and science, are traditionally considered science practices. We found that examining the dialogical relationship between material and human actors can help us understand how a STEAM activity can support integrative thinking across science and art.

For example, Martha and Leah experimented with the inks and how they behaved in water. They observed that the yellow ink spread out when dropped into the water. Martha suggested that they try a different color ink, green with the same brush, and found that it did not spread like the yellow ink. They shared their observations and hypotheses about whether the brush or some property of the ink caused the different spreading. This episode shows the dialogical relationship between materials, people, and practices. As the materials reacted, the participants responded by experimenting with materials (e.g., trying different colors, brushes) to further explore the materials.

As they continued exploring, they experimented with different sized brushes, using brushes when they were wet or dry ("I think it has worked better when the brush is wet already"), different colors of ink, and placing the paper into the water in different orientations (e.g., dipping it under the surface, placing it on top of the surface, etc.). As they made observations about both how they were using the materials and how the materials were interacting with each other, they explored different ways of using the materials.

Conclusions and implications

As Ingold (2011) argues, materials do not have objective uses apart from the purposes to which they are being put to use. There is a dialogical relationship between materials and participants who engage with materials. The materials shape how participants engage with them in a dialogical relationship. We argue that it is essential to consider the role that materials play, as agentic players, in participant learning and how learning environments are structured to allow for "reflective conversations" (Schon, 2012).

References

Gibson, J. J. (1977). The theory of affordances *Perceiving, acting, and knowing: Toward an ecological psychology*. Hillsdale, NJ: LEA.

Harré, R. (2002). Material objects in social worlds. *Theory, Culture & Society, 19*(5-6), 23-33.

Humphries, C., & Smith, A. (2014). Talking objects: Towards a post-social research framework for exploring object narratives. *Organization, 21*(4), 477-494.

Ingold, T. (2011). *Being alive: Essays on movement, knowledge and description*. New York: Routledge.

Ingold, T. (2013). *Making: Anthropology, Archaeology, Art and Architecture*. New York: Routledge.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *The journal of the learning sciences*, *4*(1), 39-103.

Nasir, N. S., & Cooks, J. (2009). Becoming a hurdler: How learning settings afford identity. *Anthropology & Education Quarterly, 40*(1), 41-61.

Schön, D. A. (1992). Designing as reflective conversation with the materials of a design situation. *Research in Engineering Design, 3*(3), 131-147. http://dx.doi.org/10.1007/BF01580516

Tholander, J., Normark, M., & Rossitto, C. (2012) Understanding agency in interaction design materials. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 2499-2508.*

Tsurusaki, B. K., Tzou, C., Conner, L., & Guthrie, M. (2017). Colors of Nature: Art/Science agency in intersecting figured worlds. Annual meeting of the National Association for Research in Science Teaching, San Antonio, TX.

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The Heart of the Matter: High School Educators' Experiences of Teaching Project-Based Learning

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Abstract: In this Work in Progress study, we report on eleven educators' teaching experiences from four high schools that have adopted Project-Based Learning (PBL). A majority of the prior PBL research has been limited to programs or courses within traditional schools, and this work furthers the conversation by capturing the educators' experiences while their schools transform into PBL high schools. We illuminate their early transformational experiences with implications for how teachers are supported in such transitions.

Keywords: Project Based Learning, School Change, Teacher Experience, Teacher Supports

Introduction

The pedagogical practice of Project-Based Learning (PBL) uses projects that engage students in authentic problem solving for teaching and learning. PBL is grounded in constructivist and constructionist learning theories. There has been a breadth of research on the topic, answering questions pertaining to the best practices, student experience, and efficacy of PBL. There have been fewer inquiries about educators' teaching experiences and the factors that contribute to positive teaching experiences for educators. In the limited research on such factors, we notice two broad themes. First, positive experiences resulting from the convergence between teachers' notions of education and the educational attributes that PBL enables. For example, being able to have closer contact with the students (Dahlgreen et al., 1998), being facilitators for student learning (Habók and Nagy, 2016), being oriented towards content learning or career preparation (Rogers et al., 2011), and teachers' intrinsic motivation to teach. Second, positive experiences attributable to situational factors like school context and culture. For example, autonomy over their practice, collegiality (Lam et al., 2010), availability of time to prepare learning activities, being able to scaffold learning experiences, and adjusting to their changing roles as educators (Ertmer and Simmons, 2006).

Methodology

We interviewed eleven high school teachers from four schools across three states in the United States. See table 1 for the teacher pseudonyms along with their school contexts. All four of the schools are part of a network of schools supported by an organization committed to rethinking and changing high school education.

Table 1: Teacher pseudonyms and school background

<table>
<tr><td>Chloe</td><td>Leah</td><td>Melissa</td><td>Naomi</td><td>Denise</td><td>Jacob</td><td>Eric</td><td>Eli</td><td>Tiffany</td><td>David</td><td>Rebecca</td></tr>
<tr><td colspan="4">Urban Public Charter</td><td colspan="2">Urban Public Charter</td><td colspan="3">Suburban Public</td><td colspan="2">Rural Public</td></tr>
<tr><td colspan="4">• Majority African American
• 24.5% economically disadvantaged
• 278 enrolled students</td><td colspan="2">• 107 enrolled students*
*other data not available</td><td colspan="3">• Majority white
• 61% economically disadvantaged
• 200 enrolled students</td><td colspan="2">• Majority White
• 22.9% economically disadvantaged
• 850 enrolled students</td></tr>
</table>

We interviewed the teachers between May 11th and June 15th, 2020, using a semi-structured interview protocol. For this paper, we limit our analyses to their perspectives on teaching with a PBL approach. We conducted inductive coding (Patton, 2014) of the interviews to understand what the teachers find exciting about PBL teaching, what they find challenging, and supports that they find most helpful, to contribute to the broader line of inquiry for this paper, which is:

> To understand educators' experiences in high schools that have adopted a Project-Based Learning pedagogy across the curriculum.

Findings

We organize the educators' experiences in three sections below:

I. Exciting aspects of the practice

Three themes emerged on how PBL provides exciting opportunities for teaching. First, the *Enactment of Teachers' Values of Education* theme is about how teachers are able through PBL to teach in a way that highlights their values of quality education. For example, Melissa spoke about being able to take an assets-based approach to teaching. The second theme *Individualized Learning Experiences for Students* highlights the space for student voice. Teachers share how they like the ability to provide dynamic individualized experiences (Eli), to "meet students where they are" (Chloe). The third theme in this category focuses on the *Disruption of Traditional Teaching Practices*. Eric enjoys the freedom to be able to do new types of activities in his classroom, "I love just being able to think of something and then just say, "Can I do that? Oh, I can? That's amazing."

II. What is challenging

Teachers pointed to three common areas of challenge with teaching through a PBL pedagogy. The first focuses on *Crafting Effective Assignments.* Each PBL project has its own final assignment, and the form of that assignment varies. Eric mentions how this openness for creativity in assignments can be overwhelming. Not only is the final assignment a challenge to create but crafting *Relevant Learning Experiences for their Students* can be a hard balance between creating connections to students' lives and accomplishing the goals of the course. As Tiffany, an entrepreneurship educator, pointed out she struggles with wanting her students to find the work they do in her class relevant even when the students may never start their own business. The third challenge that teachers pointed out was how *Transferring Control of Learning to Students* takes a big leap from the teacher in how they approach education. One of the key aspects of PBL is providing space for student voice and choice in their learning. David shares how he is working on being comfortable with not knowing all the answers as a teacher.

III. What supports are helpful

The teachers spoke about two kinds of support that they find helpful for PBL teaching: those found *within* the school and those they sought *outside* of school. All the eleven teachers we interviewed spoke about the *within school supports* including administrators' structural support, such as allocating resources to learning activities. These supports can be less formal as Tiffany shares how the teachers having "lunch together every day" helped share ideas. Five of the teachers highlighted outside of school supports including being part of online communities like teacher Facebook groups (Melissa), visiting other schools and attending events (Denise), and finding frameworks that they can adapt to their settings like those from Stanford D (Naomi) school and PBLworks (Eli).

Implications

Our findings in this work in progress study show that though the types of issues and motivational factors teachers report when teaching PBL are similar across schools, the solutions to overcoming the challenges lie within the schools. This study's findings have implications for how schools can support their teachers. When possible, appoint in-school coaches who are cognizant of the school's context and work with teachers to transform their practice. Outside providers should look to programming that builds capacity at the school level. School-wide transformation cannot be mass-produced across schools but must be created within school communities.

References

Rogers, M. A. P., Cross, D. I., Gresalfi, M. S., Trauth-Nare, A. E., & Buck, G. A. (2011). First Year Implementation of a Project-Based Learning approach: the need for addressing teachers' orientations in the era of reform. International Journal of Science and Mathematics Education, 9(4), 893-917.

Dahlgren, M. A., Castensson, R., & Dahlgren, L. O. (1998). PBL from the teachers' perspective. Higher Education, 36(4), 437-447.

Ertmer, P. A., & Simons, K. D. (2006). Jumping the PBL implementation hurdle: Supporting the efforts of K–12 teachers. Interdisciplinary Journal of Problem-based learning, 1(1), 40-54.

Habók, A., & Nagy, J. (2016). In-service teachers' perceptions of project-based learning. SpringerPlus, 5(1), 83.

Lam, S. F., Cheng, R. W. Y., & Choy, H. C. (2010). School support and teacher motivation to implement project-based learning. Learning and instruction, 20(6), 487-497.

Patton, M. Q. (2014). *Qualitative Research & Evaluation Methods*. SAGE Publications.

Rogers, M. A. P., Cross, D. I., Gresalfi, M. S., Trauth-Nare, A. E., & Buck, G. A. (2011). First Year Implementation of a Project-Based Learning approach: the need for addressing teachers' orientations in the era of reform. International Journal of Science and Mathematics Education, 9(4), 893-917.

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Educational Grantmakers' Conceptualizations of Equity

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Abstract: This interview study probes educational grantmakers' sensemaking of their foundations' contributions to equity-oriented crises and social movements. We identify emergent themes stemming from how respondents connected their equity commitments to their practice and the ways these connections shifted in the midst of COVID and the Movement for Black Lives. Themes suggest implications for possible futures in educational grantmaking—futures in which grantmakers reimagine their theories of change and power in response to socio-political conditions.

Keywords: Education Philanthropy, Grantmaking, Racial Equity, COVID-19

Introduction

In the midst of the COVID-19 pandemic upsetting daily routines, impacting communities worldwide, and disproportionately infecting and killing Black, Latinx, and Indigenous communities, the murder of George Floyd has renewed attention to the Movement for Black Lives (MBL). Synchronous to these crises, there has been a growing recognition amongst educational grantmakers that the philanthropic field's historical disengagement from racial justice has led foundations to reproduce rather than disrupt inequities in education. The convergence of these phenomena—the magnification of existing inequities and a growing interest in equity among education-focused philanthropies—creates a need for research on the intersection of grantmakers' efforts with equity movements. We conducted interviews with educational grantmakers to surface how they conceptualized their foundations' response to COVID-19, MBL, and the role of equity in their work to examine: 1) whether and how foundations' prior commitments to supporting racial equity are changing, advancing, or declining; and 2) whether and how grantmakers connect these commitments to their grantmaking practices.

Theoretical framework

Prior work has shown that foundations consistently converge around "top-down" and advocacy-focused approaches to influence policymaking, effect systems change and reduce social inequalities (Tompkins-Stange, 2016; Haddad & Reckhow, 2018; Gandara, Rippner, & Ness, 2017). Foundations have increasingly drawn on neoliberal frameworks and strategies, favoring market-based choice policies and institutional arrangements to achieve their goals (Baltodano, 2017; Ravitch, 2016). They have also been known to leverage "bottom-up" approaches, providing resources and legitimacy to social movements seeking to enact community-driven demands. Resource mobilization is a crucial component to the growth and success of social movements seeking to achieve greater social equity (McCarthy & Zald, 1977). As such, a movement's success is contingent on its access to resources. Taking top-down and bottom-up mechanisms together, a vision emerges of foundations as important (albeit problematic) arbiters of racial justice and educational equity. We examine educational grantmakers' understanding of their role in equity responses prompted by COVID-19 and MBL.

Methods, data, setting, and analytic approach

We used a comparative case study design, conducting 30- to 60-minute semi-structured interviews with grantmaking practitioners (e.g. program officers) to explore how they are changing or persisting in their practices in the face of COVID-19 and MBL. We leveraged purposive sampling (Weiss, 1994) to recruit 13 grantmakers from 7 Midwest-based foundations, 3 of which make grants nationally while 4 make regional and local grants. 5 grantmakers identified as Black, 1 as Asian, 5 as white, and 2 as Latinx. 7 identified as female and 6 as male. Interviews were conducted in 2020 and transcribed for analysis. We collaboratively analyzed transcripts, co-developing analytic memos attending to how grantmakers conceptualized their foundation's response to COVID-19 and the role of their philanthropic work in pursuing equity. We leveraged Strauss and Corbin's (1998) process of conceptualizing events to co-identify patterns of meaning revealed in the data, leading to the themes below.

Preliminary findings

Grantmakers' painted a dynamic picture of their sensemaking through reflections on what they have learned through these dual crises. We found that most noted that COVID-19 surfaced new urgency for equity and challenged their beliefs about the "right" balance between long-term strategic investment and addressing immediate, community-based needs (e.g. food, housing). Five grantmakers of color expressed frustration with the lack of urgency among colleagues across philanthropy, articulating questions about *whose* existence—and threats to that existence—matters enough to catalyze urgent philanthropic responses. While some grantmakers voiced intentions to continue top-down and policy-focused work, others questioned whether foundations focused on supporting change and community thriving should fund institutions (e.g. colleges, nonprofits) or attend to students' and families' needs. One grantmaker referred to this tension between strategy and survival as philanthropy's "privilege of patience," arguing that "not everything is about infrastructure or long-term strategy...it's time to respond to the call for some of these basic needs and supports."

Grantmakers also described multiple paths toward universally-professed equity commitments. These split between preservation (investing in existing organizations and approaches) and resourcing communities to challenge institutions. A majority of grantmakers expressed renewed interest in learning directly from the communities they aim to support. Interviewees reported efforts to have more meaningful conversations with Black, Indigenous, and Latinx-led community-based (and/or student-led) organizations about funding than they had before COVID-19. One grantmaker envisioned a model for funding PoC-led organizations, which tend to be in acute need of operating funds, that reflected interviewees' emerging interest in reconnecting with community-based organizations. Moreover, grantmakers described investing in ways that belied trust in organizations' judgement and labor as advocates. Some surfaced that supporting these organizations' autonomy and work in grassroots social movements could produce new pathways toward community thriving.

Two potential implications

First, we suspect that foundations who subscribe(d) to a top-down, systems-change model of philanthropy may be permanently troubled by how COVID-19 and MBL have: 1) made explicit systemic dysfunctions that have led to food insecurity, health-care vulnerability, fragility of cultural institutions, and unstable civil liberties; and 2) created an urgent need to strengthen connections with communities to facilitate community-informed responses. Second, new practices enacted to foster closer philanthropy-community connections may result in changing how foundations form partnerships with, and fund, community-based organizations. Grantmakers who identified as more directly rooted in BIPOC communities hoped that this moment would reveal the need to break up white-dominated networks in favor of more diversified networks of organizations. We predict that preferences for local and PoC-led organizations could gain momentum as grantmakers continue to make sense of the MBL's arguable success in changing racial conversations (i.e. defunding police).

References

Baltodano, M. P. (2017). The power brokers of neoliberalism: Philanthrocapitalists and public education. *Policy Futures in Education*, *15*(2), 141–156. https://doi.org/10.1177/1478210316652008

Gandara, D., Rippner, J. A., & Ness, E. C. (2017). Exploring the 'how' in policy diffusion: National intermediary organizations' roles in facilitating the spread of performance-based funding policies in states. *The Journal of Higher Education*, *0*(0), 1–25. https://doi.org/10.1080/00221546.2016.1272089

Haddad, N., & Reckhow, S. (2018). The shifting role of higher education philanthropy: A network analysis of philanthropic policy strategies. *Philanthropy & Education*, *2*(1), 25. https://doi.org/-10.2979/phileduc.2.1.02

McCarthy, J. D., & Zald, M. N. (1977). Resource mobilization and social movements: A partial theory. *American Journal of Sociology*, *82*(6), 1212–1241.

Ravitch, D. (2016). *The death and life of the great American school system: How testing and choice are undermining education*. Basic Books.

Strauss, A. L., & Corbin, J. M. (1998). Basics of qualitative research: Techniques and procedures for developing grounded theory. Sage Publications.

Tompkins-Stange, M. E. (2016). *Policy patrons: Philanthropy, education reform, and the politics of influence.* Harvard Education Press.

Weiss, R. S. (1995). *Learning from strangers: The art and method of qualitative interview studies*. Simon and Schuster.

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Exploring the Impact of Coursework on Literacy Teacher Candidates' TPACK Development for Technology-integrated Instructional Planning

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Abstract: Framed by TPACK and the Technological Integration Planning Cycle, this study explored how a teacher-education course impacted literacy teacher candidates' TPACK development in designing and teaching unit plans and teacher factors related to effective technology integration. Results supported the role of such a coursework, showing teacher candidates' technology use related to content and pedagogy but with variability in TPACK application. Teacher candidates' belief and confidence in technology use influenced their decisions on effective technology integration.

Introduction and theoretical framework

It's acknowledged that literacy instruction in today's school settings should extend beyond print-based reading and writing by teaching students to read, write, synthesize, evaluate and communicate in multimodal ways (Lankshear & Knobel, 2011). Technology offers classroom teachers more opportunities to establish an active and constructive learning environment in which students are able to make inquiry, explore and construct ideas, and solve problems (Goss, Castek, & Manderino, 2016). The challenge lies in how classroom teachers can help their students achieve these goals.

Since its inception, the Technological Pedagogical and Content Knowledge (TPACK; Mishra & Koehler, 2006) has provided a conceptual model for examining teacher candidates' preparation to teach with technology (Figure 1). The TPACK framework informs research examining teacher knowledge for technology integration in educational settings. However, literature has reported several challenges with the TPACK model, including transfer of knowledge to classroom instruction and teacher knowledge development (Doering, Veletsianos, Scharber, & Miller, 2009).

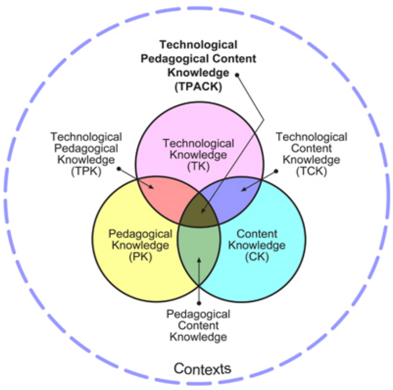

Figure 1. TPACK framework (Mishra & Koehler, 2006).

According to Hutchison and Woodward (2014), to design effective lessons, teachers must identify content focus (CK) and appropriate pedagogy (PK). Importantly, they also need to select and evaluate digital tools (TK) and determine how these can be used to support learning and how they align with content objectives and pedagogical decisions (TPACK) as part of the instructional planning cycle. Thus, the first author redesigned a literacy and technology course framed by TPACK (Mishra & Koehler, 2006) and the instructional planning cycle (Hutchison & Woodward, 2014) with the aim to provide teacher candidates with the knowledge and skills to integrate technology into literacy instruction. By examining artifacts from that course, the study aimed to understand **the impact of the technology-literacy course on teacher candidates' literacy instructional planning and investigate the teacher factors related to effective technology integration**.

Methods

This research was conducted at a small, private university in the Northeast region of the United States that offers undergraduate and graduate teacher licensure and graduate degree programs across a range of disciplines. The study was situated in a required, graduate-level course entitled Integrating Technology into Literacy, which was developed and taught by the first author. The course was designed to explicitly teach the domains of TPACK (Mishra & Koehler, 2006) and prepare candidates to use a TPACK theoretical planning model to design instruction (Hutchison & Woodward, 2014). Twenty-three teacher candidates participated in this study while enrolled in a graduate-level literacy and technology course. All participants were graduate students working toward completion of either a MAT or MA degree in education.

All data in this study were collected from course artifacts: ten-day unit plans and unit-plan reflections. These were analyzed to study teacher candidates' TPACK development through the design and the implementation of technology-integrated lesson plans. Unit plans were analyzed using a valid and reliable four-point rubric developed by Hoffer and Grandgenett (2012). First, unit plans were scored on four criteria aligned with the key components of TPACK framework: 1) curriculum goals and technologies (TCK); 2) instructional strategies and technology (TPK); 3) technology selection(s) (TPACK); and 4) curriculum-based technology use ("Fit"). For this measure, a score of 1 indicates weaker evidence while a score of 4 indicates an advanced level in meeting the criteria.

Findings and discussion

Preliminary findings of the study suggest that there are strong benefits of participation in a technology course focused on literacy. The unit plan analysis revealed that teacher candidates demonstrated stronger TCK and TPK in their instructional plans compared to TPACK and "Fit", indicting their preparation to design lessons that integration technology, pedagogy, and content objects but need for greater attention to developing the more complex domain of TPACK. We further grouped unit plan scores into four categories to better understand the wide variability in scores noted in teacher candidates' abilities to apply TPACK knowledge, based on the overall mean score of TPACK domains: low (22%; between 1 and 2), emerging (26%; 2 to 2.5), developing (35%; 2.5 to 3), high (17%; above 3). Findings from analysis of data across the four groups revealed that 1) teachers who had stronger content knowledge and pedagogical knowledge tended to produce unit plans demonstrating stronger selection of technology tools and clearer evidence of "Fit"; 2) teacher candidates who expressed stronger beliefs about the benefits of technology tended to design unit plans that demonstrated stronger TPACK; 3) teacher candidates who expressed greater confidence m in using technology demonstrated higher levels of TPACK knowledge and application. Results suggest that cognition and affective aspects of teaching influenced teacher candidates' decisions about technology integration.

This study is important to the ISLS audience as it sheds light on how teacher educators can better prepare candidates to use digital tools effectively within pedagogically sound, standards-based lessons. It highlights the need for teacher educators to explicitly teach and support TPACK development among teacher candidates by embedding theory within practice-based experiences such as designing and teaching technology-integrated lessons for the classroom. This work has important implications for teacher education.

References

Doering, A., Veletsianos, G., Scharber, C., & Miller, C. (2009). Using technological pedagogical content knowledge framework to design online environments and professional development. *Journal of Educational Computing*, 41(3), 319-346.

Goss, M., Castek, J., & Manderino, M. (2016). Disciplinary and Digital Literacies: Three Synergies. *Journal of Adolescent & Adult Literacy*, 60(3), 335-340.

Hoffer, M., & Grandgenett, N. (2012). TPACK development in a teacher education: A longitudinal study of pre-service teachers in a secondary M.A.Ed. Program. *Journal of Research on Technology in Education*, 45(1), 83-106.

Hutchinson, A., & Woodward, L. (2014). A planning cycle for integrating digital technology into literacy instruction. *The Reading Teacher*, 67, 455–464. Janssen, N., Knoef, M., & Lazonder, A. W. (2019). Technological and pedagogical support for pre-service teachers' lesson planning. *Technology, Pedagogy and Education*, 28(1), 115-128.

Lankshear, C., & Knobel, M. (2011). *New literacies: everyday practices and social learning* (3rd ed.). McGraw-Hill Education.

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record*, 108(6), 1017-1054.

Introducing Outside Experts into the Classroom: The Mediating Impact of Instructor Beliefs on the Learner Experience

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Abstract: We explore the impact instructor perspectives have on the implementation of a virtual work-based learning intervention in community college classrooms. Drawing upon three years of design-based research, we present case studies that illuminate two divergent educator perspectives. Findings suggest that the ways educators take up and incorporate the intervention into their classroom differentially affects the learners' experience and realized impacts.

Introduction

This paper reports on preliminary insights from a study of the adoption of a technology-mediated "virtual internship" in community college classrooms. Here we examine the experience of two educators who characterize different belief systems and how these beliefs in turn influence the roles, relationships, and outcomes for learners in their classrooms. We explore how an educator's perspective, manifested by their implementation of an educational intervention, impacts the learner experience and can exercise agency within the learning environment.

Starting in 2017, we implemented a virtual internship intervention with the goal of increasing access to industry engaged, work-based learning (WBL) to students, particularly those from low-income, first-generation, and underrepresented (URM) populations in STEM. Using a design-based research methodology (Wang & Hannafin, 2005), we endeavored to get the intervention into the classroom, iterate the design, and then work to scale and spread it throughout institutions. However, the 'getting in' proved more challenging than anticipated, with many implementations withering and dying before they had the opportunity to spread (Cole, 2009). Our research sought to examine potential determinants of success or failure as that intervention is taken up (or not). Educators' beliefs appears to be one of the most determining factors in this process.

To conduct this analysis, we draw on data from 16 colleges implementing virtual internships in their curriculum. All of these schools serve URM and non-traditional students. The researchers served as participant-observers, providing professional development and technical support to instructors both before and during the implementation process. Data collected include: (1) email, and video conference communications between the research team and stakeholders within the implementing institutions; (2) observations and video recordings of educator and industry partner training sessions; and (3) observations from coaching sessions with educators on the use of the data analytics dashboard supporting the virtual internship. Here we focus on an analysis of two educators whose beliefs characterize two perspectives we see emerging from the overall data corpus.

Two emergent perspectives

We illustrate the impact of educator belief or perspective appears to have on the intervention taking root through the lens of two educators' stories, who we will call Ari and Jamie (and use the pronouns they/their for both).

1) Ari is a faculty member at a suburban community college in Massachusetts. The college serves 10,000 students; 67% are students are of color. Ari saw value in the virtual internship, particularly the introduction of an industry coding project with "no right answer," a phrase used by Ari when presenting the virtual internship to their students. The value of welcoming the industry partner project into the learning environment is evident in Ari's approach in the planning phase of implementation. When engaging with a new industry partner to plan the logistics, Ari said, "Once I see the project, I will align the course outcomes," showing a willingness to let the project and industry partner influence the intended learning within the classroom.

Ari's articulated value of an industry partner's project having "no right answer" was also signaled by where Ari situated it within the curriculum. The project begins before students have the technical skills to complete the project. This positions the project as a place where knowledge and skills are developed and refined, not simply assessed. Furthermore, Ari articulated in the project kick-off meeting with students that Ari did not know the answers either, positioning themself as a knowledgeable guide within the project environment in contrast to a holder of the knowledge and solution. When asked how the students work on their virtual internship project is graded, Ari's response was "it's complicated… trying to get away from grading the actual project," an approach that they explain aligns to Feldman's (2019) Grading for Equity that holds accuracy, bias-resistance and intrinsic motivation as its pillars. Instead of grading the project artifacts directly, Ari evaluated each student based on a reflection essay and their ability to explain the code another student contributed to the project.

2) Jamie is a professor at a community college in North Carolina. The college serves 20,000 students with a Black enrollment of 39%. Jamie already had a team project in their course and perceived the virtual internship as a mechanism to bring industry feedback into the classroom. During the planning phase, Jaime made several changes to the intervention design. Two changes most relevant to the present analysis included a) having the students define their own project instead of engaging with a project supplied by industry partners and b) announcing that project artifacts would be graded. These changes repositioned the industry partners from the role of 'project sponsor,' i.e., someone who has a vested interest in the work being produced, to 'industry mentor,' i.e., someone who is using their industry knowledge to suggest possible improvements to the students' project. These moves by Jaime modified the virtual internship model and the industry partner's role to fit within their classroom as opposed to adjusting the learning environment to the design affordances offered by the virtual internship. In a preparatory call between Jamie and the industry partners, Jaime explained the graded artifacts in detail and what asked the industry partners to align their feedback with the grading criteria.

Jaime's decisions during the implementation resulted in moves with lower integrity to the goals of the intervention. When one team had missed a deliverable deadline, platform data indicated that two industry partners had not provided students with feedback on a project artifact. Jaime declined to query or prompt the industry partners about their lack of feedback and instead decided to follow up only with the student team who had missed the deadline. Ideally, a timely intervention by the educator or feedback from the industry partner can inject insight, provide new knowledge or trigger learners' reflective process. Students thus missed out on external input that could have help them construct new knowledge. A discussion between Jaime and the researchers unearthed a hesitancy to intervene in the project process beyond checking on a missed deliverable that would impact a grade.

This positionality of the virtual internship as an assessment tool is reinforced in the way grading was implemented. Student project artifacts were graded against a rubric. Industry partners provided feedback on draft versions of artifacts before being submitted to Jamie for grading. This seemed to position the industry partner's feedback as an optional extra that could add value to the students grade instead of an essential component of the learning. In contrast, Ari did not grade student artifacts, they graded each learner's ability to explain their team members contribution to the project and a reflection essay.

Implications for student learning

The different ways Ari and Jamie took up and implemented virtual internships in their classrooms illustrate how their perspective and instructional moves impact student learning. We are still examining how these and other implementations across a range of settings and populations impact student learning, motivation, career, and attitudinal outcomes. Our findings suggest that the learner's degree of agency while participating in a virtual internship is significantly impacted by their teachers' perspective and subsequent moves in taking up this innovation. Jamie's decision to grade the artifacts reduces the student agency over the experience and precludes the opportunity to learn from failure. Conversely, in Ari's class, where they used Feldman's grading for equity, a learner can fail to deliver a viable project and still passing the class, provided they can appropriately reflect upon and extract sufficient insight from the "failed" project. Our preliminary findings suggest that the different ways that educators incorporate a third-party industry expert into their classroom can dramatically impact the learners' experience and serve to reinforce or undermine the intended benefits of the virtual internship. These findings point to important conversations that should be part of teacher professional development accompanying WBL and similar experiences that engage learners and educators with workplace experiences and outside experts.

References

Cole, M. (2009). Designing, implementing, sustaining, and evaluating idiocultures for learning and development: The case study of the Fifth Dimension. In S. Bekman & A. Aksu-Koç (Eds.), *Perspectives on human development, family and culture* (pp. 331-349). Cambridge University Press.

Feldman, J., (2019). *Grading for Equity: What it is, why it matters, and how it can transform schools and classrooms*. Corwin.

Wang, F., & Hannafin, M.J. (2005). Design-based research and technology-enhanced learning environments. Educational *Technology Research and Development, 53*, 5 – 23.

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Green Chemistry in the Third Age: Engaging Older Adults in Learning about Sustainability

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Abstract: The learning sciences takes a broad interest in learning across lifespans. Yet, there is a lack of research on the learning of older adults and how they engage with pivotal socio-scientific issues. This paper reports on a series of events designed to inform older adults about sustainability. Over 200 participants engaged in discussions with experts around sustainable chemistry. Results demonstrate that these participants learned new things about sustainability and how to mediate environmental concerns.

Introduction

The learning sciences have long conceived itself as a field that takes a broad interest in learning across contexts and lifespans (National Academies of Science, 2018). Yet, there is a lack of LS research are studies and designs that focus on older adult learners of retirement age. Older adults are the fastest-growing age group globally (United Nations, 2019). Despite their relatively proportion of the population, older adults consistently turn out for elections at the highest rates of any age group. What's more, older adults tend to more skeptical of key socio-scientific issues, like global climate change, that will impact the world long after they are gone (Reinhart, 2018). While these socio-poltical concerns are certainly important, at a more basic level we know that a lack of stimulating engagement in learning activities threatens the well-being of older adults—emotionally, socially, and cognitively (Merriam & Baumgartner, 2020). Based on these concerns of improving both the personal and global situation of older adults, this paper reports on the early stages of any exploratory study of outreach efforts to engage older adults in learning activities around issues of sustainability.

Learning in the third age

Three general perspectives inform this work. First, *critical geragogy* refers to approaches to older adult learning the undermine stereotypes of dependency to promote the idea that learning can and should bolster personal freedom and work towards impact social change (Formosa, 2012). This perspective is especially useful in thinking about how older adults might influence the course of discussion around socio-scientific issues like sustainability. Similarly, the idea of *serious leisure* refers to the use of personal "down time" for dedicating pursuits that enrich both the individual and the society (Stebbins, 2007). There is some work that tries to capture pro-environmental actions as a form of serious leisure (Miller, 2018). Finally, and perhaps most importantly, is the concept of the *third age*, which divides the lifespan into "ages" (*first age* being childhood and school-going, *second* being adult working life, and *third* being old age and retirement) to centralize each group's unique needs and abilities (Laslett, 1987). The idea of older adults needing specific learning activities and engagement has led to the emergence of *The University of the Third Age* (U3A), which is an international movement dedicated to providing continuing education and stimulation to retired members of the community in a non-profit structure. Currently, there are over 1,000 U3A groups in the UK which provide community and activities to over 400,000 members (Third Age Trust, 2018). The learning sciences is in a unique position to research and understand how these groups function, in order to help provide learning activities for older adults around the world.

Methods

Since 2018, the School of Chemistry at the University of Nottingham has undertaken a programme of events to engage local U3A groups. At these event, U3A members tour the School of Chemistry's carbon neutral research building and learn how sustainable chemistry research was put into practical use in the design, construction and utilization of the building. The groups also hear formal lectures from faculty members about sustainability and participate in informal conversations and presentations from various students about how to become more engaged in sustainability in everyday life. Each U3A group was given a questionnaire to fill out before and after the activities at the School of Chemistry. The design of the questionnaire evolved over time, but generally involved six or seven closed-ended 10-point Likert scale questions and a few additional open-ended prompts. This analysis focuses on 226 respondents. In addition to the before and after questionnaire, participants were sent a follow-up survey was sent to participants anywhere from three months to a year after their visit. These surveys ask more opened ended questions about whether or not the participant believed they learned anything during their visit, what they may have learned, if they shared information from the activities with others, and whether they changed any day-to-day activities as a result of what they learned.

Results and analysis

Before-and-after survey responses

Before the events, some groups were asked to rate their level of science knowledge on a scale of 1 to 10. The mean score was 4.9 (N = 170, SD = 2.5), which can be interpreted as respondents believing they general have average science knowledge. A paired-sample t-test was performed for all question and showed that there were statistically significant differences for every question before and after the U3A events. This suggests that the U3A events resulted in significant positive shifts for all questions. Fairly dramatic shifts were seen in the respondents' perceived understanding of sustainable chemistry and knowledge of sustainable chemistry research. Views on the importance of chemistry, green chemistry, and chemistry research were high before the event, but still saw a significant shift after. The event also seemed to improve the respondents' views on the environmental impact of green chemistry and the safety of chemistry research. The results suggest that the events had significant impact on the attendees' attitudes toward and understanding of green and sustainable chemistry.

Follow-up survey responses

Nineteen participants responded to the follow-survey. All but one said they had shared information about the activities to others. The open-ended responses revealed that many of them reported about the activities back to their local U3A members at their regular meetings. When asked if they changed anything about their day-to-day lives following the visit, the participants generally said they already try to live sustainably. Others, however, claimed they had made changes, including "recycling more and certainly thinking more about the clothes industry and recycling." When asked what they learned, participants frequently mentioned details about specific topics discussed during their visits. For example, "that oil is not the only means by which plastics can be made." Perhaps the most salient impression from the responses is that participants valued the intergenerational interactions with the university students. Respondents mentioned the enthusiasm of the students and their own interest in hearing about the work being done by younger people. For example, one participant stated, "they were all very keen to show off their work and to listen. It drove home the importance of maintaining and building intergenerational links." In general, the visits seem to have been both enjoyable and informative for the participants who responded. They claimed to have learned new things about sustainability, which they passed onto friends and families and tried to use to inform their own everyday lives. While this is a small sample, the importance of physical, shareable objects and intergenerational communication can be used to inform later iterations of the U3A visits and with other learning activities for older adults.

Conclusion

This work serves as a first step in reengaging the learning sciences with the unique needs and perspectives of older adults. The findings here will inform new iterations of the School of Chemistry's outreach efforts with older communities and individuals. It also begins the process of deriving design principles for older adult learning activities — including the importance of shareable objects and intergenerational interaction — that can be used for new activities. To drive home the urgency of such efforts, I will end with a quote from a participant who after effusing about the visit and his passion for sustainability, said that it is up to others, both old and young, to take up these issues as he is "now in my eighties and with lung disease [and] I'm in lockdown, possibly forever."

References

Formosa, M. (2012). Critical geragogy: Situating theory in practice. *Journal of Contemporary Educational Studies, 63/129*(5), 37–54.

Laslett, P. (1987). The emergence of the third age. Ageing & Society, 7(2), 133-160.

Merriam, S. B., & Baumgartner, L. M. (2020). Learning in adulthood: A comprehensive guide. John Wiley & Sons.

Miller, E. (2018). "My hobby is global warming and peak oil": sustainability as serious leisure. World Leisure Journal, 60(3), 209-220.

National Academies of Sciences, Engineering, and Medicine. (2018). *How people learn II: Learners, contexts, and cultures*. National Academies Press.

Reinhart, R. J. (2018). Global Warming Age Gap: Younger Americans Most Worried. *Gallup*. May 11.

Stebbins, R. A. (1992). Amateurs, professionals, and serious leisure. McGill-Queen's Press

Third Age Trust. (2018). *Learning Not Lonely*. London: The Third Age Trust.

United Nations, Department of Economic and Social Affairs, Population Division. (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).

GuARdians of Tomorrow: A Compelling Simulation for Understanding Sustainability

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Abstract: We describe the theoretical rationale, design features, and potential implications of the Augmented Reality (AR) simulation we are developing called *GuARdians of Tomorrow*. In this simulation, users experience ramifications of sustainability-related issues by hypothesizing, testing, and perceiving threats of current action (and inaction) on local environmental context in the future through AR. This work will lead to productive discussions about theory-based simulation design for situating long-term, macro impacts of sustainable development into students' local contexts.

Introduction

Critical indicators of Earth's health—global temperature, carbon dioxide, and sea levels—are all on a steady rise (National Aeronautics and Space Administration [NASA], 2020), pointing to alarming trends that could lead to adverse social, technological, economic, and political changes related to sustainability in the near future. These indicators of global health also point to a critical educational need for schools to move beyond teaching abstract, disembodied scientific concepts and instead provide opportunities for students to engage in empathetic, embodied experiences of the social, technological, economic, and political interactions that can be both the causes and effects of sustainability issues. Acknowledging the critical role of schools to prepare scientifically literate citizenry that can productively make sense of and respond to sustainability issues, this poster will describe the rationale, design, and implications of our project, *GuARdians of Tomorrow: A Compelling Simulation for Understanding of Sustainability* (henceforth "*GuARdians*").

GuARdians is a research project in which we are currently designing and developing a mobile augmented reality (AR) simulation intended to address the disembodied spatial-temporal ambiguity of alarming sustainability trends. *GuARdians* addresses spatial disembodiedness by using AR capabilities of mobile devices that superimposes interactive 3D objects and characters based on local social, technological, economic, and political (STEP) data onto the "real world" within the player's local geographical context (in our case, a large urban area in the American Southwest). In doing so, *GuARdians* presents its users with opportunities for exploring their local context (geographical context + STEP data). *GuARdians* also addresses temporal disembodiedness by placing users within an interactive narrative that allows them to simulate what their local context might look like at various points up to 100 years in the future. This simulation will be implemented with middle school students on widely available (Pew, 2019) devices such as mobile phones. Through *GuARdians*, our research team seeks to raise understanding—especially in young people—of the direct, personal, and localized threats associated with global sustainability trends in the future.

GuARdians is designed to be what we call a *compelling simulation*. A compelling simulation results when five key research- and theory-based characteristics are coordinated: 1) **A**gency in the narrative that allows a user's actions to determine how the story unfolds; 2) **R**elevancy to the user's context by using their local geography; 3) **I**mmediacy that focuses on the urgency of local situations by shrinking otherwise large timescales to show warrants for immediate action; 4) **S**caffolds in multiple ways, including adherence to well-established multimedia design principles; and 5) **E**mpathy that requires the user to consider the perspectives of a variety of representative stakeholders. Together, these characteristics comprise the A.R.I.S.E. model that defines a compelling simulation. Each of these five characteristics are inspired by theoretical perspectives that frame learning as inseparable from participating in a system of activities deeply determined by a particular physical and cultural setting (Brown, et al., 1989; Chaiklin & Lave, 1993). As an AR-based compelling simulation, *GuARdians* helps address the National Research Council's (2012) three-dimensional framework of science instruction by incorporating tenets of Situated Learning Theory (Lave & Wenger, 1991) which holds that learning happens best when conducted in authentic environments.

This poster will lead to productive discussions about theory-based approaches for situating long-term impacts of sustainability into relevant contexts for users. In addition, we look forward to discussing our model for compelling simulations with attendees, as we believe it will make meaningful contributions to the field of simulation-based learning by providing a theoretically based design model (the A.R.I.S.E. framework) for designing compelling simulations. This project will also investigate the impact of an AR-based curriculum on students' engagement, self-efficacy, and knowledge gains when approaching complex concepts related to sustainability. Broadly speaking, *GuARdians* will help young people better understand prominent challenges related to ecological sustainability.

Sample images to be used in the poster are included in Figures, 1, 2, and 3.

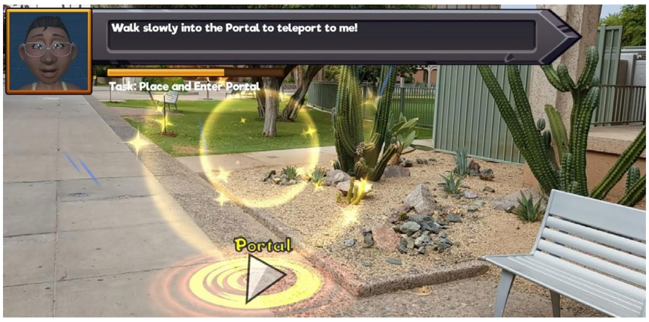

Figure 1. Sample visual of the AR simulation: The time travel portal

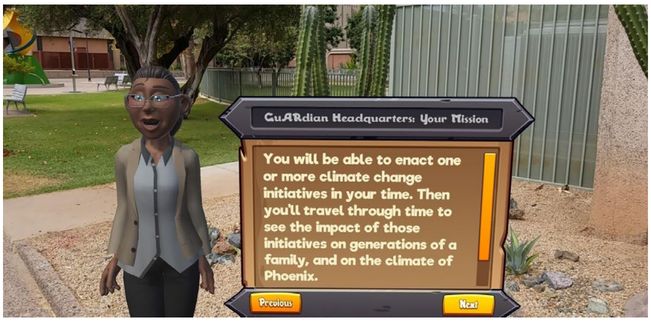

Figure 2. Sample visual of the AR simulation: Interaction with non-player characters

Figure 3. Sample visual of the AR simulation: Interaction with AR objects

References

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational researcher, 18*(1), 32-42.

Chaiklin, S., & Lave, J. (Eds.) (1993). *Understanding practice: Perspectives on activity and context*. Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

National Aeronautics and Space Administration. (2020). Climate Change Evidence: How Do We Know? https://climate.nasa.gov/evidence/

National Research Council. (2012). *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. Washington, DC: The National Academies Press

Pew Research Center (2019, June). Mobile fact sheet. https://www.pewresearch.org/internet/fact-sheet/mobile/

Developing a Conceptual Framework for Dignity-Affirming Care in Collaborative Research

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Abstract: Applying a Black womanist perspective, I develop a conceptual framework to explain how two types of care, *validating care in the present* and *validating care for potential* can be used to understand the conditions under which dignity is affirmed in collaborative research.

Collaborative research projects and the potential for dignity-affirming care

The purpose of this paper is to develop a framework that can be used to explore how and when collaborative research settings are *dignity-affirming learning environments* for participants. Collaborative research, as I define it, encompasses a range of ways that researchers engage with school or community partners while doing research *with* rather than *for* and *on* participants (Penuel et al., 2020). An aim of this type of research is the "transformation of the research relationship from one in which communities were objects of study to one in which community members were participating in the inquiry" (Wallerstein & Duran, 2017, p. 28).

Following Espinoza, Vossoughi, and others, I characterize dignity as a "multifaceted sense of a person's value" that "inheres in the person," however, the experience of that is "contingent"; it cannot be taken as a given that a person's dignity will be recognized and affirmed within interactions (Espinoza, Vossoughi, Rose, Poza, 2020, pgs. 1-2). The acknowledgement of intrinsic worth is the result of struggle and social action, such as through education. Dignity involves the ability to feel valued and to value others, but it is a "historical accomplishment," not something received *a priori* (Espinoza & Vossoughi, 2014). This work is concerned with the ways that dignity is accomplished through interaction within collaborative research.

Collaborative research projects contain the potential to be dignity affirming because of their focus on equality, mutuality, and/or reciprocity, in contrast to more traditional, transactional models. The current turn toward more collaborative approaches to research is promising, however, "simply invoking the language and ideals of participation is insufficient" (Shirk, 2012. p. 29). Uncritical attempts at collaboration and participation may actually result in further marginalization as participants are erased and their knowledge and experience commodified. Routinized instances of researchers commodifying, appropriating, and making research participants invisible are still common (Patel, 2015). As collaborative research in the United States takes place within a racist milieu that prioritizes property rights over human rights (Ladson-Billings & Tate, 1995), participants in collaborative research must be vigilant to combat framing research as the property of researchers, rather than as a dignity-conferring activity. Therefore, new ways of thinking about relationships within collaborative research are needed. Black womanists' perspectives on caring provide one model for understanding the caring interactions between research partners that support dignity in research.

Black womanist perspectives and the need for care in research

Scholars that theorize Black womanist caring have firmly linked practices of care to supporting human dignity. For instance, Collins (2009) describes Black mothers' efforts to instill a strong sense of self-worth in their children by meeting their physical needs. Some scholars use Black feminist and womanist interchangeably while others make distinctions, however, both terms refer to theory that centers Black women's experiences and efforts towards self-determination and self-identification within the context of communal liberation. In these traditions, care is reciprocal and mutually beneficial, designed to affirm the humanity, value, and self-esteem of individuals, and to combat negative assessments and stereotypes from dominant cultures (Collins, 2009). Therefore, the aim of care in this practice is the collective benefit and the liberation of everyone, as well as a focus on individual empowerment (Beauboeuf-Lafontant, 2002). Black women's traditions of care attend to the particular history, experiences, and physical reality of people with multiple marginalized identities (Thompson, 1998; Ward, 1995), as well as to understanding how multiple layers of oppression and privilege interact within a power structure defined as a *matrix of domination* (Collins, 2009). Black womanist theories of care view self and communal care, or "mothering," as political action (Collins, 2009; Lorde, 1992). Care is both inward focused and healing, as well as outward oriented and seeking the formation of strategic coalitions (Reagon, 1983).

Connecting care to dignity in collaborative research

Using Sandoval's (2014) idea of conjecture mapping, I reviewed scholarship on collaborative research, dignity, and Black womanist conceptions of caring to map the relationships between design processes in collaborative research, mediating processes related to caring interactions, and the dignity and learning outcomes that collaborative research projects present when caring mediating processes exist. I also reviewed empirical data describing the interactional norms across seven different collaborative research projects.

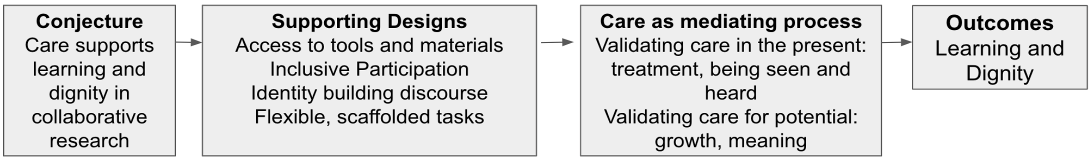

Figure 1. Conceptual Framework for Care and Dignity in Collaborative Research

I find that *validating care for the present* and *validating care for potential* are salient categories for understanding caring interactions within collaborative research. Understanding these facets of caring and how they are present (or not) within the practices of collaborative research projects is one promising step in ensuring that these projects are dignity affirming.

References

Beauboeuf-Lafontant, T. (2002). A Womanist Experience of Caring: Understanding the Pedagogy of Exemplary Black Women Teachers.*The Urban Review*, 16.

Collins, P. H. (2009). *Black feminist thought: Knowledge, consciousness, and the politics of empowerment*. New York: Routledge.

Espinoza, M. L., & Vossoughi, S. (2014). Perceiving Learning Anew: Social Interaction, Dignity, and Educational Rights. Harvard Educational Review, 84(3), 285–313. https://doi.org/10.17763/haer.84.3.y4011442g-71250q2

Espinoza, M. L., Vossoughi, S., Rose, M., & Poza, L. E. (2020). Matters of participation: Notes on the study of dignity and learning. Mind, Culture, and Activity, 1–23. https://doi.org/10.1080/10749039.2020.-1779304

Hill, S. R., & Tollerud, T. R. (1996). *Restoring Dignity in At-Risk Students*. 12.

Ladson-Billings, G., & Tate, W. (1995). Toward a critical race theory of education. *Teachers College Record*, *97*(1), 47–68.

Lorde, A. (1992). *Burst of light*. Women's Press (CA).

Reagon, B. J., (1998). Coalition politics: Turning the century. In B. Smith (Ed.), *Home girls: A Black feminist anthology* (pp. 343-356). New Brunswick: Rutgers University Press.

Patel, L. (2015). *Decolonizing Educational Research: From Ownership to Answerability*. Taylor & Francis Group. http://ebookcentral.proquest.com/lib/ucb/detail.action?docID=4219192

Penuel, W. R., Riedy, R., Barber, M. S., Peurach, D. J., LeBouef, W. A., & Clark, T. (2020). Principles of Collaborative Education Research With Stakeholders: Toward Requirements for a New Research and Development Infrastructure. *Review of Educational Research*, 90(5), 627–674.

Sandoval, W. (2014). Conjecture Mapping: An Approach to Systematic Educational Design Research. *Journal of the Learning Sciences*, *23*(1), 18–36. https://doi.org/10.1080/10508406.2013.778204

Shirk, J. L., Ballard, H. L., Wilderman, C. C., Phillips, T., Wiggins, A., Jordan, R., McCallie, E., Minarchek, M., Lewenstein, B. V., Krasny, M. E., & Bonney, R. (2012). Public Participation in Scientific Research: A Framework for Deliberate Design. *Ecology and Society*, 17(2). https://doi.org/10.5751/ES-04705-170229

Thompson, A. (1998). Not the Color Purple: Black Feminist Lessons for Educational Caring. *Harvard Educational Review*, *68*(4), 522–555. https://doi.org/10.17763/haer.68.4.nm436v83214n5016

Wallerstein, N., & Duran, B. (2017). The theoretical, historical and practice roots of CBPR. *Community-Based Participatory Research for Health*: Advancing Social and Health Equity, 17–29.

Ward, V. (1995). *Cultivating a Morality of Care in African American Adolescents: A Culture-Based Model of Violence Prevention*. 14.

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Who Are the Data Scientists in Education? An Investigation of the Identities and Work of Individuals in Diverse Roles

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Abstract: To understand how the new discipline of data science is impacting education and the learning sciences, we surveyed 68 individuals who identified as or worked in roles related to educational data science. Findings from an analysis of the surveys and follow-up interviews with key participants show that educational data scientists have more confidence with the mathematical and substantive aspects of their work (relative to programming) and that beliefs about what educational data science is has a bearing upon who identifies with this new domain.

Introduction

Across education, several new courses, degree programs, and jobs have been created that share a focus on applying novel research methods to new data sources. Such emergent data sources include students' interactions with digital technologies and teachers' participation in online professional learning communities. Although these courses and areas of work have different names (e.g., learning analytics, educational data mining, and educational data science) that reflect different assumptions about education, they also share a number of common features and can be broadly understood as applications of data science methods in education (Wise, 2020), or *data science in education* (Estrellado et al., 2020).

The role of data science in education has been established through foundational (Lee & Wilkerson, 2018) and forward-looking scholarship (Wise, 2020). In addition, efforts have been made to integrate disparate areas of research. However, some core questions pertaining to this new area of scholarship and work remain. Who identifies as an educational data scientist? Are educational data scientists similar to or different from learning analytics and educational data mining researchers? What do individuals across professional roles (e.g., researchers and analysts in educational organizations or school districts) in education who identify as educational data scientists do?

In this early-stage research, we developed and collected responses to a survey of educational data scientists. We then followed-up our survey with interviews of select respondents in order to learn about the identities and work of those individuals from diverse roles who identify as educational data scientists.

Method

We developed a short survey to understand (a) the backgrounds of educational data scientists, (b) their initial ideas regarding their identification with an educational data scientist role, and (c) the nature of their own work. To administer the survey, we shared the questionnaire directly with interested colleagues and asked influential individuals to reshare in their organizations and with their networks. This resulted in a total of 68 responses from individuals in a variety of professional roles.

In addition to questions on individuals' backgrounds, the survey also included questions on (a) whether individuals saw their work as relating to educational data science, (b) their confidence in three aspects of educational data science that have been used to define the domain (Rosenberg et al., 2020)—mathematics and statistics, computer science and programming, and knowledge about teaching, learning, and educational systems—and (c) what software they used in different contexts (e.g., work, in a degree program). The interview protocol we used with three individuals (with the plan to interview more) included 15 questions organized around (a) identification with educational data science, (b) relevant prior experiences, and (c) present work.

As presented in Table 1, we received responses from 21 faculty or post-secondary instructors, six graduate students, 14 data scientists or analysts, 11 K-12 teachers, and seven individuals from other roles, including non-University instructors of data science courses at the post-secondary level. After being presented with a definition of educational data science as an activity or work involving mathematics and statistics, computer science and programming, and knowledge of teaching, learning, and educational systems, most (82%) respondents reported doing educational data science (or related work); 10% of individuals were unsure.

Table 1: Participants' Professional Roles, Self-Reported Genders, and Identification as Under-Represented

Professional Roles	*n*	Does educational data science	Self-reported gender: Female	Self-reported gender: Male	Identification as under-represented
Data Scientist	18	17	5	9	2 (1)
Faculty	21	16	8	13	2 (2)
Graduate Student	6	5	3	3	1 (2)
Teacher	11	7	7	4	6
Other	7	2	5	2	1

Note. Parentheses following values in the identification as under-represented column denote individuals who preferred not to respond. Four individuals did not report a professional role and gender.

Findings

Individuals in our sample reported (using a 1-5 scale, indicating very little to very great confidence) more confidence with teaching, learning, and educational systems ($M = 4.23$, $SD = 0.85$) and mathematics and statistics ($M = 4.22$, $SD = 0.76$) than computer science and programming ($M = 3.55$, $SD = 1.01$). The most widely used software programs were Microsoft Excel, R, and Google Sheets, all three of which were used frequently in individuals' current work; these were followed by Python, SQL, and SPSS. R was used more than any other software in degree programs; Python was second most-frequently-used in this context.

Preliminary analysis of the three interviews revealed that whether individuals identified as educational data scientists—and, if they identified as educational data scientists, with what parts of the domain they identified—distinguished individuals more than the nature of their work or area of study. For example, one individual noted that they thought of educational data science as being focused on "big data" and machine learning. Although this interviewee often used computer programming in their work, they did not consider themselves to be programmers; if educational data science were defined more broadly, they might have been more inclined to identify with it. Another tentative finding pertained to the challenges of analyzing educational data due to its complexity and the individuals at multiple levels (i.e., teachers and students) involved with its production.

Discussion

Our aim with this study was to understand who identifies as an educational data scientist and what people from education-related roles who identify as educational data science do. Our results showed that even among individuals who reported doing educational data science, they were less confident with aspects related to computer science and programming. In addition, we found that a variety of data science tools were used. While R was widely used by individuals in degree programs, other common statistical software (see McNamara, 2018) were also used. Interviews suggested that identifying as an educational data scientist is distinct from doing educational data science (or being in a data science job or degree program), which highlights how both one's identification with a domain as well as recognition by others contribute to individuals identifying as educational data scientists.

References

Estrellado, R. A., Freer, E. A., Mostipak, J., Rosenberg, J. M., & Velásquez, I. C. (2020). *Data science in education using R*. London, England: Routledge.

Lee, V. R., & Wilkerson, M. (2018). *Data use by middle and secondary students in the digital age: A status report and future prospects.* Commissioned Paper for the National Academies of Sciences, Engineering, and Medicine, Board on Science Education, Committee on Science Investigations and Engineering Design for Grades 6-12. Washington, D.C.

McNamara, A. (2019). Key attributes of a modern statistical computing tool. *The American Statistician, 73*(4), 375-384.

Rosenberg, J. M., Lawson, M. A., Anderson, D. J., & Rutherford, T. (2020). Making data science count in and for education. In E. Romero-Hall (Ed.), *Research methods in learning design & technology* (pp. 94-110). Routledge: New York, NY.

Wise, A. F. (2020). Educating data scientists and data literate citizens for a new generation of data. *Journal of the Learning Sciences, 29*(1), 165-181.

International Society of the Learning Sciences

The Immune System and Hindu Nationalism: Nation Making in a Grade 8 Biology Lesson

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Abstract: We explore how (supposedly objective) science phenomena (the immune system) emerged as co-constituted with the nation-state and the militarization of bodies in a Grade 8 science lesson in South India. The teacher wove narratives of recent military action in the contested region, Kashmir, with explanations of how antibodies activate in the human body. We illuminate how, at the microgenetic level, Hindutva logics shaped students' understandings of scientific concepts, and how this entanglement served Hindu nationalism.

Introduction

On August 6, 2019, in a town outside Chennai (1), Bond (2) began a lesson on the immune system: "You must have heard in the news that in the past few days there is a lot of mobilization of weapons, infantry and all towards the Kashmir border?" Immediately, the class erupted with chatter as students shouted out "Article 370", to Bond's smiling approval. On August 5, 2019, the Indian government abrogated Article 370 in the constitution, making more official India's occupation of Kashmir by imposing added curfews and widespread communication shutdowns (Al Jazeera, 2019). The occupation of an already deeply militarized region was problematically being purported by the Indian government and media as an effort to 'unify the nation', rather than the enactment of a Hindu-nationalist agenda aimed at diluting the Kashmiri Muslim majority to a Hindu majority (Hafsa, 2019).

In the lesson, Bond wove together stories of war and memory cells to describe the ways in which the students' immune systems protected their bodies from pathogens. Science knowledge, typically considered an 'objective' domain, is often described using analogies involving the military and warfare (Martin, 2010). Through the "self/non-self" model (Martin, 2010), the immune system is framed as an army that protects the body against foreign threats, despite research that increasingly recognizes non-static boundaries within human-microbe relations (Gilbert, Sapp, & Tauber, 2012). In this paper we build on research that explicates the use of modern science for engendering Hindu nationalism (Subramaniam, 2019) and highlight one mechanism through which everyday practices in science classrooms reify Hindutva (3) logics implicated in Hindu nation-making in India and the ongoing occupation of Kashmir. We ask: *How did the immune system emerge as co-constituted with the Indian state and military occupation in Kashmir; and with what consequences for nation making through science education in India today?* Through analysis that explores one way that (supposedly objective) science phenomena (the immune system) emerged as co-constituted with the nation-state and the militarization of bodies, we illuminate how the Kashmiri occupation was implicated through science education and simultaneously, how science teaching may serve to naturalize nation-making through postcolonial – Hindutva - logics.

Theoretical framework

We draw on a relational ontology to recognize human-more than human (MTH; Bang & Marin, 2015) boundaries as emergent through encounters (Ahmed, 2000) that are entangled (Barad, 2007) with relationships between "other others" (Ahmed, 2000, p. 8) in the past, present and future space-times. Indigenous ways of knowing (IWOK) stand in sharp contrast with the Eurocentric impositions that assert humans and the MTH as implicitly separate (Bang & Marin, 2015). Recognizing the MTH world as active in co-constructing reality (rather than as the passive recipient or object, of human action or subjectivity) requires a reformulation of how we come to know from knowing the other to knowing in relation (Marin & Bang, 2018). In South India, non-colonial and IWOK are complicated by the caste system where Brahmanical supremacy has and continues to oppress Dalit communities' knowledge systems. 'Indigenous' knowledge systems such as the Vedas are intimately connected with Brahmin supremacy and were historically only accessible to upper caste communities (Subramaniam, 2019). With Brahminical and Dalit ways of knowing both rooted in a relational ontology, we draw on Indigenous scholars from Turtle Island to recognize the commonality in ontological commitments between IWOK globally and those of South Indian and Dalit communities where knowledge creation is emergent in and through deep relationship with the MTH. Therefore, we consider nation-making an ongoing emergence that reifies which relations are positioned as the 'other' through everyday encounters, and we recognize science phenomena emergent in the classroom as entangled with MTH elements inside and outside of the classroom space.

Data and methods

This paper draws on data collected from a larger study that explored the role of materiality in science teaching in a South Indian school. While not explicitly religious, the school exuded strong Hindu and nationalist sentiments, enrolling students and teachers of diverse religions and castes. Data analyzed included field observations (Childers, 2013), field-noting body movements/position of humans and MTH. Using a 2.5-minute audio excerpt of Bond's narration, we took a dialogic approach to analyze the "interactional positioning accomplished" (Wortham, 2001, p. 34) through human utterances. We used micro-ethnographic and interaction analysis (Jordan & Henderson, 1995) methods to examine Bond's narrative that positioned human and MTH entities socially. We examined how particular elements of the immune system entangled with elements of the Kashmir story; how human-MTH entities were positioned through power'd boundary enactments; and how these relations became naturalized as subject-object relations.

Results

In this episode, immunity was not a neutral biological concept. It emerged as political through a Hindutva framing that valued human-nation exceptionalism and necessitated mechanisms of protection against 'foreign' others who might pose a threat in the future. Bond's narrative enacted a boundary that clearly defined the human body (and therefore nation state) as distinct, making it simple to identify and separate "foreign" entities. Bond separated the human body-nation from other MTH entities to protect the integrity of the 'self'. Entities "foreign" (Kashmiris) to the human body-nation boundary would necessarily be a "problem", and were expected to invade eventually, even if "dead or deactivated" now. The immune system-army then, emerged as necessary defense systems not only for protecting the integrity of the human body-nation boundary, but also ensuring that the body-nation would not perish. The power'd boundary enactment justified and naturalized the need for defenses (antibody-weaponry) to "get triggered" automatically against entities (Kashmiri-pathogens) with the potential to "create a problem" in a future space-time. Students' immune systems were not neutral entities in the human body. 'Memory cells-soldiers' detected and attacked foreign 'pathogen-Kashmiris' through the 'antibody-weapon' phenomena, to protect and establish the 'healthy body-country' entity. As Hindu nationalism pervades India, this paper contributes to nuancing *how* the expansionist agenda to occupy Kashmir can be reified through science teaching.

Endnotes

(1) Chennai is a large city in South India, the capital of Tamil Nadu and over 3000Km south of Kashmir
(2) All names are pseudonyms. Bond is a Hindu Brahmin grade 8 biology teacher.
(3) The logics that inform Hindu nationalism with the goal of securing a 'Hindu' nation

References

Ahmed, S. (2000). *Strange encounters: Embodied others in post-coloniality*. Psychology Press.

Barad, K. (2007). *Meeting the universe halfway quantum physics and the entanglement of matter and meaning*. Duke University Press.

Bang, M., & Marin, A. (2015). Nature–culture constructs in science learning: Human/non-human agency and intentionality. *Journal of Research in Science Teaching*, *52*, 530–544.

Childers, S. M. (2013). The materiality of fieldwork: an ontology of feminist becoming. *International Journal of Qualitative Studies in Education*, *26*, 599–609

Gilbert, S. F., Sapp, J., & Tauber, A. I. (2012). A symbiotic view of life: we have never been individuals. *The Quarterly review of biology*, *87*(4), 325-341.

Hafsa, K. (2019, September 23). *Article 370 and Its Aftermath: A Panel Discussion* [Video]. Youtube. https://www.youtube.com/watch?feature=youtu.be&v=NJQCRJlQKvM\

India revokes disputed Kashmir's special status with rush decree. (2019, August 5). Al Jazeera. https://www.aljazeera.com

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practice. *Journal of the Learning Sciences*, *4*, 39–103.

Marin, A., & Bang, M. (2018). "Look it, this is how you know:" Family forest walks as a context for knowledge-building about the natural world. *Cognition and Instruction*, *36*(2), 89-118.

Martin, A. (2010). Microchimerism in the Mother (land): Blurring the Borders of Body and Nation. *Body & Society*, *16*(3), 23-50.

Osuri, G. & Zia, A. (2020) Kashmir and Palestine: Archives of coloniality and solidarity. *Identities, 27*, 249-266.

Subramaniam, B. (2019). Holy science: The biopolitics of Hindu nationalism. University of Washington Press.

Wortham, S. E. F. (2001). *Narratives in action: A strategy for research and analysis*. Teachers College Press.

Promoting Reflection in a Community-Oriented MOOC

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Abstract: We examine approaches for fostering critical reflection in a community-oriented MOOC. We used a four-category coding scheme to analyze a sample of learners' journal entries in a digital workbook tool, which was integrated into a MOOC on resilient teaching. Our analysis shows that learners engaged in high levels of reflection across all three weeks of the course. This study offers a promising approach for enabling deep learning and knowledge sharing in large-scale, open-access learning environments.

Introduction

Massive Open Online Courses (MOOCs) have long been associated with transfer-oriented pedagogies and self-paced learning approaches (Eisenberg & Fischer, 2014). However, the self-paced, individualistic nature of MOOCs can hamper opportunities for learners to engage in significant learning in concert with peers.

Given the affordances of MOOC platforms, how can instructors and designers pragmatically advance forms of interaction that support deep comprehension and offer opportunities for meaningful interaction? One possible means is through threaded discussion forums, which are the most widely used venue for communication and social learning in MOOCs. However, discussion forums exhibit problems such as a demonstrable lack of deep reflection by learners. Additionally, the chaotic structure of forums can create a disjointed experience for learners who must piece together fragmented threads (Almatrafi et al., 2018). Given that MOOCs typically utilize a standard, limited set of features, what is needed is an alternative venue for learners to engage in reflective knowledge sharing practices within structured, self-paced environments.

In this study, we examine the role of a new digital workbook tool situated within a MOOC whose stated goal was to foster reflective practices amongst learners—educators and instructional designers grappling with the new realities of "emergency remote teaching," brought on by the COVID-19 pandemic. Integrated into a standard MOOC platform using Learning Technology Interoperability (LTI) protocols, the instructional team utilized the workbook tool to offer learners a space to reflect on course concepts, with the possibility of sharing their reflections with others within an interactive gallery.

Our aim is to investigate the utility of the digital workbook to address known challenges of discussion forums, namely lack of quality responses and disjointed structure. Guiding our inquiry of the use of this new digital workbook are the following research questions:

1. What levels of reflection can we observe in learners' journal entries?
2. To what extent do learners choose to share their journal entries with peers for review and comment?

Relevant literature

In the Learning Sciences, the role of reflection in learning has long been acknowledged as an integral part of the learning process. Boud et al. (2001) characterized reflection as an "intellectual and affective [activity] in which individuals engage to explore their experiences in order to lead to new understandings and appreciations" (p. 19). Within professional learning contexts, Schön's (1983) influential work on the role of reflection "in" and "on" action presents reflection as a catalyst for improving practice.

Research context

This study explores the use of a digital workbook tool for reflective journaling within a MOOC on the topic of Resilient Teaching. Launched in June 2020, the MOOC was developed during the COVID-19 pandemic to support educators who sought effective pedagogical approaches to address instructional challenges in the early phases of the crisis and beyond. Designers of this community-oriented MOOC sought to create a venue for sharing ideas, offering mutual support, and providing mutual encouragement for instructors at all levels (Quintana et al., 2020). The MOOC was composed of four weeks (modules), each consisting of 3-4 hours of instructional content, activities, and assessments. Across the first three weeks, learners were encouraged to engage with 12 workbook prompts, which provided immediate opportunities for learners to reflect on key concepts just after they were introduced throughout the course.

Digital workbook

The MOOC utilized the Gamut Workbook tool, which was integrated into the Coursera platform using LTI protocols. Indexed to specific topics and activities within the MOOC, the workbook tool provided learners with a secure place to save their reflections and facilitated easy retrieval and editing of ideas. Workbook prompts were structured such that workbook entries could serve as the building blocks for a resilient teaching plan, the culminating assignment of the course. Importantly, the tool offered learners the choice to keep journal entries private or to publish them to a gallery, making them available for review and comment by peers.

Method

Data sources

We collected data from the first four months of the Resilient Teaching MOOC. During this time, 2820 learners were "active" participants in the course, meaning that they engaged with at least one course item (e.g., watched a video, or participated in a discussion forum). We analyzed responses to one workbook prompt from each of the first three weeks of the course. From these prompts, we randomly selected 80 responses to ensure that we could analyze an identical number of responses for each prompt, analyzing 240 journal entries in total.

Coding scheme and coding approach

We adopted Kember et al.'s (2008) four-category coding scheme for written work: habitual action, understanding, reflection, and critical reflection. We modified their original categories by removing "habitual action," replacing it with our own term called "isolated action." Our code had a similar meaning, which is that an intended or planned action is described without explicit connection to course concepts. Four coders participated in the coding process, with one pair independently coding 20% of the data for each prompt, resolving disagreement through discussion, and one member of the pair completing coding for the prompt. We applied these codes as discrete categories (i.e., one per journal entry), following our coding book.

Findings and discussion

Our findings show high levels of reflection and critical reflection across all three weeks of the course, with the highest levels occurring in responses to the Week 2 prompt. To explain why the highest levels occurred in week two, we surmise that the variability in the prompts themselves likely influenced the levels of reflection we observed across the prompts we analyzed. In sum, we can see that the quality of reflection within journal entries is high and contrasts vividly with the stark lack of reflection that Almatrafi et al. (2018) noted are characteristic of MOOC discussion forums. Further, as the workbook prompts were indexed to course concepts and were preserved within a logical sequence that was easily retrievable by learners, the issues of disorganized and fragmented threads that Almatrafi et al. (2018) surfaced about MOOC discussion forums were circumvented.

Our findings also show that learners increasingly chose to publish their journal entries to the public gallery, making them available to their peers for review and feedback. Although it is beyond the scope of this study to understand possible reasons for this increase, this finding shows that the use of the workbook tool shows promise for learners to share deep learning within large-scale, open-access environments. Future research will examine how MOOC learners interacted with peer responses in the public gallery of the digital workbook.

References

Almatrafi, O., & Johri, A. (2018). Systematic review of discussion forums in massive open online courses (MOOCs). IEEE Transactions on Learning Technologies, 12 (3), 413-428.

Boud, D. (2001). Using journal writing to enhance reflective practice. New Directions for Adult and Continuing Education, 2001 (90), 9-18.

Eisenberg, M., & Fischer, G. (2014). MOOCs: A perspective from the learning sciences. In Proceedings of the 11th International Conference of the Learning Sciences (ICLS), 190–197

Kember, D., McKay, J., Sinclair, K., & Wong, F. K. Y. (2008). A four-category scheme for coding and assessing the level of reflection in written work. Assessment & Evaluation in Higher Education, 33 (4), 363-379.

Schön, Donald A. (1983). The reflective practitioner: How professionals think in action. New York: Basic Books.

Quintana, R. M., Hearn, C., Peurach, D. J., & Gabriele, K. (2020). Self-directed, community-supported Learning in Practice: A Case of Elevated Support (pp. 312-333). In L. Wilton & C. Brett (Eds.). Handbook on Research on Online Discussion-based Teaching Methods. (pp 312-332). IGI Global.

Exploring Affordances Provided by Online Non-Curricular Resources to Undergraduate Students Learning Software Development

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Abstract: This study explored how students learning software development used online non-curricular resources during three months. It combined digital traces, self-reports, interviews and course documents to analyze how these resources provided learning affordances and support for pursuing learning purposes. Findings reveal complex arrangements of people and resources across different contexts, which translated into several interrelated affordances and purposes.

Introduction

Computer and software engineering (CSE) students' learning software development increasingly integrate online ecosystems related to the work of professional developers (e.g., GitHub or Stack Overflow) (Storey et al., 2017). Previous studies indicate students use resources from such ecosystems while learning programming, even when those resources are not integrated in the course curricula (Damşa & Nerland, 2016). Such studies suggest these resources are used for different purposes and that they play a key role in student learning by enabling the access to information, socialization and the understanding of knowledge (Dommet, 2019; Mills et al., 2014). Yet, learning and educational research has given little attention to how student learning happens and what processes are at play when students use such online non-curricular resources.

This study aims at shedding some light on this matter by exploring students' use of online resources that are related to the work of professional developers. It views the use of these resources as part of the enactment of learning practices. Practices are seen as enacted in context, in the form of discursive-material configurations that involve affordances and purposes (Mahon & Kemmis, 2017). That is, relations between abilities of people and the features they perceive in resources (Chemero, 2003), and the subjectivities that explain why these relations are formed (Garrick & Solomon, 1997). Thus, the enactment of practices is analyzed in relation to how resources are 1) used in context (higher education, personal life, work life), 2) how they function as learning affordances (e.g., to communicate, understand concepts, collaborate), and 3) which purposes they help serve (e.g., obtaining future rewards, advancing in tasks, belonging to groups). Different types of data are combined to answer these research questions: RQ1: What people and resources describe students' use of websites connected to professional development? RQ2: How do these relations translate into configurations of contexts, affordances and purposes?

Methods

This study is part of a larger research project that collects different types of data on students' use of online non-curricular resources for learning. Participants were 16 students from CSE programs at four large universities in Norway. Using a mixed-methods design, students were asked to answer a questionnaire about four categories of activities linked to professional developers' work, the websites used for these activities and other background questions. Once submitted, a custom-made software collected three months of digital traces of each website reported. These traces served as an input for stimulated recall interviews (Dempsey, 2010) that explored in-depth the enactment of practices during the three months. The analytical strategy involved two stages. To answer RQ1, qualitative content analysis of the interview data combined with questionnaire responses was applied to identify relations involving people and resources related to the four categories of activities. To answer RQ2, a qualitative analysis of affordances and purposes of the interview data was applied in combination with course documents.

Findings

The findings indicate large arrangements of websites, online resources and people connected to four practices enacted during the three-month period. In total, the enactment of these practices involved 34 different websites and relations with different people, such as teachers, students, friends and professional developers. Groups of people and resources, notably, were sometimes seen more as a single entity than as sums of components. These practices (see Table 1) often wise were enacted simultaneously, in a complementary way, and sometimes different practices were seen as inseparable. The second stage of the analysis revealed practices were enacted in several contexts, including course assignments, daily life situations and business projects, involving relations that translated into different types of learning affordances (see Table 2). These affordances differed greatly between project-based course assignments and theory driven ones, involving different people and types of online resources. Moreover, affordances were also sometimes interrelated with one another and established for different purposes. These purposes included contributing to student groups, family and friend projects, seeking future job opportunities, advancing in programming tasks, understanding concepts, personal interests and diversifying skills.

Table 1: Examples of websites, online resources and people observed in the enactment of practices

Practice	Examples of Websites (# of students)	Examples of Online Resources
1. Problem solving	W3Schools (14), Stack Overflow (15), Google (16), YouTube (16), FB Messenger (10)	Code components, source code, tutorials, text messages, solutions to problems
2. Staying up to date with trends	YouTube (11), Google (9), Stack Overflow (6), GitHub (6), Discord (4), Twitter (3)	Technology news, professional developers opinions
3. Deliberate learning	W3Schools (14), Stack Overflow (12), YouTube (16), Geeks for Geeks (7)	Code components, source code, explanations of concepts and methods
4. Future career management	LinkedIn (4), GitHub (3), Gmail (2), YouTube(2), Google (2)	Job offer descriptions, career guidance blogs

Table 2: Examples of affordances found in the interview data by category

Category	Examples of Affordances	Excerpts from Interview Data
Material Affordances	Communicating, sharing code, and searching for explanations of methods.	"[We] show pictures or prototypes of the app that we made, by screen sharing [on Zoom] (…)".
Mental Affordances	Examining code and looking at explanations of methods or concepts.	"[I] read what they say or try to interpret the code [on Stack Overflow] (…)".
Intersubjective Affordances	Giving and receiving feedback, planning activities, discussing code.	"[They] sit [on Discord] and tell you: 'this is wrong [in your code] because this and this'."
Translation Affordances	Reusing code components into own source code, repeat steps in tutorials.	"[I] copy/paste [code components from Stack Overflow], with tweaks to make it work".

Discussion and conclusion

Findings show learning practices were enacted in ways similar to the work of professional developers (Nerland, 2008). Furthermore, these practices' configurations varied across contexts and involved interrelated learning affordances and purposes that emerged out of complex relations established between different people and online resources. It comes to light from the findings that these relations were central for students' learning processes, and that their purposes cannot be just related to the accomplishment of curricular goals and academic performance. Students used websites and online resources with a future oriented approach that went even beyond graduation itself and that was influenced by people, groups and resources in complex ways. The current project intends to explore further the use of websites and online resources by examining how these configurations are formed.

References

Chemero, A. (2003). An Outline of a Theory of Affordances. Ecological Psychology, 15(2), 181–195.

Damşa, C. I., & Nerland, M. (2016). Student Learning Through Participation in Inquiry Activities: Two Case Studies in Teacher and Computer Engineering Education. Vocations and Learning, 9(3), 275–294.

Dempsey, N. P. (2010). Stimulated Recall Interviews in Ethnography. Qualitative Sociology, 33(3), 349–367.

Dommett, E. J. (2019). Understanding student use of twitter and online forums in higher education. Education and Information Technologies, 24(1), 325–343.

Garrick, J., & Solomon, N. (1997). Technologies of compliance in training. Studies in Continuing Education, 19(1), 71–81.

Mahon, K., Kemmis, S., Francisco, S., & Lloyd, A. (2017). Introduction: Practice Theory and the Theory of Practice Architectures. In K. Mahon, S. Francisco, & S. Kemmis (Eds.), Exploring Education and Professional Practice: Through the Lens of Practice Architectures (pp. 1–30). Springer.

Mills, L. A., Knezek, G., & Khaddage, F. (2014). Information Seeking, Information Sharing, and going mobile: Three bridges to informal learning. Computers in Human Behavior, 32, 324–334.

Nerland, M. (2008). Knowledge Cultures and the Shaping of Work-based Learning: The Case of Computer Engineering. Vocations and Learning, 1(1), 49–69.

Storey, M., Zagalsky, A., Filho, F. F., Singer, L., & German, D. M. (2017). How Social and Communication Channels Shape and Challenge a Participatory Culture in Software Development. IEEE Transactions on Software Engineering, 43(2), 185–204.

Reorienting Co-Design toward Care during a Pandemic

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Abstract: Care is an essential, but under-conceptualized aspect of successful educational co-design. We reflect on our experiences as researchers co-designing with teachers during the COVID-19 disruption. As researchers, we reframed our goals around an ethics of care to support teachers as they strove, and at times struggled to enact care for their students. We illustrate how co-design might be more dynamically responsive to partners' needs in times of crisis, and potentially lead to more effective outcomes.

Expanding co-design through an ethics of care

Care and kindness are foundations of any relationship, and should ground and propel all education research endeavors. Whereas most research has only focused on care in teacher-students' face-to-face relationships, care should also be embedded in the educational co-design process between teachers and researchers, which in turn can also support care between teachers and students. Crises offer unique opportunities to enact care. Building on related work (Kara & Khoo, 2020), we reflect on how our research team renegotiated our co-design process within an ethics of care amid our early experiences with the COVID-19 pandemic.

Co-design is a partnership between teachers and researchers to develop educational materials that can ensure usability and effectiveness and can lead to increased teachers' increased agency and reflection on their practice, and ownership over the resulting design (Penuel, Roschelle & Shechtman, 2007). Typically, co-designers contend with tensions that arise from differences in values and workplace norms. In times of crisis, these tensions are exacerbated and new ones can arise, such that there is a greater need to be caring and responsive toward teachers', students', and researchers' needs.

Care is expressing concern for others that is manifested in behaviors, emotions, and bonds between individuals). An ethics of care calls for relationships to be constantly negotiated in terms of the roles of "carer" and "cared for" in order to prioritize the needs of others (Bergmark, 2020). Research finds that care in teacher-student relationships positively impacts students' academic engagement, well-being, and self-esteem; as well the meaning that teachers draw from their work (Lavy & Naama-Ghanayim, 2020). However, nurturing caring relationships assumes that teachers and learners are co-located, and can rely on routines to enact care. For example, when students attend in-person class, teachers can notice whether they are academically disengaged. Teachers can also use formal and informal opportunities for dialog to enact care (e.g., in the school hallways, during class discussion). Crises introduce uncertainty in the conditions of learning, but they also introduce new opportunities for enacting care. We extend the notion of *knowing* and *responding* in education from what has traditionally focused on domain understanding and professional routines, to also focus on personal experiences. We examine how we, as researchers partnering with teachers, re-oriented our co-design process during the pandemic, and with the goal of enabling teachers to better respond to, and care for their students.

Participants and context: A co-design process disrupted

This work emerges from the Data Literacy through Art project, an effort to design and explore the value of an arts-based curriculum for supporting data literacy. Our co-design team comprised 7 cross-institution researchers, a middle school art teacher, and a middle school math teacher from the same school. During the previous and first year of the project, we spent a day in in-person art-making and data exploration to identify disciplinary synergies, and to generate initial ideas for an interdisciplinary classroom unit. Throughout the following academic year, our team of teachers and researchers held regular meetings to co-develop those units in preparation for a Spring 2020 classroom implementation. By March 2020, New York City schools had closed due to the pandemic, and classroom activities shifted to be asynchronous and online; university IRBs suspended in-person research; and several team members struggled to balance their home and work routines. Despite these challenges, our teacher partners felt that continuing with the curriculum implementation would be worth the effort to engage students with the content. Thus, our research team strategized how to adapt our project given new restrictions in what we could observe and learn from the students for whom we designed.

Methods and findings: Re-orienting co-design toward care and compassion

We video recorded eight 1-hour long co-design sessions leading up to, and during the unit's teachers' implementation, and an individual 1-hour post-implementation interview with each teacher. Our research team read through these transcripts, and through an inductive process (Strauss & Corbin, 1998), we identified how we adapted our activities to align with the ethics of care. In the moment, these adaptations felt to be instinctive reactions to new constraints. In identifying our process and design decisions, what spurred those decisions, and our intentions behind them, we came to view them to be aligned with an ethics of care. We outline them below.

Find alternative ways to connect to students. Without in-person interaction, we came to lean on teachers' contact with students to inform potentially compelling activities, and to address students' emerging needs. Our co-design meetings furthermore became essential for us to reflect together on student work, and to notice aspects of learning that we could not observe ourselves.

Use circumstances as learning opportunities. At the time of implementation, the city was under lockdown and students were learning from home. According to the teachers, students struggled to focus, and some who were typically engaged had begun to miss assignments. We thus abandoned our attempts to align the unit to standards, and turned to allowing students to reflect on their current circumstances. We created a series of activities in which students collected data to describe their lock-down experiences (e.g. 'How many times you hear the word "pandemic"? and 'With whom, when, and how do you have conversations?'), and then communicate their findings through individual artworks. To account for home distractions and uncertain technology and materials access, we extended the unit from 5 days to 3 weeks, and had students use household items to create a data sculpture that represents their perspectives and the data that they explored.

Create social connections for learning. The school's mandated asynchronous format, designed to accommodate families' home-bound schedules, meant there were fewer opportunities for peer and teacher feedback and for teachers to engage students in the dialogue that is central to care. We thus created a digital bulletin board in Padlet for students to share their artwork. One of our team members joined to support the teachers in commenting on students' work, which created chances for students to share ideas with an external audience. While this promoted some students' participation, the teachers noted that it was still not a substitute for in-person peer and teacher interaction. This highlights the difficulties of a remote format for enacting certain forms of care, and the need to consider further solutions.

Significance

We argue that researchers and teachers must show mutual care for themselves and students in any design process for learning, and particularly so in times of crisis. Given similar circumstances in which personal contact is limited, future work might explore how, through co-design, we can make students' needs more visible to teachers (e.g., opportunities to share impacts of their personal situations). In revealing our process of adapting to our project's changing circumstances, we highlight how care, as a guiding principle, can create new opportunities for teaching, learning, and research.

References

Bergmark, U. (2020). Rethinking researcher–teacher roles and relationships in educational action research through the use of Nel Noddings' ethics of care. *Educational Action Research*, *28*(3), 331-344.

Kara, H. & Khoo, S-M. (2020). Researching in the Age of COVID-19. Volume II: Care and Resilience. Rapid Responses. Policy Press. Retrieved from policy.bristoluniversitypress.co.uk/researching-in-the-age-of-covid-2

Lavy, S., & Naama-Ghanayim, E. (2020). Why care about caring? Linking teachers' caring and sense of meaning at work with students' self-esteem, well-being, and school engagement. *Teaching and Teacher Education*, *91*, 103046.

Penuel, W. R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. Research and practice in technology enhanced learning, 2(01), 51-74.

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Teacher Roles in Prison Learning: Contradictions and Provocations

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Abstract: As the Learning Sciences continues to investigate teacher learning, it is important to recognize the myriad and complex contexts teachers may be a part. This poster explores initial findings from an interview study of teachers who teach in prisons. I draw on social practice theories of learning and concepts of 'emotional relationality' and 'transformational possibility' to argue that teaching in prison requires a level of care and love that calls into question any other normative claims of teaching in these contexts.

Introduction

The significant role teachers play in contexts of learning is getting attention throughout the field of the Learning Sciences. For example, ICLS 2020 explicitly suggested we as a field apply our critical methodologies to teacher learning (Gresalfi & Horn, 2020). This poster contributes to this aim of expanding our understanding of teaching in an effort to inform learning theory more generally and how to design for learning in different settings. In line with this year's theme of "reflecting the past and embracing the future," this work reimagines traditional roles of teaching and embraces how teachers are relational and emotive actors in learning systems.

This poster explores initial findings from an on-going study of increasing STEM teaching and learning in prisons. In preparation for the study, I interviewed 36 teachers from a variety of disciplines on their experiences teaching both inside incarceration facilities as well as in traditional classrooms. Prisons present a unique context for researching teaching and learning as they are contested spaces with a myriad of contradictions that unsettle your assumptions. It extends research that recognizes teacher beliefs and decision making for instruction are important to how we support and design learning environments (Cobb, Zhao & Dean, 2009).

Theoretical perspective and conceptual framework

The poster takes a broadly socio-cultural perspective on learning and more specifically draws on ideas from social practice theory to argue that learning is contextual, situated in activity, and an ontological process of coming to be of persons, practices and tools (Weidler-Lewis, Wooten, McDonald, 2020). This perspective entails that teaching itself is a situated social practice and previous scholarship has demonstrated how teaching is constituted relationally between learners in cultural communities (e.g., Cazden, 2001). Attending to the social dimensions of teaching highlights how learning occurs through the interaction between teachers, students, and settings (Greeno, 1998; Horn & Little, 2010).

This work centers how teachers create the relationships between themselves and their students, content, and contexts (Liston, 2004). Teaching is a process that is emotional, relational, and personal (Nieto, 2003) Many have argued teaching requires not only respect for students but heart, love, and a belief in the transformational power of education (Parker, 1997; Nieto, 2003). Liston (2004) argues: "At the core of an educational experience are a felt sense of awe and wonder, an encounter marked with struggle and frustration, and understandings that are precious and transforming" (p. 459). Similarly, Nieto (2003) suggests that good teachers imagine the possibilities for their students beyond the dire circumstances in which many of them live. I combine these teacher education theorists with social practice theory to foreground two primary conceptual understandings. First, the 'emotive relationality' that is captured in both the essence of Liston's (2004) notion of "love" and Parker's (1997) notion of "heart" foregrounds the direct relation between teacher and student. Second, 'transformational possibility' relates to students' understanding of self-growth and/or changes in institutional and material configurations; both of which are facilitated by the teacher situated in a learning context. This research seeks to better articulate the salient features of teacher facilitation by answering the question: *what relational roles do teachers fill in STEM learning contexts in prisons?*

Background and methods

An impetus for this study was to inform my work implementing STEM learning in prisons. Interview respondents were solicited through a listserv supporting higher education in prison contexts. The only criteria for participation was experience teaching both inside prisons and in traditional classroom and was not restricted to STEM disciplines. I used a structured interview protocol which included questions about content taught, challenges and rewards teaching in prisons, and how traditional classroom practices shifted or not based on experience teaching students incarcerated.

To date 36 interviews have been conducted with teachers from a variety of disciplines and prison programs. Interviews lasted between 30 and 60 minutes. The majority were conducted via video-conference. All audio was recorded and then transcribed. The transcripts were coded deductively according to emotional relationality and transformational possibility and then inductively. Case narratives (Yin, 2009) were written for select participants based on their representativeness of common themes.

Findings

My findings suggest there is a spectrum of relation roles dependent on the variation between: agency and structure, the individual and community, and knowledge for its own sake and as a means towards a liberated future. Every interview was evocative and prevented any quick judgment of the teachers' beliefs and practices. Because of this, contradictions were rampant. However, normative judgments recede when the complexity of the context emerges, thereby challenging any prescriptive claims regarding what roles *ought* teachers play.

I highlight three roles that represent different places on the spectrum. First is Jan, the benevolent disciplinary expert. Jan sees power in knowledge of her discipline, astrophysics and its reliance on math. Since math is the language of science, without it: "you're not going to get anywhere...and there's no use pretending you are." She revels when her students master the content. Next, is Rebecca, the sympathetic intermediary. Unlike Jan, Rebecca hated math and sympathizes with her students that say math is scary. "Algebra is terrifying to a felon. I always joke that these guys - if they knew they were going to have to take algebra when they came to prison, they would not have gotten in trouble." She sees her role as finding the means to help students conquer their fears. Then, there is David, the empathetic preceptor. He attends to the systemic problems of drug addiction rampant in prison contexts and sees the need for systems to bear responsibility that have criminalized health problems. Jan locates transformation in individuals whether they are teachers or students; Rebecca foregrounds changes to systems and practices that can support students' who lack testing abilities; and David analyses the interplay between the individual and society.

Discussion and conclusion

Although these instructors seemingly rest on a continuum of where they locate possibilities for transformation, it remains unclear whether any value ought to be assigned to this continuum. Each teacher has evidence for "success" of their students whether it is being able to help a daughter with homework, obtain a high school diploma, or have a new outlook on life. Embracing learning as a relation between teachers, students, and contexts entails that multiple configurations of teacher-student-goal relations will be present. Furthermore, the cases presented here are a reminder that both schools and prisons exist in socio-political contexts that present challenges to teachers who view their profession as a liberatory project that amplifies access to not only further educational opportunities but also economic and democratic opportunities (Nieto, 1992). There ought to be more than one path to liberation.

The most salient constant of these teachers is their care and love for their students, and their belief in their students' futures. As we as a field continue to apply our knowledge and methods towards teacher learning, we ought to remain vigilant that we do not interfere with this care and love, because in some spaces, like prisons, students are unlikely to have any future without them.

References

Cazden, C. B. (2001). The language of teaching and learning. The language of teaching and learning, 2.

Cobb, P., Zhao, Q., & Dean, C. (2009). Conducting design experiments to support teachers' learning: A reflection from the field. *The Journal of the Learning Sciences*, 18(2), 165-199.

Greeno, J. G. (1998). The situativity of knowing, learning, and research. *American psychologist*, 53(1), 5.

Gresalfi, M., and Horn, L. (Eds). (2020). *The Interdisciplinarity of the Learning Sciences,* 14th International Conference of the Learning Sciences (ICLS) 2020. Nashville, TN: International Society of the Learning Sciences.

Horn, I. S., & Little, J. W. (2010). Attending to problems of practice: Routines and resources for professional learning in teachers' workplace interactions. *American educational research journal*, 47(1), 181-217.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge university press.

Liston, D. P. (2004). The lure of learning in teaching. *Teachers College Record*, 106(3), 459-486.

Nieto, S. (1992). *Affirming diversity: The sociopolitical context of education*. New York: Longman.

Nieto, S. (2003). *What keeps teachers going?*. New York, NY: Teachers College Press.

Palmer, P. J. (1997). The heart of a teacher identity and integrity in teaching. *Change: The Magazine of Higher Learning*, 29(6), 14-21.

Weidler-Lewis, J., Wooten, M., & McDonald, S. P. (2020). The ontological construction of technology and behavior through practice. *Human Behavior and Emerging Technologies*, *2*(4), 377-386.

Yin, R. K. (2009). *Case study research: Design and methods*, 4th. Thousand Oaks.

“You Get to See for Yourself”: Immersive Media to Facilitate Observation and Engagement in Remote Schooling

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Abstract: With protracted school closures forcing young people to learn remotely, schools are in urgent need of innovative approaches that can keep students engaged in their education and support their learning. This poster describes a pilot using Google Cardboard virtual reality viewers and 360-degree videos in remote high school science classes to help motivate and engage students. Early findings from interviews indicate students find them engaging and may be particularly useful for facilitating observational learning.

Introduction

Disruptions to traditional schooling due to COVID-19 are likely to have effects far into the future, including increased high school dropout due to students disengaging from school (McKinsey, 2020). Innovative approaches that create engaging activities and make learning more relevant can be an important strategy for dropout prevention in remote schooling (Kassner et al., 2020). Immersive technology has the potential to increase student engagement, as the sense of “being there” in a virtual space can impact motivation and interest (Dede et al., 2017), including by increasing their focus and attention (Bailenson et al., 2008) and facilitating implicit or observational learning (Slater, 2017). Even short virtual reality (VR) experiences with engaging content may make a difference for students in remote classes that often rely on lectures and static materials, but little is known about their feasibility and effectiveness in this context. Given the myriad distractions young people currently face, and scarcity of engaging and observational learning opportunities, this poster describes a pilot integrating activities that use cardboard VR viewers and 360-degree videos within remote high school engineering classes.

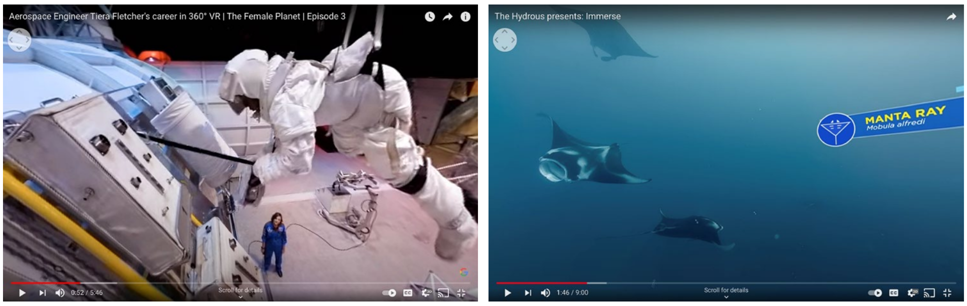

Figure 1. 360 videos used in class. Left: *Aerospace Engineer Tiera Fletcher's Career* (Google). Right: *Immerse: Journey into the Deep Sea* (The Hydrous)

Intervention

This study was conducted in two engineering classes at a public charter high school in a Boston-area midsize city, serving students of whom 100% are eligible for free/reduced-price lunch, 87% are Black or Hispanic, and 13% are English Language Learners. Sixteen of 30 students opted in to the research: seven 12th-grade and nine 11th-grade students, three identify as female and 13 as male. 14 students’ parents, and two students themselves, were born outside the United States. Students are referred to here by pseudonyms.

Initial activities were conducted with five students as one-on-one virtual interviews with the author. Students watched 3-5 videos about structures around the globe related to their engineering projects with a Google Cardboard, and completed pre- and post-surveys and interviews. The second phase consisted of whole-class activities in which all students viewed a 360-video followed by discussions in Zoom breakout rooms. Students participating in the research filled out pre- and post-surveys, and their discussions were recorded and facilitated as focus groups. These activities included a Google video about aerospace engineer Tiera Fletcher and The Hydrous virtual dive about climate change and coral reefs (see Figure 1). The final activity asked students to work in small groups to choose and watch videos together in Zoom breakout rooms.

This poster describes students’ experiences based on interview and focus group data, which were transcribed and analyzed following a flexible thematic coding procedure (Deterding & Waters, 2018). Findings are presented based on the “big picture” themes that emerged from coding by the author and a research assistant.

Student experiences in remote school: “Harder to learn”

Students discussed it being “harder to learn” (Maya) remotely, particularly concepts or subjects they find difficult, where they need to go in-depth, or when material is fast-paced. Students attributed this difficulty to a lack of time with teachers and peers, as well as feeling unmotivated. As Diana put it: “I just feel that [online learning] makes me unmotivated. I don’t want to do it, but I just have to.” They attributed lack of motivation in part to materials, media, and technology in their remote class activities. For instance, Nora said videos and other materials used are not interesting, and “I don’t want to do work at home, I want to watch YouTube, so I am very distracted.” Maya said she finds online classes lacking because she is a “hands-on, visual learner.” Jack described how he missed “the environment” of being in school, and he is discouraged: “I put in a lot, [but] learn less.”

360-degree videos are “more engaging” and facilitate observation

Most students described the videos as *engaging*, demanding focus because “you can’t take your eyes off of it…you have to give your complete attention to it” (Diana) and “because it’s everywhere, it’s all you can see” (Nora). Others described it feeling more “interactive,” because “you can control it, and there’s multiple stuff to look at” (Matthew) and “I can look at what I want to” (Logan). They also found the videos engaging as they related to their interests in travel, careers in engineering, and the environment. Even despite not being very passionate about climate change, Logan said, “I was surprised at how engaged I was” by the beauty of the virtual dive. This may indicate potential for VR to leverage students’ intrinsic motivation if they tie course content to students’ interests and help develop new interests. It is important to note students also discussed the limitations of the media. Students who had tried other VR equipment noted it would feel more immersive if it was a higher quality and more interactive. Others were uncomfortable holding their phones, and felt dizzy or motion sickness.

A theme that emerged from interviews is that students described the benefit of immersive videos as being able to more deeply observe than they have the opportunity to do in other online class activities. Logan felt this through increased agency, “I found it more interesting to be able to look around and look at specific things I want to look at.” Nora described this in contrast to more typical instruction: “You just kind of follow them around and just observe… instead of talking at you, you get to see for yourself.”

This deeper observation may help students learn about places and phenomena in a way that is particularly difficult in remote schooling. Logan described the virtual dive as very useful to show “how beautiful the ocean looked…during the pandemic VR gives us—closer to reality, to a more interactive experience.” And for Maya it made her feel “okay with the quarantine… especially now that we can’t [travel], this is like the next best thing.” The ability to look around freely and at different angles also made it easier for them to understand the environment.

Conclusions

This small pilot points to interesting findings to inform future work. First, students are clearly struggling with remote schooling, and they feel their learning is suffering. Given the likelihood that this and many other schools will remain online for the foreseeable future, schools urgently need to find solutions to support them, to increase their engagement, and help make learning easier. While the intervention described here, utilizing immersive videos and cardboard headsets, will not address many of the students’ challenges, the pilot suggests they may be helpful in engaging students and giving them a different way to work with curricular materials.

References

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The Use of Immersive Virtual Reality in the Learning Sciences: Digital Transformations of Teachers, Students, and Social Context. *Journal of the Learning Sciences*, 17(1), 102–141.

Dede, C., Jacobson, J., & Richards, J. (2017). Chapter 1: Introduction: Virtual, Augmented, and Mixed Realities in Education. In D. Liu, C. Dede, H.-M. Huang, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education.* Springer Nature.

Deterding, N. M., & Waters, M. C. (2018). Flexible Coding of In-depth Interviews: A Twenty-first-century Approach. *Sociological Methods & Research*.

Kassner, L., Jonas, D., & Klein, S. (2020). *Dropout Prevention in the Time of COVID-19*. IES.

McKinsey. (2020). *Achievement gap and coronavirus*. McKinsey.

Slater, M. (2017). Implicit Learning Through Embodiment in Immersive Virtual Reality. In D. Liu, C. Dede, R. Huang, & J. Richards (Eds.), *Virtual, augmented, and mixed realities in education*. Springer Nature.

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Datafication in Figured Worlds: Narrating COVID-19 Data

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Abstract: The COVID19 pandemic offers an opportunity to inspect how people make sense of the world with data in their everyday lives. Using a theoretical framework based on the construct of *figured worlds,* we conducted think-aloud interviews to study the ways people narrate their routines with data during the pandemic. The analysis enabled us to characterize people's constructions of their agency as interpreters of data; the ways they manage the uncertainties of data; their data-mediated judgements and decisions during the pandemic. These constructions of agency and identity in a data-infused world help us understand both how we learn about the pandemic with data, and more generally, how data mediates our learning about the social world.

Data and data representations permeate many facets of our lives (Couldry, 2018): how we make decisions, and define social structures and positions, such as race, justice, health or pathology (Dourish & Gómez Cruz, 2018). Data interpretations and reasoning with data "play an ever more important role in decision-making and knowledge about the world" (Kennedy, Hill, Aiello, & Allen, 2016, p. 715). Understanding the ways people reason with data in everyday life is key for better preparing learners for civic participation in a datafied world (Feinstein, Allen, & Jenkins, 2013; Rubin, 2020). The information ecosystems (Bhargava, Deahl, Letouzé, Noonan, Sangokoya & Shoup, 2015) around COVID19 present a valuable context in which to examine everyday data literacy. The kinds of information-seeking, sensemaking, and critical judgments that people engage in as they try to understand the pandemic provide a rare window into how people engage with data in a way that is personally meaningful and consequential. We present an analysis of diverse people's interpretations of COVID-19 data representations.

Theoretical framing

We draw on Holland, Lachiotte, Skinner and Cain's (1998) framework of *figured worlds*, which are "socially and culturally constructed realm[s] of interpretation in which particular characters and actors are recognized, significance is assigned to certain acts, and particular outcomes are valued over others" (p. 52). For Holland et al, people are constantly constructing the figured worlds in which they live and narrate themselves and others into relationships in which their agency and identity are positioned in particular, culturally-embedded ways. The narratives that people tell about their use of data (Radinsky, 2020) enable us to see the meanings that they attribute to the resources that they regularly use.

Methods

We conducted semi-structured, task-based interviews in which we asked people to re-enact (using think-aloud) their routine practices with online data and other sources of COVID information. We analyzed the interview transcripts using content analysis and an immersion approach (Crabtree & Miller, 1999) based on the figured worlds framework. We present a set of illustrative examples drawn from 6 interviews, based on initial analysis of a subset of data from a study that is still under way.

Findings

We identified diverse data routines across participants, each of whom was easily able to describe routine information-seeking practices they had developed since the onset of the pandemic. In their descriptions of these routines, we found that people narrated figured worlds in which they were positioned in notably different ways with respect to the data, and to the represented-world phenomena that those data described. Here we present brief, illustrative examples of some of these findings.

Degree and forms of agency as interpreters of data

Interviewees positioned themselves differently in terms of their own agency as consumers and interpreters of COVID19 data. Some described situations in which they would regularly seek out particular information, but were not sure why those data were important, and offloaded the decision-making agency to others:

> I would just check this as an update to know, like, what's the situation in [my country], mostly to see if it's good, bad, or it's or if it's getting better. … I don't remember how they said it, you

> have to do like people per million cases or something, that's also another calculation that they do. … I don't remember 100%, I could be wrong. [P4]

In contrast, others positioned themselves as critical consumers of data with specific expectations, based on how they intended to interpret and use the data:

> And also trying to find sources that show numbers per population, because just the numbers by themselves aren't as helpful if they're not referenced to, you know, the same, per 100,000 people or something like that. … Like just the other day I was trying to compare [my country] and the US. And I was like, That's not very helpful because their populations are different. So unless I can find a source that just shows percentage, or unless I calculate percentage myself, which I've done, it's not – the population is so different, where it's not worth comparing. [P5]

Judgments and decisions mediated by data

Participants positioned themselves as critics of various public policy decisions, narrating scenarios to illustrate why their judgments made sense, and to applaud or critique others' judgments:

> Some of the decisions made didn't make sense, were not rational. … people could have weddings and other religious events [where] we have 250 people participating, when everyone knows that the chances of physical distancing at an event like that are zero. Whereas other events [were prohibited] -- such as cinema, theatre, where it's relatively easy to make sure that there's physical distancing, simply because these are events where people have a ticket assigned to a particular seat. [P3]

Judgments of reasonableness and safety colored many of the characterizations of data, which were often recruited as evidence to support or refute a particular policy argument:

> In the beginning, … you would think maybe wearing a mask is not – at first there was not a lot of data to support [the idea that] it's going to help, [we] mostly thought that it helps people who are sick [not] to spread. But now, since you don't know who's sick, then everybody should wear a mask. Those kinds of arguments changed over time. [P6]

These policy judgments were interwoven with descriptions of data and characterizations of societal phenomena, such that interpretation of data and evaluation of policy decisions were often inseparable.

Discussion and conclusion

Data interpretation involves more than cognitive skills and statistical algorithms. When people interpret data as part of their everyday lives, and in ways that have high personal stakes, it is part of a discursive process through which identities are constructed and relationships are negotiated. During this period of the COVID19 pandemic, data constitute an important resource with which people are constructing complex social realities. Our interviewees constructed different narratives mediated by differences in their information-seeking and data-consumption routines. These differences were not determined simply by the sources they used; rather, they were manifested in different narratives that positioned themselves, the data, and the people, places and policies of the represented world in markedly different ways. A robust understanding of data literacy will be informed by an understanding of the ways in which data function within people's narrations as participants in figured worlds.

References

Couldry. (2018). Deconstructing datafication's brave new world. *New Media & Society*, 146144481877596. Retrieved from https://dx.doi.org/10.1177/1461444818775968DOI - 10.1177/1461444818775968

Crabtree, B. F., & Miller, W. L. (Eds.). (1999). *Doing Qualitative Research* (Second ed.): Sage Publications Inc.

Dourish, P., & Gómez Cruz, E. (2018). Datafication and data fiction: Narrating data and narrating with data. *Big Data & Society, 5*(2), 2053951718784083.

Holland, D., Lachicotte, W., Skinner, D., & Cain, C. (1998). *Identity and agency in cultural worlds*. Cambridge: Harvard University Press.

Kennedy, H., Hill, R. L., Aiello, G., & Allen, W. (2016). The work that visualisation conventions do. *Information, Communication & Society, 19*(6), 715-735.

Radinsky, J. (2020). Mobilities of Data Narratives. *Cognition and Instruction, 38*(3), 374-406.

Discursive Identity Negotiation through Questioning in Student Presentations of Learning

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Abstract: This study considers how high school students from diverse backgrounds work to discursively construct their own identities in a learning community through *presentations of learning.* At one school in the Western United States students prepare presentations to highlight major learnings, in and out of the classroom. While students do prepare scripted presentations, analysis suggests much of the articulation of students' evolving identities happen collaboratively through the discursive practice of fielding unanticipated questions from audience members.

Research context

The research site is an alternative, independent residential school, with students recruited primarily from urban communities. While the particular criteria for admission vary on a case-to-case basis, all students were 'otherwise not finding success' in traditional learning environments. Each term students design and perform public facing "Presentations of Learning" which consist of both scripted performances regarding academic content and personal growth followed by an open question period. These unscripted questions offered by peers, faculty, and community members provide and command an invitation for student introspection and articulation about their own personal development, identity in the community, and broader agency in their social worlds.

Conceptual framing and methods

The presentations of learning (POLs) offer an avenue for students to articulate a social identity through narrative performance. Here, I follow Bucholtz & Hall's (2005) understanding that identity is an emergent product of linguistic and semiotic interaction, not a constant internal state that endures in an individual. While students at this site do show some unifying consistent self-narrative, much of the purpose of the POL is to demonstrate growth through time and change since previous trimesters. Identity might also be considered more as a trajectory of short performances that create an evolving narrative chain manifest through speech events (Wortham & Rhodes, 2015). Through these repeated performances, student presenters work to establish both stance and position in their communities. Positioning and stance involve a justification of why a position is taken, and also includes the anticipation or criticism of contrary opinions by other people in contexts. Students prepare for questions from the guest panel and peers prior to the POL and then defend their claims against perhaps unanticipated forms of inquiry.

Ideas, identities, and narratives draw and build upon prior public instantiations and discourse (Wortham & Rhodes, 2015). Many of the ideas students hold about self -dentification 'in their head' perhaps are more accurately conceived of as happening through public discourse. This idea is in concert with Vygotsky's 'general genetic law,' which suggests learners first participate in the social exchange of cultural tools and ideas on the *inter*-mental plane (public) and later take up these ideas on the individual or *intra*-mental plane (Polman, 2010). In this sense, private thoughts and public discourse happen dialogically. All meta-cognitive reflection is mediated by public inter-semiosis. The sort of facilitated public dialogue in events like POLs allows for participants to develop shared vocabularies, thus allowing groups to collaboratively access and generate new reflective awareness of their own experiences situated within a community of practice.

Through a qualitative discourse analysis, I examine POLs as events that allow for and invoke this sort of scaffolded identity articulation and development. As students present their work to a public audience their pre-existing, self-defined identity position is dialogically negotiated through engagement with the community and the mediating venue at hand. The POL model serves as an externally authentic cultural tool that allows students a venue to express their perceived identities while the actual performance creates a space of authentic community connections through questioning (Polman, 2010). In both everyday and institutional speech, questioning is one of, if not *the,* central communicative practices in interaction (Tracy & Robles, 2009). Questions in various forms are not simply means of seeking clarification, but rather perform discursive work to direct conversation in a particular direction that provides interlocutors the opportunity to clarify an utterance and repair any uncertain terms. And, importantly, the responses to said questions provide a platform for the speaker to expand upon, clarify and further justify initial claims.

Data and analysis

In this early work, I focus on two vignettes during one day of POLs. The first episode describes a school administrator coaching visiting community panelist on what forms of questioning are appropriate. The second is an account of a tenured student struggling to answer some challenging questions from a staff member who knew them well. In episode one the school administrator coaches:

Nicholas: We'd like your questions to come from a place of genuine curiosity. If you have been in education for a long time, or been in lots of traditional schools you know there's the "guess what's in my head question" that teachers often ask. Our students have lots of experiences with those kinds of schools; it hasn't worked for them. And so they don't work very well here.... You might ask a question like "Shouldn't you pay more attention to your teachers?" That would be like advice giving, not a great question.

He points out that in 'traditional schools' teachers and adults use questions that do not seek authentic or novel responses from interlocutors. These are not genuine information seeking questions, rather they are discursive power plays to limit the range of possible response (Tracy & Robles, 2009). Nicholas makes clear that these students are used to this form of discursive power maneuver and that it does not work for them. The second vignette describes a second year student's presentation with central themes related to her identity as a black woman, transition to adulthood, and concerns of growing up. In the excerpt below she describes a mathematics class focused on personal finance and life choices and subsequently fields questions from a community panelist.;

Beth: Um, my next class I took was Math for Life, and it talks about like what do I need to be successful in life, and like, what I want myself to look like after [school], and I would say this class taught me that I don't wanna grow up, , I won't, I don't know how, It's hard. I would not, nu-uh, I can't

Anna: I think you make jokes and when you are feeling uncomfortable.. So I guess I'm gonna ask you to sit here for a second, cuz I took my time today to be here and I would like to get some thoughts from you about where you are with that. (Beth laughing, begins to whimper)

Beth: And I don't know anymore (wavering voice), I don't know anymore what my passions are....

Anna: And you mentioned social justice, where does that fit in? (Beth, Laughing... "um, alright....")

Beth goes on to describe her interest in criminal justice reform, fitness coaching, artistic expression and explains that she is not so much afraid of 'growing up', as she feels overwhelmed by the choices and commitments she will make in the upcoming years. Without Anna's insistence, Beth would not have articulated these ideas.

Discussion, implications, and areas for future research

Presentations of Learning offer students an avenue for collaborative reflection, identity exploration and the negotiation of positioning/stance that many high school students are not afforded. POLs provided a ritualized, scaffolded environment that appears to invite a synthesis of personal growth and content knowledge that happens through authentic engagement and discourse with peers and community members. Audience panelists challenge students to clearly articulate their claims and can help maintain high standards and accountability. In responding to unanticipated audience questions student presenters are challenged to reconsider, refine and communicate their evolving ideas, commitments, and sense of self.

The preliminary data presented here suggests that the framing and practices of questioning in POLs is of key importance to best solicit student reflection and engagement. The early implications of this work indicate that engaging in the discursive process of questioning as part of presentations of learning affords students a venue to more fully articulate their own agency and identity, as situated in their broader communities of practice.

References

Bucholtz, M., & Hall, K. (2005). Identity and interaction: A sociocultural linguistic approach. *Discourse studies*, *7*(4-5), 585-614.

Polman, J. L. (2010). The zone of proximal identity development in apprenticeship learning. *Revista de Educación* (special issue on Identity and Education), *353*, 129-155.

Tracy, K., & Robles, J. (2009). Question, questioning, and institutional practices. *Discourse Studies, 11, 131-152.* doi:10.1177/1461445608100941

Wortham, S., & Rhodes, C. R. (2015). Narratives Across Speech Events 8. *The Handbook of Narrative Analysis*

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“You Get to See for Yourself”: Immersive Media to Facilitate Observation and Engagement in Remote Schooling

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Abstract: With protracted school closures forcing young people to learn remotely, schools are in urgent need of innovative approaches that can keep students engaged in their education and support their learning. This poster describes a pilot using Google Cardboard virtual reality viewers and 360-degree videos in remote high school science classes to help motivate and engage students. Early findings from interviews indicate students find them engaging and may be particularly useful for facilitating observational learning.

Introduction

Disruptions to traditional schooling due to COVID-19 are likely to have effects far into the future, including increased high school dropout due to students disengaging from school (McKinsey, 2020). Innovative approaches that create engaging activities and make learning more relevant can be an important strategy for dropout prevention in remote schooling (Kassner et al., 2020). Immersive technology has the potential to increase student engagement, as the sense of “being there” in a virtual space can impact motivation and interest (Dede et al., 2017), including by increasing their focus and attention (Bailenson et al., 2008) and facilitating implicit or observational learning (Slater, 2017). Even short virtual reality (VR) experiences with engaging content may make a difference for students in remote classes that often rely on lectures and static materials, but little is known about their feasibility and effectiveness in this context. Given the myriad distractions young people currently face, and scarcity of engaging and observational learning opportunities, this poster describes a pilot integrating activities that use cardboard VR viewers and 360-degree videos within remote high school engineering classes.

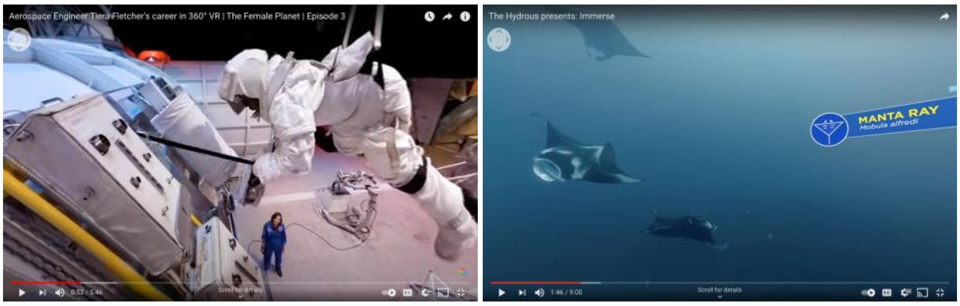

Figure 1: 360 videos used in class. Left: *Aerospace Engineer Tiera Fletcher's Career* (Google). Right: *Immerse: Journey into the Deep Sea* (The Hydrous)

Intervention

This study was conducted in two engineering classes at a public charter high school in a Boston-area midsize city, serving students of whom 100% are eligible for free/reduced-price lunch, 87% are Black or Hispanic, and 13% are English Language Learners. Sixteen of 30 students opted in to the research: seven 12th-grade and nine 11th-grade students, three identify as female and 13 as male. 14 students’ parents, and two students themselves, were born outside the United States. Students are referred to here by pseudonyms.

Initial activities were conducted with five students as one-on-one virtual interviews with the author. Students watched 3-5 videos about structures around the globe related to their engineering projects with a Google Cardboard, and completed pre- and post-surveys and interviews. The second phase consisted of whole-class activities in which all students viewed a 360-video followed by discussions in Zoom breakout rooms. Students participating in the research filled out pre- and post-surveys, and their discussions were recorded and facilitated as focus groups. These activities included a Google video about aerospace engineer Tiera Fletcher and The Hydrous virtual dive about climate change and coral reefs (see Figure 1). The final activity asked students to work in small groups to choose and watch videos together in Zoom breakout rooms.

This poster describes students’ experiences based on interview and focus group data, which were transcribed and analyzed following a flexible thematic coding procedure (Deterding & Waters, 2018). Findings are presented based on the “big picture” themes that emerged from coding by the author and a research assistant.

Student experiences in remote school: “Harder to learn”

Students discussed it being “harder to learn” (Maya) remotely, particularly concepts or subjects they find difficult, where they need to go in-depth, or when material is fast-paced. Students attributed this difficulty to a lack of time with teachers and peers, as well as feeling unmotivated. As Diana put it: "I just feel that [online learning] makes me unmotivated. I don't want to do it, but I just have to." They attributed lack of motivation in part to materials, media, and technology in their remote class activities. For instance, Nora said videos and other materials used are not interesting, and "I don't want to do work at home, I want to watch YouTube, so I am very distracted." Maya said she finds online classes lacking because she is a "hands-on, visual learner." Jack described how he missed "the environment" of being in school, and he is discouraged: "I put in a lot, [but] learn less."

360-degree videos are "more engaging" and facilitate observation

Most students described the videos as *engaging*, demanding focus because "you can't take your eyes off of it…you have to give your complete attention to it" (Diana) and "because it's everywhere, it's all you can see" (Nora). Others described it feeling more "interactive," because "you can control it, and there's multiple stuff to look at" (Matthew) and "I can look at what I want to" (Logan). They also found the videos engaging as they related to their interests in travel, careers in engineering, and the environment. Even despite not being very passionate about climate change, Logan said, "I was surprised at how engaged I was" by the beauty of the virtual dive. This may indicate potential for VR to leverage students' intrinsic motivation if they tie course content to students' interests and help develop new interests. It is important to note students also discussed the limitations of the media. Students who had tried other VR equipment noted it would feel more immersive if it was a higher quality and more interactive. Others were uncomfortable holding their phones, and felt dizzy or motion sickness.

A theme that emerged from interviews is that students described the benefit of immersive videos as being able to more deeply observe than they have the opportunity to do in other online class activities. Logan felt this through increased agency, "I found it more interesting to be able to look around and look at specific things I want to look at." Nora described this in contrast to more typical instruction: "You just kind of follow them around andjust observe… instead of talking at you, you get to see for yourself."

This deeper observation may help students learn about places and phenomena in a way that is particularly difficult in remote schooling. Logan described the virtual dive as very useful to show "how beautiful the ocean looked…during the pandemic VR gives us—closer to reality, to a more interactive experience." And for Maya it made her feel "okay with the quarantine… especially now that we can't [travel], this is like the next best thing." The ability to look around freely and at different angles also made it easier for them to understand the environment.

Conclusions

This small pilot points to interesting findings to inform future work. First, students are clearly struggling with remote schooling, and they feel their learning is suffering. Given the likelihood that this and many other schools will remain online for the foreseeable future, schools urgently need to find solutions to support them, to increase their engagement, and help make learning easier. While the intervention described here, utilizing immersive videos and cardboard headsets, will not address many of the students' challenges, the pilot suggests they may be helpful in engaging students and giving them a different way to work with curricular materials.

References

Bailenson, J. N., Yee, N., Blascovich, J., Beall, A. C., Lundblad, N., & Jin, M. (2008). The Use of Immersive Virtual Reality in the Learning Sciences: Digital Transformations of Teachers, Students, and Social Context. *Journal of the Learning Sciences*, 17(1), 102–141.

Dede, C., Jacobson, J., & Richards, J. (2017). Chapter 1: Introduction: Virtual, Augmented, and Mixed Realities in Education. In D. Liu, C. Dede, H.-M. Huang, & J. Richards (Eds.), *Virtual, Augmented, and Mixed Realities in Education.* Springer Nature.

Deterding, N. M., & Waters, M. C. (2018). Flexible Coding of In-depth Interviews: A Twenty-first-century Approach. *Sociological Methods & Research*.

Kassner, L., Jonas, D., & Klein, S. (2020). *Dropout Prevention in the Time of COVID-19*. IES.

McKinsey. (2020). *Achievement gap and coronavirus*. McKinsey.

Slater, M. (2017). Implicit Learning Through Embodiment in Immersive Virtual Reality. In D. Liu, C. Dede, R. Huang, & J. Richards (Eds.), *Virtual, augmented, and mixed realities in education*. Springer Nature.

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Scientific Model Evaluation during a Gallery Walk

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Abstract: Students in science education struggle with creating and iteratively revising models based on evidence. We report on an implementation of a "gallery walk" activity where 5th grade students used the Model and Evidence Mapping Environment (MEME) software tool to develop and then critique each other's models of an algal bloom. MEME was designed to support students in creating visual models organized around the components and mechanisms of the target phenomena, linking evidence to those models, and then providing and responding to comments on the specific features of the model. Findings illustrate how this was a productive environment for students to make their ideas about modeling criteria visible, and how their ideas cut across normative dimensions of modeling expertise.

Keywords: modeling, science education, complex systems, peer critique

Objectives or purposes

Modeling is a core practice across scientific domains, and thus an important practice for students to learn (NRC, 2013). Scientists create models of phenomena based on the evidence they currently have, and iteratively refine these models in response to feedback and new evidence (Pierson, Clark, & Sherard, 2017; Schwarz, Reiser, Davis, Kenyon, et al., 2009). Thus, helping students learn how to engage in modeling practices necessarily means helping them understand the epistemic elements of this practice, including the value of continuously refining models of a phenomenon to reflect new evidence (Duncan, Chinn, & Barzilai, 2018). The Scaffolding Explanations and Epistemic Development for Systems (SEEDS) Project aims to understand how fifth grade students engage with evidence as they explore a phenomenon (algal blooms) through modeling. To support this modeling practice, we developed the Model and Evidence Mapping Environment (MEME): a software tool that helps students create a simple visual model, view new evidence of the phenomena being studied, iteratively refine their model in response to the evidence, and explicitly link evidence to the model to help indicate how the features of their model are supported by the available evidence (see Figure 1). To help students reflect upon and revise their models, MEME also includes a "comment" function that the teacher and other students can use to offer feedback on specific aspects of the model. The current paper reports on the implementation of a "gallery walk" activity in which students offered feedback on two of their peers' models, then responded to their peers' feedback. This activity was intended to help students identify opportunities for improving their models, and to help make students ideas about modeling and its' relationship to evidence public for discussion and reflection.

Methods

The gallery walk was a single activity incorporated into a five-week long unit with a grade five classroom of 20 students (of which 15 boys and 4 girls consented to participate in the research) at a public elementary school in the American Midwest. The students worked in dyads throughout most of the unit with each dyad assigned a computer to access MEME. During the unit, students were introduced to modeling, presented with the phenomenon of interest (green "stuff" on a pond leading to fish dying), and provided access within MEME to research reports and computer simulations to use as evidence while iteratively updating their own models. New evidence was introduced and explored each session, with students encouraged to revise their models as they uncovered new ideas. After 10 sessions, the students participated in the gallery walk. All sessions were video recorded.

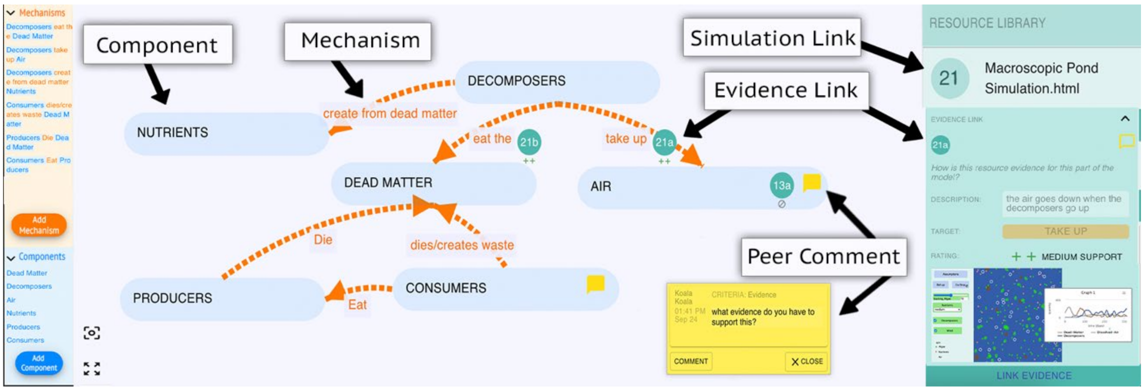

Figure 1. A student groups' model, with an open comment that asks what evidence the authors had to support their choice, a common question when students were unclear about an element, or thought it was incorrect

Results

Our analysis of students' interactions with MEME re-enforce the evidence that 5th grade students can engage in productive model critique sessions, particularly when organized around a "gallery walk" model and shared collective criteria. Furthermore, they shed light on students' negotiation and understanding of good modeling practices, and the role of evidence in these practices. Notably, students appear to focus first on obvious gaps in the model (e.g., a missing mechanism connecting a component to the rest of the model), or missing evidence. However, with the help of MEME, students did look for evidence to support their peer's models, and even discussed whether the evidence they had available to them supported or contradicted the model in clear ways. While our long-term hope is that students will focus primarily on these more nuanced evidentiary standards, we also recognize that it is hard to evaluate a model that doesn't make sense to the viewer. Thus, this apparent sequence of moving from seemingly superficial comments to more nuanced critique is quite intuitive, and future work would benefit from engaging both levels as those seemingly superficial levels are in fact necessary groundwork for the more robust sensemaking.

References

Duncan, R. G., Chinn, C. A., & Barzilai, S. (2018). Grasp of evidence: Problematizing and expanding the next generation science standards' conceptualization of evidence. *Journal of Research in Science Teaching, 55*(7), 907-937.

NRC. (2013). Next Generation Science Standards. In: National Academy Press Washington DC.

Pierson, A. E., Clark, D. B., & Sherard, M. K. (2017). Learning progressions in context: Tensions and insights from a semester-long middle school modeling curriculum. *Science Education, 101*(6), 1061-1088.

Schwarz, C. V., Reiser, B. J., Davis, E. A., Kenyon, L., Achér, A., Fortus, D., . . . Krajcik, J. (2009). Developing a learning progression for scientific modeling: Making scientific modeling accessible and meaningful for learners. Journal of Research in Science Teaching, 46(6), 632-654. doi:10.1002/tea.20311

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Computational Art Practice in Transdisciplinary Contexts

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Abstract: Leveraging Dewey's vision of learning as an aesthetic experience, we join other contemporary scholars in arguing for transdisciplinary approaches to STEM education that harness computational thinking and art. We present a transdisciplinary STEM context: a game design course, Modeling Time, focused on supporting students' exploration of history. We use a mixed-methods approach to capture the ways students create and share computational and art knowledge with peers. This work contributes to understanding computational art practices.

Introduction

Computational thinking (CT) education has largely focused on integration within computer science (CS) and, more recently, in science, technology, engineering, and mathematics (STEM) (Grover & Pea, 2013; Weintrop et al., 2016). We seek to broaden this perspective, drawing upon Dewey's vision of learning as an aesthetic experience (Dewey, 1934) to argue that these computational practices should not be siloed within one field. Proponents of transdisciplinary education in STEM argue for the importance of bringing art together with STEM disciplines (Sengupta et al., 2019; Kafai, Proctor, Lui, 2019). For these contemporary scholars, art is not simply a context for STEM integration. Instead, art fundamentally shapes the experience of STEM in a way similar to Dewey's notion of aesthetic experience (1934). Within education, efforts to combine CT, art, and STEM have been shown to be successful in engaging children's deep thinking while sparking creative epistemologies (Sendova & Grkovska, 2005; Turkle & Papert, 1990). In this paper, we respond to this call with the design of a computational learning environment at the intersection of history, art, and STEM, or game design more specifically. We build on the successes of other scholars who designed and implemented game design environments to support computational thinking and creative practices in learners. We also add a historical layer to game design. In this paper, we explore the ways that students gained, shared, and co-created knowledge related to their computational art practices. More specifically, we ask: How do students collectively explore and share computational art practices within a STEM context?

Methods

We explore this intersection of art and computational thinking through the context of a game design course called Modeling Time, which took place during a weekend enrichment program in a Midwestern city in the US. The course totaled 10 educational hours. In this course, eight 5th grade students learned how to create 2D and 3D game environments using the Unity game engine. Both authors designed and co-taught the course. More information about the design, educational scaffolding, and student artifacts can be found in the authors' prior work (Martin & Anton, 2018). Seven students, ranging from 10-11 years old, participated in the research study (4 F, 3M). For this paper, researchers analyzed 5.5 hours of video of the class while the students were working in a large group with computational tools. We coded the data with themes and practices related to sharing knowledge and critiquing design found in literature on practices of art spaces (Becker, 2008). The finalized coding scheme captures the four codes: *showcasing* (a student showing others their work), *auditory reaction* (a student vocalizing a reaction to their design without response from others), *peer help seeking* (a student asking another student a question), and *facilitator prompted design* (facilitators providing support or help without prompting).

Findings

A total of 99 episodes were identified across the 5.5 hours of video analyzed. The total counts for each code are as follows: *showcasing,* 37; *auditory reaction,* 35; *peer help seeking,* 21; and *facilitator prompted design,* 23. We graphed these codes to show their occurrence over time (in minutes) (see Figure 1). This graph shows that there were more episodes of *facilitator prompted design* during the first day. The students were more expressive about their designs starting near the end of the first day and continuing throughout the second day. We observed higher occurrences of *showcasing*, *auditory reaction*, and *peer help seeking* during these periods, especially during the second day. There were more coded events, and higher occurrences of these student-initiated events (*peer help seeking*, *auditory exclamations*, and *showcasing*) on Sunday compared to Saturday.

There are several explanations for why we might observe these differences across the two days of the course. From a social perspective, students got to know each other over two days, so we would expect to see more social behavior emerging as they spent more time together and became more comfortable with each other.

Qualitatively exploring the coded episodes, we found that on the first day, students more often showcased their work to facilitators; students would raise their hands to show off progress or make comments as the facilitators walked past them in the room. This pattern aligns with the social hypothesis that students may not have felt as confident to share with peers.

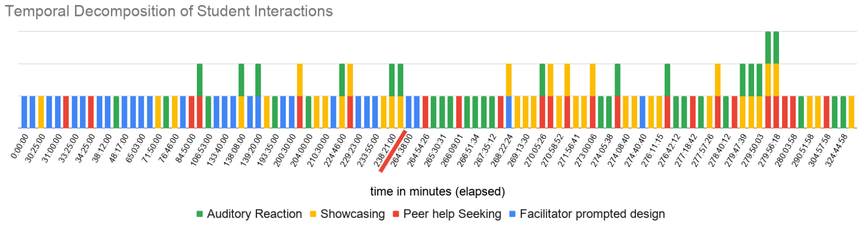

Figure 1. Temporal decomposition capturing the temporal pattern of codes across the course.

Looking more closely at the data, we began to see that these patterns of limited social engagement with peers also aligned with the times when students were exploring 2D game environments. During the end of the first day, we introduced layering 3D elements within the 2D spaces to create depth within their platformer games (specifically at 1:36:20 minutes). After this was introduced, students began to showcase with more frequency to peers. On the second day, we observed that students showcased to peers throughout the entirety of the day. Moreover, they began to engage in help seeking from peers, suggesting emergent perceived expertise. These moments of help seeking encapsulated both computational questions (e.g., “Ice? Where do you have ice? How do you do it? Show it to me”) as well as artistic or design questions (e.g., “Should I get a snow mountain?”, “Does the desert have a lot of trees?”). This shift may relate to a deeper connection with the 3D medium compared to 2D. When asked if anyone had experience with 2D platformer games, only one student indicated they had played a 2D platformer game. When asked about 3D games, all students indicated at least some experience with 3D games, and several compared it to popular sandbox videogames.

Discussion and conclusion

We explored the role that students take in creating and sharing computational art practices within a transdisciplinary STEM course. We found that students, if interested and inspired, are vocal in reacting to their designs and seek to share their achievements with others, particularly peers. This work reflects the outcome of a small group of students over a short period of time. As such, these patterns of engagement may not appear in larger, more traditional courses. We seek to explore how this work translates into formal classrooms to further support sustainable efforts in transdisciplinary computational art practices. Additionally, future work will explore the deeper interactions between learners. The success of this course design in sparking the interest and computational artistic practices in learners suggests the utility of this type of transdisciplinary, aesthetic STEM learning experience.

References

Becker, H. S. (2008). Art worlds: updated and expanded. University of California Press.

Dewey, J. (1934). Art as experience. Penguin.

Kafai, Y., Proctor, C., & Lui, D. (2019, July). From theory bias to theory dialogue: Embracing cognitive, situated, and critical framings of computational thinking in k-12 cs education. In *Proceedings of the 2019 ACM Conference on International Computing Education Research* (pp. 101-109).

Martin, K. & Anton, G. (2018). Modeling Time: A constructionist learning environment for history learning in unity. In Constructionism Conference.

Sendova, E., & Grkovska, S. (2005). Visual modeling as a motivation for studying mathematics and art. *Educational Media International*, *42*(2), 173-180

Sengupta, P., Shanahan, M.-C., & Kim, B. (2019). Reimagining STEM Education: Critical, Transdisciplinary, and Embodied Approaches. In P. Sengupta, M.-C. Shanahan, & B. Kim (Eds.), Critical, Transdisciplinary and Embodied Approaches in STEM Education (pp. 3–19). Springer International Publishing. https://doi.org/10.1007/978-3-030-29489-2_1

Turkle, S., & Papert, S. (1990). Epistemological pluralism: Styles and voices within the computer culture. Signs: Journal of women in culture and society, 16(1), 128-157.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. Journal of Science Education and Technology, 25(1), 127-147.

Constructivist Dialogue Mapping: A Comparison of Museum Experience

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Abstract: We employ constructivist dialogue mapping to provide a comparison between the learning experience in a traditional museum exhibit, and the experience while using an agent-based modeling game built for learning in a museum. This paper serves as an example of the power of CDM to track the results of turning knowledge authoring over to the visitors.

Key Words: Museums, Evaluation, Agent-Based Models, Ants, Complexity, Constructivist Dialogue Mapping, Elaboration as Learning

Introduction

Since Leinhardt and Crowley (Leinhardt et al., 2003; Leinhardt & Crowley, 1998) presented their vision for studying elaboration as learning, museum studies has been looking for a way to operationalize studying elaboration. The framework makes it clear that it is essential to attend to the richness of visitor conversation around an exhibit. In this paper we offer a tenable means to track these elaborations using constructivist dialogue mapping (CDM) (Martin et al., 2020) and use it to compare between two museum experiences. Using CDM, we operationalize Leinhardt and Crowley's vision to present findings from exhibits that show divergent interaction types: deep behavior observation and wide recognition. Thomas Humphrey and colleagues argue that hands-on interaction with science museum exhibits is not the same as active, prolonged engagement (Humphrey & Gutwill, 2005). They argue that designers should look beyond attracting and initially engaging visitors to focus more on creating situations that invite prolonged exploration. *Learning Conversations in Museums* (Leinhardt et al., 2003) proposed a means to study how learning actually occurs in museums. The authors' work in museum learning addresses and attempts to solve a core issue: what constitutes learning in museum research, and specifically, what terms or actions do we track in order to measure it. From these problems, the authors propose three outcomes, the last of which is important for CDM. They argue that their approach provides a novel, stable, and distributable methodology to conceptualize, collect, and analyze conversations as a process and as an outcome of learning in the museum context. The qualitative method we use in this study, CDM, has the same aim and could solve core operations issues with the original framework, which we will demonstrate in this paper.

Methods

In this paper we compare the outcomes of the two exhibits using constructivist dialogue mapping (Martin, et al., 2020). Using conversational elaboration measured through CDM, we present the analytical result of the experience of a traditional exhibit and compare it to the result from a game-based exhibit. The game, Ant Adaptation, was designed to afford participants agency in authoring their experience. One hundred fifty participants played the game in the museum, and six participants walked through the traditional exhibit. We recorded all the interactions. We recruited participants as they approached the exhibits. we asked participants for permission to conduct a pre-interview. The three participants featured in this report were white women aged 30, 40, and 22. They were selected to make the samples more comparable. When patrons played the game, they walked up to it and interacted with it. We collected pre- and post-interviews, as well as recorded audio of their interaction. We then transcribed these recordings for a total of 150 interactions.

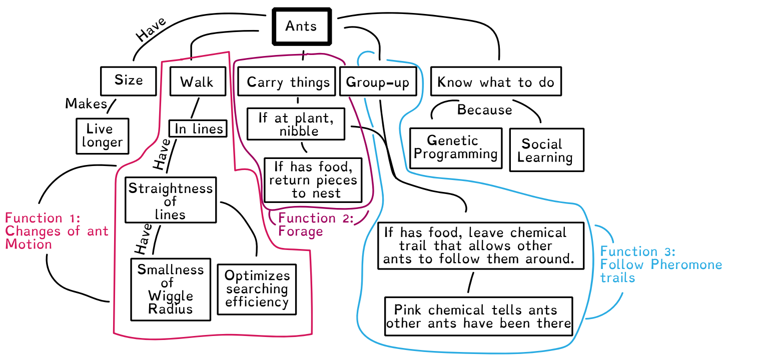

Figure 1. Change of ant motion, foraging, and pheromone trails explains how ants explore space.

Findings

We found participants name more total items in the traditional museum experience — wide recognition — but they elaborate more on items when using the dynamic agent-based model — deep behavior observation. Groups in the traditional exhibit referenced far more items during their visit. To demonstrate the differences in elaborations, we present an example of each exhibit below.

Marcia engages in deep behavior observation during a one-hour interaction with the game, Ant Adaptation. Marcia learned that size does not negatively affect an ant's chance to reproduce. But what led to her discovery was more complex: she first had to learn that an ant colony is a complex system where only the queen reproduces, and all the individual insects work towards that collective's betterment. At the beginning of the interview, she made basic observations about ants. When the interviewer asked if she'd ever noticed anything about ants she said "Yeah, they walk around and sometimes they appear in big groups walking around and sometimes they carry things from place to place. Like food stuff, and house building materials."

While playing, as shown in Figure 1, she ideates three functions: (1) 'Changes of Ant Motion', (2) 'Forage', and (3) 'Lay Pheromone Trails'. They are labelled in red, magenta, and blue, respectively. Extrapolating on these functions, she attains her big learning moment: that more, small ants collect more food faster and, therefore, "Smaller ants will reproduce at a faster rate." This implies a systems-understanding of how food flows into the colony.

We juxtapose this deep elaboration with the much wider, shallower elaboration afforded by the traditional exhibit. Two women—a mother and a daughter—attend an exhibit about biodiversity. During the pre-interview they named only one first order item, and two elaborations that expand its meaning: "Specimens (are) pieces of the natural world (that are) studied." While they walk through the exhibit, they elaborate on the items they notice but offer almost no behavioral elaboration. As shown in Figure 2, as they walk through, they mention a turtle they are looking at and take note of its aesthetic. They notice a bear brain that is "not very big", and gar, which the daughter hates. They note a pit viper would have made "Indian Jones unhappy", and that the tube worm is "gross and creepy". Notably, there is very little elaboration: of the 28 items they notice while walking through, they offer 18 elaborations, with an average elaboration of less than 1 per item. The elaborations they offer are surface level, such as "really pretty," "hates them," or "not very big." These are in contrast to the elaborations of functions noted while playing the game. After attending the traditional exhibit, during the post-interview, the two only mention six total items.

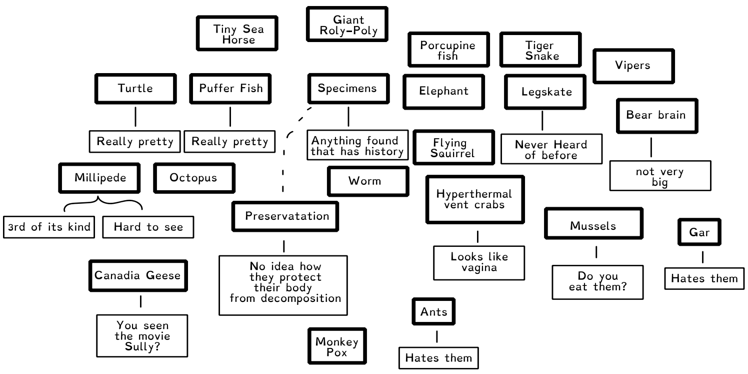

Figure 2. What was noticed during the biodiversity exhibit.

Conclusion

We seek to gain a better understanding of how constructivist dialogue mapping can help researchers understand how learners elaborate on their understanding, both in dynamics of systems and more traditional museum exhibits. In this paper, we saw two different types of learning unfold: (1) wide recognition and (2) deep behavior observation. In the biodiversity exhibit, we saw participants name a wide range of ontological items they noticed as they walked through. In contrast, while playing Ant Adaptation, participants deeply elaborated on the behavior of fewer ontological items. This paper has shown that CDM can demonstrate learning as elaboration, operationalizing Crowley and Leinhardt's earlier work. As seen through using CDM, we demonstrate that we can evaluate the design of museum exhibits and their impact on the type of learning the exhibit affords.

References

Humphrey, T., & Gutwill, J. (2005). *Fostering Active Prolonged Engagement. The Art of Creating APE Exhibits. Exploratorium*. Left Coast Press, Walnut Creek, CA.

Leinhardt, G., & Crowley, K. (1998). Museum learning as conversational elaboration: A proposal to capture, code, and analyze talk in museums. *Report Available at Http://Mlc. Lrdc. Pitt. Edu/Mlc*.

Leinhardt, G., Crowley, K., & Knutson, K. (2003). *Learning conversations in museums*. Taylor & Francis.

Martin, K., Horn, M., & Wilensky, U. (2020). Constructivist Dialogue Mapping Analysis of Ant Adaptation. *Informatics in Education*, *19*(1), 77–112. https://doi.org/10.15388/infedu.2020.05

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Development of a Faculty Community of Practice for Scholarship of Teaching and Learning

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Abstract: Long-term sustainability of high-impact pedagogical practices following faculty development is often difficult. Thus, a multidisciplinary community of scholars, the Innovation and Design for Exploration and Analysis in Teaching Excellence (IDEATE) community, was created. The IDEATE model is grounded in learning sciences, complex conceptual systems, situated learning theory, and design-based research to enable faculty to implement transformative practices, evaluate impact, and iteratively improve learning designs. Scholars participated in interviews regarding teaching and learning, attended learning sciences workshops, generated collaborative artifacts, and developed scholarship of teaching and learning (SoTL) projects. Preliminary analysis suggests changes in practice and understanding of relevant learning theories. Design moves for the second iteration will be discussed.

Background

The purpose of this study is to develop theoretical and practical knowledge regarding the design, implementation, iteration, and impact of this innovative model for conducting Scholarship of Teaching and Learning (SoTL) through the development, support, and long-term sustainability of a community of scholars. The participants, who are also core members of the community, will engage in SoTL studies using the theoretical and methodological framework co-developed by the researchers and the community.

Methodology

This design-based research (DBR) project (Barab & Squire, 2004) involved aspects of case study, grounded theory, and complex systems analysis methodologies. As a DBR study, the primary inquiry is the efficacy of the program design over multiple iterations. The first iteration has been completed, and data analysis is currently underway. Our initial step was the creation of the Innovation and Design for Exploration and Analysis in Teaching Excellence (IDEATE) model for the development, support, and long-term sustainability of a community of practice with strong theoretical grounding and shared practices in SoTL. The first core element of the IDEATE model is grounded in situated learning theory, which defines learning as increasing identification with, and engaging in the practices of a community (Lave & Wenger, 1991). The second core element is grounded in complex conceptual systems theory, in which practices in teaching and learning are identified as emergent in conceptualizations of learning (Donaldson, 2019). The third core element is the use of Design-Based Research (DBR) methodology for all studies conducted by the community in classroom contexts (Barab & Squire, 2004; Sandoval & Bell, 2004). The fourth and final core element in the IDEATE model is the adoption of definitions of learning prominent in the learning sciences, including conceptualization of learning as: 1) construction of knowledge and artifacts, 2) as becoming, and 3) as enactive, embodied, embedded, and extended (Donaldson & Allen-Handy, 2019; Steier et al., 2019). The IDEATE model also integrates additional learning sciences theories, including identity theories, constructionist learning (Kafai, 2006), cultural-historical activity theory (Greeno & Engeström, 2014), and 4E cognition theories (Steier et al., 2019). This IDEATE model is visualized in Figure 1 in which the center squares represent the four grounding frameworks, and the outside circles represent design principles. Participants in the initial iteration of the program are 10 academic professional track (APT) faculty and one tenured faculty from various disciplines and departments at a large R1 university in the Southern United States. Before participating in the IDEATE program, community members engaged in semi-structured, in-depth interviews about their current beliefs and practices regarding teaching and learning. As research participants in this study, the community members participated in regularly scheduled, bi-weekly activities and collaborated to produce artifacts such as a community philosophy statement, vision statement, and goals statements. Also, as part of the program activities, each participant produced bi-weekly reflection papers. Semantic network analysis is being used to develop network maps of interacting and interdependent ideas in the complex conceptual systems. Prior to beginning the second iteration of the IDEATE program, data was analyzed for evidence of strengths and weaknesses in design features and the findings have been translated into design moves to inform the next iterations (Barab & Squire, 2004) of the IDEATE program as it expands into a larger group of faculty participants. This

Second phase of the IDEATE program will grow the community of scholars from the initial “core” to a larger self-sustaining community.

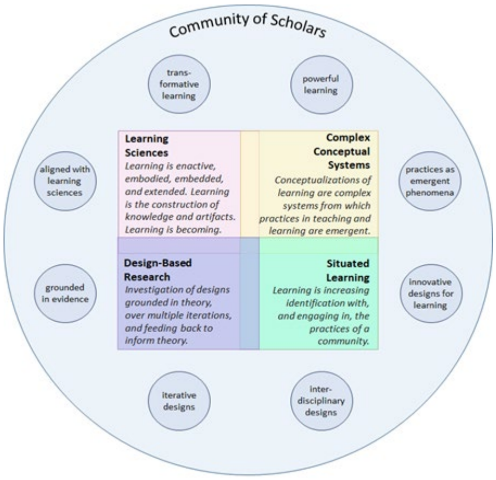

Figure 1. The IDEATE Model.

Preliminary findings

Preliminary findings regarding the community formation suggests that conceptualizations of learning have shifted. The community was highly generative, including creation of robust community documents, and developed three fully-formed SoTL research projects and secured IRB approval. Preliminary findings have been translated into a set of design moves that are being implemented in the second iteration. The first change is in workshop scheduling. In the second iteration of this program, learning for the community (theory and research methodology) will be further integrated with practical application in ongoing SoTL research projects. Transformation of the multidisciplinary community (current form) into an interdisciplinary community is an additional goal of the second iteration. To accomplish this, we are recruiting new members to introduce ideas, technologies, or methodologies from their own disciplines to the broader IDEATE community which could potentially inform new areas of research in teaching and learning.

Significance and discussion

The purpose of this model is to enable faculty to take charge of the implementation of innovative and transformative practices in teaching and learning in a substantive way. This study will add to knowledge regarding scholarship of teaching and learning practices, particularly in the innovative approach of developing a community of scholars around the clearly defined, evidence-based IDEATE model. This study will also provide empirical evidence regarding the impact of addressing conceptualizations of learning as complex conceptual systems from which practices in teaching and learning are emergent. Finally, SoTL projects being investigated by the core community members will result in subsequent publications that will further inform the field of SoTL.

References

Barab, S., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences, 13*(1), 1-14.

Donaldson, J. P. & Allen-Handy, A. (2019). The nature and power of conceptualizations of learning. *Educational Psychology Review, 32*(2), 545-570.

Kafai, Y. B. (2006). Constructionism. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 35-46). NY: Cambridge University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Sandoval, W. A., & Bell, P. (2004). Design-based research methods for studying learning in context: Introduction. *Educational psychologist, 39*(4), 199-201.

Steier, R., Shapiro, B., Christidou, D., Pierroux, P., Davidsen, J., & Hall, R. (2019). *Tools and Methods for ‘4E Analysis’: New Lenses for Analyzing Interaction in CSCL*. International Conference on CSCL

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International Society of the Learning Sciences

How Community-Driven Design Research Endures When the World is on Fire

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Abstract: Scholars have called for *equity-oriented, community-centered approaches* to STEM-related research and design to help address the persistent disparities and inequities in these fields. In response to this need, we explore a *community-driven design research* approach, a collaborative research process in which Indigenous partners maintain sovereignty. As a team of Indigenous and non-Indigenous educators, researchers, and designers, we present our thinking-in-progress of how we have engaged the initial phases of our community-driven research and endured in the midst of global pandemic and unrest in 2020. Findings capture a snapshot of our ongoing insights for effective strategies to engage and sustain community-driven design research as a critical methodological approach.

Introduction

Leaders in informal science education have argued for *equity-oriented, community-centered* approaches to STEM-related research, design, and practice and called for a recognition of the broad and diverse cultural, historical, and political roots of research, science, and technology (Bevan, Barton, & Garibay, 2018). One persistent challenge to broadening participation in this way is that many efforts operate from the assumption that science and research are acultural and apolitical, which results in a deep epistemological tension to *how* (Bang & Medin, 2010; Johnson, 2018; Morales-Doyle, Vossoughi, Vakil, & Bang, 2020). As a team of Indigenous and non-Indigenous educators, researchers, designers, and community members, we take a *community-driven design research* approach, a collaborative design process in which Indigenous partners maintain sovereignty as designers, to our partnership work. In this paper, we share the initial phases of our community-driven design research approach with the shared goal of preserving and sharing the culture of the Northwestern Band of the Shoshone Nation (NWBSN). In particular, we focus and reflect here on how our community-driven work endured and continues to endure both the coronavirus pandemic (i.e. COVID-19) and the global reckoning with racial injustice. We are guided by the following research question: *What are effective strategies and processes for sustaining community-driven design research in 2020?* We present a collective reflection on how our work together has been shaped by the catastrophic events of 2020.

Methods

Our community-driven process is heavily informed by TribalCrit Theory's (Brayboy, 2005) three key principles for partnering with tribal communities: respect and reciprocity in relationships, self-determination, and sovereignty. Our community-driven process is also shaped by community-based design research (CBDR; Bang et al., 2016) approach. This methodological orientation recognizes the historical, cultural, and political nature of partnering with Indigenous communities. We are collectively engaged in a five-year critical ethnographic (Madison, 2011) study. Data include: *fieldnotes* that are collaboratively written every week, *partnership-building artifacts* such as meeting agendas or resources shared, and *in-depth interviews* with the project team. We understand our design process as an intrinsic case (Stake, 2008), which has the purpose of understanding the case itself. We employed a collaborative and reflexive meaning-making analytic approach to construct cases. We collaboratively triangulated interpretations and claims across partners, perspectives, and documentation. Tribal partners' (Author 2, 3, 4 & 5) analytic insights are integrated in this work as transcriptions of data analysis meetings. University-affiliated drafted a re-telling of our collective insights and Tribal Elders reviewed the manuscript and these re-tellings prior to submission.

Insights & Implications

The simple practice of *gathering* was an act of resistance to the isolation the pandemic has brought. Every week we come together as a whole. This showing up, even in the virtual world, is something we attribute to our persisting together as a collective through serious personal challenges and unanticipated project roadblocks. Here are five practices we employed in our gatherings that helped us endure:

Building a collective foundation and vision together. We completed research ethics training, a cultural competence course, and mapping our shared values and goals. Gwen Davis, NWBSN Tribal Elder explains, “I’ve never been part of the ground work like this before. It makes me feel young! It is such an energy…you know, somebody asking you what your opinion is.” Gwen further expounds that this foundation allowed us “to express ourselves [and made] our group stronger.”

Staying flexible and open to new possibilities. Zoom afforded connections amongst the team and, even more significantly, between tribal elders and youth in new ways and across previous geographical constraints. Gwen reflects, “Learning how to Zoom…this is a whole new brand new area, you know, having to speak and talk on a computer.” From these new kinds of connections, a need emerged for a youth coordinator, Monica Smiley, NWBSN Tribal Member. She shares her experience with this practice, “Everyone has a flexible schedule and someone is always available…having this support there is really good like a support system.”

Reflexivity and responsivity. Our weekly gathering became a safe space for reflection and iteration. Patty Timbimboo-Madsen, NWBSN Tribal Elder, highlights, “Because it is research, you know, we have the ability to change...to step back and look at it and review it again to see if we can come up with a better way...”

Adapting technology. Rios Pacheco, NWBSN Tribal Elder, shares “Now we're using the technology and people like what we're doing and we're still sharing our traditions. But what we don't visualize is that other people are tuning into those and now they're generating more information than if we could just talk to them…so it's really helping a lot to share our culture and share the ideas…the stories so that way more people can understand the culture that we have.”

Humor. Put simply, we laugh together. This, for us, is a sign of deepening trust in our relationships.

In our work, we join scholars who came before us (e.g., Bang & Medin, 2010; Johnson, 2018; Morales-Doyle, Vossoughi, Vakil, & Bang, 2020) and argued for a fundamental shift in what it means to conduct research and do science. Our insights build on and contribute to existing work exploring and defining community-based and design-based methodologies (e.g., Bang et al., 2016). We posit that, now more than ever, we must humanize our research methodologies not only for positive community impact, but also to decenter harmful and marginalizing notions of what it means to do research.

References

Bang, M., Faber, L., Gurneau, J., Marin, A., & Soto, C. (2016). Community-based design research: Learning across generations and strategic transformations of institutional relations toward axiological innovations. *Mind, Culture, and Activity*, *23*(1), 28-41. doi:10.1080/10749039.2015.1087572.

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education*, *94*(6), 1008-1026. doi:10.1002/sce.20392.

Bevan, B., Barton, A.C., & Garibay, C. (2018). Broadening Perspectives on Broadening Participation in STEM: Critical Perspectives on the Role of Science Engagement. Center for Advancement of Informal Science Education: Washington, DC.

Brayboy, B. M. J. (2005). Toward a Tribal Critical Race Theory in education. *The Urban Review*, *37*(5), 425–446. doi:10.1007/s11256-005-0018-y.

Johnson, S. R. (2018). Native philosophies as the basis for secondary science curriculum. *Critical Education*, *9*(16), 84-97. Retrieved from http://ices.library.ubc.ca/index.php/criticaled/article/view/186271.

Madison, D. S. (2011). *Critical ethnography: Method, ethics, and performance*. Thousand Oaks, CA, Sage Publications.

Morales-Doyle, D., Vossoughi, S., Vakil, S., & Bang, M. (2020). In an Era of Pandemic and Protest, STEM Education Can’t Pretend to Be Apolitical. *Truthout* [Op-Ed], 08/19/2020. Retrieved from: https://truthout.org/articles/in-an-era-of-pandemic-and-protest-stem-education-cant-pretend-to-be-apolitical/

Stake, R. E. (2008). Qualitative case studies. In N. K. Denzin & Y. S. Lincoln (Eds.), Strategies of qualitative inquiry (3rd ed., pp. 119–150). Thousand Oaks, CA: Sage.

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Implicating Practice: Using Rehearsals to Move Toward Equitable Science Teaching

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Abstract: Student-centered discourse is a key component of "ambitious" science teaching practices in which teachers facilitate discussion that engages students in scientific practices to understand scientific concepts. Simultaneously, teachers must create learning environments that counteract inequities along intersecting axes of identity. But how do teachers learn teaching practices that both support student sensemaking via discourse and respond to issues of equity? We examine one method of in-service teacher learning: rehearsals, or approximations of practice. Building on emerging evidence from prior research, we explore the role of rehearsals in developing secondary science teachers' adaptive expertise in facilitating equitable productive discussion. We analyze data from 17 "debrief" discussions that followed rehearsals, asking how shared knowledge 1) develops around discourse-centered science teaching and equity, and 2) is deployed in teachers' adaptive expertise as they reconsider past practice. Preliminary results reveal the possibility of rehearsals and also highlight the need for clear supports.

Introduction

There have been many calls for science learning experiences to be grounded in student-centered discourse (e.g. Kelly & Chen, 1999). Using "ambitious science teaching" practices, teachers are expected to facilitate productive discussions through which students come to have a stronger understanding of science concepts and increase their capacity for engaging in scientific practices (Windschitl, Thompson, & Braaten, 2020). At the same time, we acknowledge the unequal and unfair landscape of science classrooms; inequities related to marginalization along multiple and intersecting axes of identity, such as ethnicity, race, home language, SES, and others abound (Bang, M. et al., 2012). More and more calls for equity in education put the onus on teachers to counteract these historic inequities (Cochran-Smith et al., 2016). To support teachers in both of these efforts, innovative professional learning practices are needed. Rehearsals are a high-leverage, high-impact, and low-cost practice that show promise for supporting teachers in pursuing ambitious teaching practices and creating more equitable learning spaces (Kavanagh et al., 2020).

Facilitating productive discussion remains a challenging pedagogical practice, as it is a type of practice that demands adaptive expertise, or the expert performance of complex professional practices that shift in response to the contexts of their use (Kavanagh et al., 2020). Baldinger and Munson (2020) hypothesized that rehearsals could be valuable in developing adaptive expertise not only for the teacher doing the rehearsing but also for teachers participating as learners. In this study, we aim to clarify the explanatory power and extent of Baldinger and Munson's model as applied to science teacher learning and also to propose potential extensions an adaptations.

Methods

This study analyzed video recordings of rehearsal debriefs by in-service secondary science teachers in a professional learning experience (PLE) in the United States. Using a qualitative coding framework that integrated *a priori* codes from Baldinger and Munson (2020) with emergent codes, we examined rehearsal debriefs by 17 science teachers, who taught at 15 different schools serving historically marginalized student populations. Each teacher assumed the role of rehearsing teacher (RT) during a 12-minute rehearsal oriented around a discussion-based learning activity, while the 16 non-rehearsing teachers (NRT) participated as students. The authors were the facilitators of this PLE, and we facilitated a 5-minute debrief.

Drawing on teacher noticing research as an analytic framework, we use concepts established in noticing literature, such as attending, interpreting, and implicating (Sherin & Van Es, 2005) to characterize what participants noticed from the rehearsal and then brought into the social space of the debrief for further deconstruction by teachers. We see the moments that participants attended to, surfaced, and made meaning from socially in the debrief as important to understanding the affordances and constraints of rehearsals for the development of adaptive expertise around equitable science teaching. In an iterative process of analysis, we watched video recordings of each debrief discussion, wrote analytic memos, and discussed our interpretations. We then transcribed the debrief videos and applied coding frameworks from Baldinger and Munson (2020) integrated with emergent codes, using utterances as the unit of analysis. Our coding scheme is shown in Table 1.

Table 1: Coding scheme applied to transcripts of rehearsal debriefs

	Code: Definition
Noticing	**Attending:** Statements or description of observable events from the rehearsal
	Interpreting: Statements that assign meaning or analyze an event from the rehearsal
	Implicating: Statements that suggest revisions or how events could have gone differently
Focus of Noticing	**Students:** Noticing (attending, interpreting, or implicating) about students or student thinking
	Practice: Noticing about a specific teaching practice, move, or strategy used during the rehearsal
	Content: Noticing about the disciplinary content of a rehearsal
Position	**Student:** NRT speaks from position of the student or learner
	Teacher: NRT speaks from position of the teacher
Attention to Equity	**Equity:** Any attention to equity within a noticing, including references to specific strategies learned in the PLE to support equity

Findings

Our initial analysis has identified preliminary findings that converge around three broad themes. First, the vast majority of NRTs' noticings utterances were either attending or interpreting, with few instances of implicating, the key type of noticing that can lay the groundwork for growth in adaptive expertise. We suggest that the low frequency of implicating observed here is likely related to the structure through which NRTs were accustomed to giving feedback, which did not create adequate opportunity for implicating. As a result of this protocol, much of the implicating, an important act to support teacher learning via rehearsals, was done in the final phase of the debrief where the RT responds to the comments of the NRTs.

Where we did identify acts of implicating, we saw significant possibility for the development of adaptive expertise. In their acts of implicating, RTs built off of the NRTs' comments that were noticing and interpreting their experience from a student's perspective. RTs used that information to consider revisions for future lessons. Another trend was that ideas and issues of equity were often implicit and emerged through common language used in the PLE. For example, across the PLE, there is emphasis on "equity of voice," or a principle that emphasizes the importance of all students having equitable opportunities to speak and be heard in the classroom. NRTs often referenced "equity of voice" in noticing aspects of rehearsals. We also identified moments in which inequity was implicit, such as in emphases on "academic language." Overall, equity did not figure strongly in the debriefs, despite the PLE having an explicit focus on equity.

Implications

These findings indicate that rehearsals are useful and beneficial for both rehearsing and non-rehearsing teachers. However, structures for providing feedback affect both the content and quality of the debrief discussion. Prompts or feedback protocols that support NRTs in being explicit about whether feedback is attending, interpreting, or implicating may help them analyze and learn from rehearsals. In particular, teachers need increased support around implicating, including examples, prompts, and reflection about how to provide this type of feedback. Finally, structures that support noticings related to equity are especially crucial if teachers are to engage in implicating and increase their adaptive expertise around issues of equity.

References

Baldinger, E. E., & Munson, J. (2020). Developing adaptive expertise in the wake of rehearsals: An emergent model of the debrief discussions of non-rehearsing teachers. Teaching and Teacher Education, 95,

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. Human Development, 55(5-6), 302-318.

Cochran-Smith, M., Ell, F., Grudnoff, L., Haigh, M., Hill, M., & Ludlow, L. (2016). Initial teacher education: What does it take to put equity at the center? *Teaching and Teacher Education*, *57*, 67-78.

Kavanagh, S. S., Metz, M., Hauser, M., Fogo, B., Taylor, M. W., & Carlson, J. (2020). Practicing Responsiveness: Using Approximations of Teaching to Develop Teachers' Responsiveness to Students' Ideas. Journal of Teacher Education, 71(1), 94–107. https://doi.org/10.1177/0022487119841884

Kelly, G. J., & Chen, C. (1999). The sound of music: Constructing science as sociocultural practices through oral and written discourse. Journal of Research in Science Teaching, 36(8), 883–915.

Sherin, M. G., & van Es, E. A. (2005). Using video to support teachers' ability to notice classroom interactions. Journal of Technology and Teacher Education, 13(3), 475-491.

Windschitl, M., Thompson, J., & Braaten, M. (2020). *Ambitious science teaching*. Harvard Education Press.

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MineArt: Active Prolonged Engagement through Participatory Exhibits in Art Museums

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Abstract: Learning in museums has increasingly come to be characterized in terms of participatory and active engagement on the part of visitors. In this poster, we present a design prototype for an interactive art museum exhibit called MineArt. This exhibit allows visitors to create art pieces through modifications of famous artworks with folded notes as scaffolding and a postcard wall for critique and engagement. In this work, we hope to facilitate the meaning-making process of art by creating exhibits that incorporate audience participation and APE (active prolonged engagement).

Introduction

Museums can be described as public institutions of learning—places that people seek out to satisfy their curiosity and to learn more about their worlds. Museum learning is a subset of a larger, ever-evolving continuum of learning and meaning-making across the life span (Falk & Dierking, 2000). Recent trends in participatory museum learning have invited people to create, share, and connect around content and exhibits. Particularly for cultural institutions with a mandate to use their collections for the public good, digitization, and accessibility of content have become a top priority (Simon, 2010). In recent decades, a broad range of digital technologies and devices have been introduced into interpretive encounters with art in museums (Garmil, 1997; Witcomb, 1997) with visitors accessing and producing interpretations across different types of interfaces, platforms, and devices (Steier, et al., 2015).

As a result, we have seen more participatory exhibits emerge from art museums. The Denver Art Museum (DAM) provided a constrained participatory museum experience in their *Side Trip* gallery on display in 2009. Visitors can make their rock music posters with provided materials (Simon, 2020). However, *Side Trip* focuses on the creation instead of understanding and interpretation of existing posters. De Youngsters Studio encourages children to explore art fundamentals through hands-on activities and visual technology (De Youngsters Studio, 2020). However, users explore the fundamental elements of art out of the context of specific artworks.

Inspired by this prior work, we are designing an art learning exhibit called MineArt that we intend to enhance the meaning-making process through personal interpretation and APE (Humphrey & Gutwill, 2005). An APE exhibit aims to foster visitor behavior that includes questioning, exploratory activity, observation, collaborating with other visitors, and searching for and reflecting upon causal explanations for exhibit phenomena (Humphrey & Gutwill, 2005).

Our goal is to enable learners at art museums to 1) appreciate and curate art pieces through modifications of colors and textures on famous artworks; 2) formulate their interpretations through reading the folded; 3) deepen engagement through discussing, critiquing, and taking home a postcard of other visitors' artworks in front of a postcard wall. To sum up, MineArt provides art knowledge in an intriguing and open-ended format while maintaining a free-choice learning environment (Falk & Dierking, 2000) for users to curate and critique as they see fit.

Design principles

In this exhibit, users can change colors and strokes of Monet's Sunset on a tablet. There are folded notes around with questions about the artworks. After unfolding the notes, users will see answers and encouragement of interacting with the tablet. Then users can print their artworks on postcards. They can take them home or hang their postcards on a postcard wall for visitors to appreciate and discuss.

Interpretation and curation stage: An APE environment with constrained participation

We hope to curate an APE by supporting open-ended exploration with gentle guidance, promoting slow looking (Tishman, 2018), and encouraging visitor-initiated observation, speculation, play, and construction. By shifting the visitors' role from that of recipients to that of participants in the generation of activities, questions, and explanations, visitors are more likely to actively interpret and curate art instead of passively receiving information as APE promotes them to create and delight them with beauty (Simon, 2020). Visitors observe more carefully when drawing over the painting, paying attention to the details. This slow looking process helps visitors discern complexities that cannot be grasped quickly and serves as an important counterbalance to the natural human tendency toward fast looking (Tishman, 2018). This is also a process of co-constructing meaning with other visitors, with questions on the card giving anchoring point. Offering learners a famous painting instead of an empty canvas is to purposefully stage constrained participation that provides opportunities for partial self-expression as meaningful constraints motivate and focus participation (Simon, 2020).

Sharing and discussion stage: Deepen and diversify engagement

The process of discussing and taking home users' artworks is of vital significance. We facilitate this process by creating an emotional relationship between exhibit subjects and visitors by asking them to write their design rationale. The Skyscraper Challenge shows that take-home experiences establish deeper engagement and inspire repeat visitation (Simon, 2020). Museum visitors tend to enact one or various combinations of five museum-specific identities, categorized by Falk as explorer, facilitator, professional/hobbyist, experience seeker, and spiritual pilgrim (Falk, 2006). The idea of a postcard wall where visitors can observe, critique, and collect visitor-created artworks serves to offer opportunities for non-explorers such as facilitators to participate in the exhibit. Here, knowledge and interpretations are not owned by any individual actor but are instead treated as patterns of participation that may be attributed to the group (Knutson, Karen, et al, 2021). The postcard-wall also exists as a mediating barrier to invite visitors to engage with each other in some unusual and valuable ways, avoiding potential awkwardness of in-person critique of visitors' artworks (Simon, 2020).

Current progress

At the time of this poster, we have created a full-scale working prototype of MineArt, received feedback from fellow researchers and participants informally. To adjust to the COVID situation, we moved our exhibit online to a website with flip cards as folded notes and an online gallery as the postcard wall. The poster will be accompanied by an interactive demo.

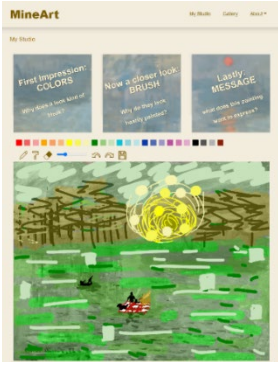

Figure 1. Screenshot. Note the learner-generated artwork based on Monet's

Future work and implications

We plan to launch an initial version of MineArt in early 2021, with the expectation of help inform exhibit curators and create a new experience for visitors to engage with artworks. We hope it will help attract and engage more audiences in the art field. At this time, we are particularly interested in A) better knitting together multiple artifacts into a coherent visiting experience to encourage engagement. B) the emergent learner interactions in its online community and how we can design to better support them.

References

de Youngsters Studio. (2020, April 23). Retrieved from https://deyoung.famsf.org/education/de-youngsters-studio

Falk, J. H. (2006). An Identity-Centered Approach to Understanding Museum Learning. *Curator: The Museum Journal*, *49*(2), 151–166. https://doi.org/10.1111/j.2151-6952.2006.tb00209.x

Falk, J. H., & Dierking, L. D. (2000). *Learning from Museums: Visitor Experiences and the Making of Meaning* (American Association for State and Local History) (First Edition (US) First Printing ed.). Lanham, MD: Rowman & Littlefield Publishers.

Humphrey, T., & Gutwill, J. P. (2005). *Fostering Active Prolonged Engagement: The Art of Creating APE Exhibits (Exploratorium Museum Professional Series)*. Abingdon, United Kingdom: Routledge.

Jones-Garmil, K., & Anderson, M. (1997). *The Wired Museum: Emerging Technology and Changing Paradigms*. Arlington, VA: American Association of Museums.

Knutson, Karen, et al. *Multidisciplinary Approaches to Art Learning and Creativity: Fostering Artistic Exploration in Formal and Informal Settings*. Routledge, 2021.

Simon, N. (2010). *The Participatory Museum* (First Edition). Santa Cruz, California: Museum 2.0.

Steier, R., Pierroux, P., & Krange, I. (2015). Embodied interpretation: Gesture, social interaction, and meaning making in a national art museum. *Learning, Culture and Social Interaction*, *7*, 28–42. https://doi.org/10.1016/j.lcsi.2015.05.002

Tishman, S. (2018). *Slow looking: The art and practice of learning through observation*. New York, NY: Routledge.

Witcomb, A. (1998). Beyond the Mausoleum: Museums and the Media. *Media International Australia*, *89*(1), 21–33. https://doi.org/10.1177/1329878x9808900106

International Society of the Learning Sciences

Outside Learning Environments

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Abstract: The author examines the notion of learning environments while reflecting on a photographic method as an identity resource. As the photographic portraits migrate across spatial contexts and power relationships, the author theorizes about his research practice and the *settled expectations* in the learning sciences. In search of new constructs, terms and practices that foreground nondominant ways of being, he interrogates the dominant construct of *learning environment* in relation to Black spaces.

Introduction, position and purpose

In this paper, I theorize the notion of learning environments in the context of a longitudinal community-based design research project (Bang et al. 2016) in a cohort-based STEM program for nondominant youth in grades 6-11. Using the ongoing project as the background for this discussion, the goal of this paper is to ponder the ontology of *learning environments*—a term deeply entrenched in the vocabulary and epistemology of the learning sciences—in the context of nondominant, specifically Black spaces in and outside of education. I do so from a position of a learning scientist, a foreigner, a migrant with shifting racialized, cultural and linguistic identities working in a dominant Western academic, colonial space and anti-Black system, i.e., within an inherently violent socioeducational context (Sierschynski, 2019).

Photographs, identities and environments

The focus of our community-based design research project has been a simultaneous decentering of settled, settler-colonial expectations of what constitutes scientific practices and the notion of STEM (Bang, Warren, Roseberry & Medin, 2012). I introduced large scale photographic portraits as a main *identity resource* (Nasir & Hand, 2008; Nasir & Cooks, 2009) that rendered nondominant students, instructors and community scholars aesthetically as *being(s) in practice* and space. Ultimately the photographs became objects that they curated and exhibited in their homes. The movement and transformation of the photographs during the project from research data to sovereign objects, i.e., photographic portraits that were used (or stowed away) by the participants in their homes changed the frame of reference for thinking about my work as a researcher who (with the photos) migrated into the realm of public art, i.e., outside of learning environments.

Politicizing learning environments and commitments

Vakil (2020, p.93) writes, "I begin with the position that disciplines are themselves political in that they are dynamically evolving, historically accumulated representations of knowledge congealed together through complex interactions between history, politics, and culture (Bang & Vossoughi, 2016; Medin & Bang, 2014). Learning environments, therefore, always carry and convey political values." Most of us have been disciplined into understanding our participation as researchers in terms that have been defined without us, for us. One such construct is the heuristic of learning environments (Barron & Bell, 2015), a term that has historically allowed us to define a region of interest with broad connotations of arrangements often divided into formal and informal. In a more recent sociopolitical turn in the learning sciences, accepted heuristics are marked as never neutral, thus requiring both marking of space and self in terms of our positionality and commitments as scientists and citizens (Politics of Learning Writing Collective, 2017; Esmonde & Booker, 2016; Vakil, 2020). The Politics of Learning Writing Collective (2017) reaffirmed a direction that requires "more explicit attention to how power imbues the purposes, mechanisms, and consequences of learning, as well as our approaches to the design, study, and theorization of learning environments" (p.92).

In search of new constructs

What does one do when a construct generates normative epistemological commitments while suppressing nonconforming, nondominant personal commitments? Again Vakil (2020, p.88) points to possible paths worth pursuing: "Sometimes this will entail conceptual layering, thickening, or refining of these constructs, while at other times it may mean inventing new frames for seeing and imagining learning anew." So, what does it look like if a preexistent heuristic is in need of further specificity and why does it matter? Dumas and ross (2016) provide the following example in the context of Critical Race Theory (CRT) by refining CRT to become, BlackCrit, "BlackCrit becomes necessary precisely because CRT, as a general theory of racism, is limited in its ability to adequately interrogate what we call "the specificity of the Black" (Wynter, 1989)….it cannot fully employ the counterstories of Black experiences of structural and cultural racisms, because it does not, on its own, have language to richly capture how antiblackness constructs Black subjects, and positions them in and against law, policy, and everyday (civic) life" (p.417). Reading ross (2016) I was struck by what one of her main participants, Ms. C., a Black teacher said about *Black girl spaces*, i.e., specific, thick, refined, identity sustaining spaces: "A part of "just being them" entails the creation of a space where Black girls can hash out what it means to be themselves in an anti-black, patriarchal society" (p. 47). In the absence of such specificity, "the space couldn't really hold" their identities. Nondominant experiences call for thicker terminology that frame oppressed realities and spaces (see Hartman, 2019, Sojoyner, 2016, 2017 on enclosures). Serving as theoretical entry points for approaching oppressive socioeducational contexts and realities, thicker constructs offer the possibility of being able to represent nondominant spaces in ways that I think learning environments do not.

Conclusion

Given that learning scientists seek to understand learning across contexts, at times our research takes us into home environments. In the context of this project, my community participants and their families ultimately received the photographic portraits in their homes. Several of them curated and displayed the images so that they could be seen. In one case, the family of an instructor hung the portrait in a central location of their living room and begun hanging other family photos around it. Finally, thinking of interacting with spaces in the context of the ongoing, transgressive systemic murder of Black citizens in their homes, the need for nondominant intersectional constructs to talk/think about concurrently about learning and space becomes especially urgent. hooks (1990) writes,

> This task of making homeplace was not simply a matter of black women providing service; it was about the construction of a safe place where black people could affirm one another and by so doing heal many of the wounds inflicted by racist domination. We could not learn to love or respect ourselves in the culture of white supremacy, on the outside; it was there on the inside, in that "homeplace," most often created and kept by black women, that we had the opportunity to grow and develop, to nurture our spirits. (p.384)

References

Bang, M., Faber, L., Gurneau, J., Marin, A., & Soto, C. (2016). Community-based design research: Learning across generations and strategic transformations of institutional relations toward axiological innovations. *Mind, Culture, and Activity*, *23*(1), 28-41.

Bang, M., Warren, B., Rosebery, A. S., & Medin, D. (2012). Desettling expectations in science education. *Human Development*, *55*(5-6), 302-318.

Dumas, M. J., & ross, k. m. (2016). "Be real black for me" imagining BlackCrit in education. *Urban Education*, *51*(4), 415-442.

Esmonde, I., & Booker, A. N. (2016). *Power and privilege in the learning sciences: Critical and sociocultural theories of learning.* Abingdon, UK: Routledge.

Hartman S. (2019). *Wayward lives, beautiful experiments: Intimate histories of social upheaval*. New York: WW Norton & Company.

hooks, b. (1990). Homeplace: A site of resistance. In *Yearning race, gender, and cultural politics* (pp. 41–49). Toronto, Ontario, Canada: Between the Line.

Nasir, N. I. S., & Hand, V. (2008). From the court to the classroom: Opportunities for engagement, learning, and identity in basketball and classroom mathematics. *The journal of the learning sciences, 17*(2), 143- 179.

Nasir, N. I. S., & Cooks, J. (2009). Becoming a hurdler: How learning settings afford identities. *Anthropology & Education Quarterly, 40*(1), 41-61.

The Politics of Learning Writing Collective. (2017). The learning sciences in a new era of U.S. nationalism. *Cognition and Instruction, 35*, 91–102.

ross, k. m. (2016). *Black girls speak: Struggling, reimagining, and becoming in school.* (Doctoral dissertation, University of California, Berkeley). ProQuest Dissertations & Theses Global. (2135780167).

Sojoyner, D. M. (2016). *First strike: Educational enclosures in Black Los Angeles*. University of Minnesota Press.

Sojoyner, D. M. (2017). Another life is possible: Black fugitivity and enclosed places. *Cultural Anthropology, 32*(4): 514–536.

Vakil, S. (2020). 'I've always been scared that someday I'm going to sell out': Exploring the relationship between political identity and learning in computer science education." *Cognition and Instruction, 38*(2), 87-115.

International Society of the Learning Sciences

Differentiated Instruction in Online Teacher Professional Development

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Abstract: The integration of computer science into K-12 learning environments requires that teachers be prepared to teach computer science. Due to the pandemic, we transitioned an in-person professional development (PD) for upper elementary teachers to an asynchronous online format. Using reflective interviews, we examine the affordances of this approach. We discuss how the online PD provided advantages for differentiation of instruction and teacher reflection.

Keywords: online, professional development, affordances, differentiated instruction

Introduction and background

Increasingly, meaningful participation in society requires knowledge of computer science and computational thinking (CS/CT). To prepare individuals to become educated citizens capable of computational participation (Kafai & Burke, 2014), governments throughout the world have poured unprecedented resources into computing education, professional organizations have developed K-12 standards for computing and technology usage, and educational systems have worked to integrate computing into K-12 curricula. Despite this push, the number of trained CS teachers remains insufficient to meet the new demand. Researchers in the computing education space have been concerned with how to prepare teachers to teach computing. One of the encouraging avenues to provide CS and CT training to teachers is asynchronous online professional development (PD) (Fishman et al., 2013).

Online PDs are able to provide similar learning as in-person workshops and have been supported by the U.S. Department of Education (2010). High-quality teacher PDs focus on strategies for teaching content and incorporate active learning opportunities for teachers to test and evaluate teaching strategies (Darling-Hammond et al., 2017). Online PDs afford unique opportunities to teachers, such as providing for differentiated instruction by allowing teachers to review new content as many times as necessary to grasp the key ideas or skipping over content that is already familiar. We address the following research question: What are the affordances of asynchronous online professional development for teachers engaged in learning introductory computer science at the elementary level?

Methods

The ESTITCH PD prepares grades 3-6 teachers to implement the ESTITCH curriculum in their classrooms. The ESTITCH curriculum leverages the affordances of making with electronic textiles materials and programmable electronic components that can be integrated into fabric and paper. This allows CS/CT to be integrated with social studies, language arts, and science standards. Originally, we designed the ESTITCH PD to be completed in person, but public health concerns related to the COVID-19 pandemic forced us to move our PD to an asynchronous online model. Teachers were provided with access to a Canvas course that walked them though key ideas in each of the integrated disciplines and provided guides for how to make each of the three ESTITCH projects: (1) a programmable paper circuit timeline, (2) an e-textile quit square based on the patterns of freedom quilts that helped formerly enslaved peoples navigate their passage on the Underground Railroad safely, and (3) a programmable quilt square telling about a meaningful moment in one's life (see Figure 1). We also provided Zoom office hours with project research assistants for troubleshooting and debugging.

Twenty-seven elementary school teachers were recruited from throughout the state of Utah to participate in the online PD, two of whom were master teachers completing the PD for the second time. Of the 27 teachers who started the PD, 23 teachers completed the training. Teaching experience ranged from none to several years. Importantly, some districts in Utah have robust dual-language immersion programs and actively recruit speakers of those languages to come teach at an immersion school for a period of several years. These teachers teach half the day in their native language (e.g. Portuguese, Mandarin, Spanish) while another teacher teaches the other half of the day in English. Our participant population included Portuguese and Mandarin immersion program teachers.

In order to understand teachers' experiences with the ESTITCH asynchronous online PD, we conducted a post-survey that asked about teachers' online PD experiences. We also conducted exit interviews with each of the teachers. We focus on teachers' final reflective interviews about their PD experiences. We examined the interview transcripts using emergent thematic coding (Nowell et al., 2017). We were interested in the affordances of asynchronous online PD for teachers engaged in learning introductory computer science at the elementary level.

Findings

A central finding of our analyses was that teachers liked the built-in differentiation provided by an online asynchronous learning environment. It allowed them to utilize a variety of strategies to master the content and to troubleshoot and debug their own projects, including reviewing the material independently, connecting with other PD participants, and seeking help from the PD providers.

Time to practice and plan

Many of the teachers appreciated the built-in differentiation provided by an online asynchronous learning environment. Unlike in a traditional in-person PD setting, teachers were able to go back and review content until their understanding was sufficient to create a functional project or pause the modules and create a plan for their classroom in that moment. For instance, one teacher observed, "I went to, the lessons that I read through, and then, I would tell myself, maybe I missed something and I need to restart it again. I would follow through the instructions, and it always helped me figure it out in the end (Interview, 07/24/20)." The asynchronous online format allowed teachers to work through the materials at their own pace, to go back and review when their projects did not work, and to create things for their classrooms in real-time. Further, teachers appreciated being able to read other teachers' discussion posts about things that didn't work in their projects or experiences the master teachers had in their classrooms during the previous school year.

Creative collaboration

Prior to implementing the online PD, we envisioned the lack of opportunities for teachers to connect with one another as a major disadvantage, but teachers found creative ways to reach out to one another and collaborate. As one teacher said, "So we just kinda did it together like that through texting or Face-timing each other and working through it and troubleshooting and stuff like that" (Interview, 07/24/20). Often, we think online asynchronous PD will not offer the same opportunities to connect with one another and form meaningful PLC's. While the teachers who worked together on projects typically already knew one another and worked together, the online asynchronous format supported rather than detracted from their ability to work together.

Discussion

When we transitioned from what had previously been a weeklong, face-to-face PD experience to an asynchronous online course, we were concerned that the experience we provided would be less optimal and present teachers with fewer opportunities for developing PLC's. However, as Fishman and colleagues (2013) argued, the online PD was able to provide a similar, if not better, experience than the face-to-face PD. Teachers' reflections highlighted aspects of an effective PD as outlined by Darling-Hammond and colleagues (2017). In particular, it is significant that the asynchronous nature of the online PD provided teachers with the opportunity to work at their own pace, review materials, and learn from their mistakes. In addition, while teachers' abilities to connect with other teachers were more limited, those teachers most likely to form a PLC, such as a grade-level teaching team, leveraged existing connections to help each other with projects. And, when all else failed, teachers were supported by the PD facilitators for Zoom. Because of the asynchronous online nature of the PD, facilitators were able to provide more focused attention to the teachers struggling the most with technical aspects of the projects.

References

Darling-Hammond, L., Hyler, M. E., Gardner, M., & others. (2017). *Effective teacher professional development*. Palo Alto, CA: Learning Policy Institute.

Fishman, B., Konstantopoulos, S., Kubitskey, B. W., Vath, R., Park, G., Johnson, H., & Edelson, D. C. (2013). Comparing the Impact of Online and Face-to-Face Professional Development in the Context of Curriculum Implementation. *Journal of Teacher Education*. https://doi.org/10.1177/0022487113494413

Kafai, Y. B., & Burke, Q. (2014). *Connected code: Why children need to learn programming*. Mit Press.

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic Analysis: Striving to Meet the Trustworthiness Criteria. *International Journal of Qualitative Methods*. https://doi.org/10.1177/1609406917733847

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Exploring Gender Gap in Students Understanding, Self-Efficacy and Motivation During Maker Activities

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Abstract: This pilot study explored the potential gender gap in understanding, self-efficacy, and motivation while engaging in different making procedures (Assemble or Dismantle). In the Assemble activity, male students made four times more remarks on their understanding than females. The Dismantle activity appeared more compatible with high school/college female students when developing understanding, voicing challenges, contemplating interests, self-efficacy, and motivation. Male students in the Dismantle group showed a decrease in self-efficacy and motivation.

Introduction

The maker movement has provided students opportunities to leverage their developed identities, interests, and knowledge within STEM fields (Martin, 2015). However, gender gaps in maker activities still exist, as makerspaces still reflect stereotypes, lack of women's voices and female leadership roles (Eckhardt et al., 2020). This has led to female students' perceived low competency in technology and making, regardless of their actual competency (Thanapornsangsuth & Holbert, 2017). There is a recognition that maker activities need to be gender-neutral and part of their everyday lives (e.g., dismantling jammed printers). Studies have shown that engaging in reverse engineering, where students assemble and dismantle a product, has helped increase learning, motivation, and perceived helpfulness (Dalrymple et al., 2011). While much effort has been put into maker education, there is limited knowledge of whether gender differences exist in understanding, recognizing challenges, self-efficacy, and motivation while engaging in maker activities. Further examination is needed to explore whether different making procedures (Assemble or Dismantle) may contribute to such outcomes.

Methodology

A total of eighteen students (9 females and 9 males) aged 14-21 from local high schools and colleges (non-science/engineering majors) in Shenzhen and Hong Kong participated in this study. Students were randomly assigned to one of two conditions, Assembling or Dismantling a robotic wind-up generator for 30 minutes (figure 1). In measuring student understanding during the maker activity, all students were asked two questions: "*please put the gear aside for a moment. Can you describe what you understand so far by assembling/dismantling the robotic gear?*" and "*Is there anything you find particularly challenging or interesting?*" These questions were prompted twice, once at the 15 minute-mark (midway), and the second time at the 30-minute mark (at the end). To see how maker activity influences student's self-efficacy and motivation, students filled out a survey before and after the study. The self-efficacy survey used two subsets of the engineering self-efficacy scale: tinkering self-efficacy and design self-efficacy (Mamaril et al., 2016). The survey consists of 11 questions on a Likert scale of 1-6, with 1 at completely uncertain and 6 at completely certain. The motivation survey uses three subsets of the Intrinsic motivation inventory: enjoyment, value and importance, perceived competency (Deci & Ryan, 1986), and consists of 15 questions on a Likert scale of 1-7 with 1 at strongly disagree and 7 at strongly agree.

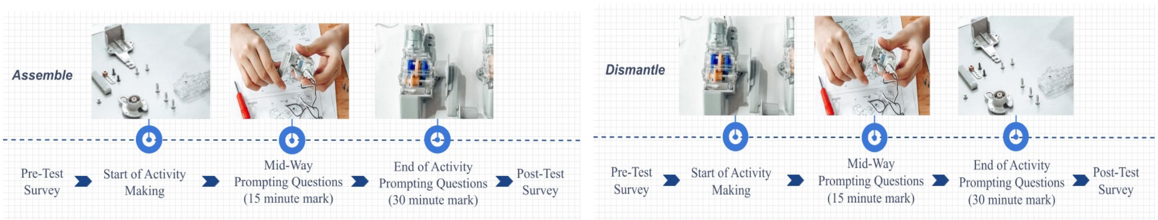

Figure 1. Research Procedure (*Left: Assemble condition; Right: Dismantle condition*).

Analysis and Findings

A coding scheme was developed to label students' remarks from the "understanding" prompt that reflected either basic knowledge on how hand-held generators work (e.g., "*gears move together to drive the* *motor*") or advanced concepts (e.g., "*rotation of the gears generates mechanical energy, which then rotates the motor to generate electricity*") that require interpretation that draws from multiple sources of information. Overall, there was little gender difference in the Dismantle group between female students (total of 22 remarks, avg. 2.4 per student) and male (total 21 remarks, avg. 2.3 per student). In the Assemble group, male students made four times more remarks on their understanding of basic concepts than female students (Male total of 22 remarks, avg. 2.4 per student, Female total of 5 remarks). Interestingly, for female students, the number of remarks on advanced concepts differed significantly across conditions (Female: Dismantle 8 remarks, Assemble 0 remarks), while male students had no difference across conditions (Male: Dismantle 8 remarks, Assemble 8 remarks). In response to the "challenge and interest" prompt question, many of the challenges (41 remarks) addressed either metacognitive reflections (28 remarks, e.g., "*Thinking about where I went wrong. Now I know where I went wrong*") or difficulty in the making (7 remarks, e.g., "can't *unscrew the screw, for some reasons*"). Overall, for both the Dismantle and Assemble group, female students voiced their challenges (Female: Dismantle group 13 remarks, Assemble group 11 remarks) more than male students (Male: Dismantle group 10 remarks, Assemble group 7 remarks). This gender gap was seen in metacognitive reflection remarks (Female: Dismantle group 9 remarks, Assemble group 9 remarks vs. Male: Dismantle group 5 remarks, Assemble group 5 remarks). No gap was seen in voicing difficulty in making. The interest remarks ranged from general (e.g., "it's *interesting to see a lot of gears*") to specific future interests and explorations (e.g., "*I want to try some new methods to assemble and see how many assembly combinations there are*"). In general, male students made twice as many remarks (12 remarks) as female students (a total of 6 remarks) on how the making activity was interesting. Female students in the Dismantle group (4 remarks) made slightly more remarks than those in the Assemble group (2 remarks).

Due to the small sample size and exploratory nature of this study, no extensive statistical analysis was conducted; only preliminary descriptive analysis (i.e., mean and standard deviation) was examined. For self-efficacy, the Dismantle group showed a larger increase from pre- to post-test ($M=.59$, $SD=1.31$) than the Assemble group ($M=.19$, $SD=1.16$). Looking at gender by condition, male students showed a slight increase in self-efficacy for the Assemble group ($M=.25$, $SD=1.55$), but decreased for the Dismantle group ($M= -.23$, $SD=1.21$). For female students, only a slight increase was seen in the Assemble group ($M=.11$, $SD= .64$), but a larger increase was seen in the Dismantle group ($M=1.24$, $SD=1.07$). For motivation, the Dismantle group showed a larger increase from pre- to post-test ($M=.47$, $SD=1.15$), compared to the Assemble group ($M=.15$, $SD=1.14$). Looking at gender by condition, male students showed a small increase in motivation ($M=.21$, $SD=1.53$) for the Assemble group, but a decrease was seen for students in the Dismantle group ($M= -.35$, $SD= .54$). For female students, a slight increase (no difference) was seen in the Assemble group ($M=.07$, $SD= .58$), but a larger increase was seen in the Dismantle group ($M=1.12$, $SD=1.11$).

Implications

This exploratory study offers important guidance for educators when designing maker activities. Educators may want to consider implementing different making procedures to bridge the gender gap, help students voice challenges, foster in-depth understanding, and develop higher self-efficacy and motivation. Compared to Assembling, the Dismantle process seems to allow female students to be more comfortable voicing their challenges and fostering higher self-efficacy and motivation. Other findings are aligned with benefits of using reverse engineering and product dissection in engineering education (Dalrymple et al., 2011). This study provides insight into how gender plays a role in different making procedures, which has not been extensively explored.

References

Dalrymple, O.O., Sears, D.A., Evangelou, D. (2011). The motivational and transfer potential of disassemble/analyze/assemble activities. *J. Eng. Educ. 100*(4), 741–759

Deci, E. L., & Ryan, R. M. (1986). The dynamics of self-determination in personality and development. *Self-related cognitions in anxiety and motivation,* 171-194.

Eckhardt, J., Kaletka, C., Pelka, B., Unterfrauner, E., Voigt, C., & Zirngiebl, M. (2020) Gender in the making: An empirical approach to understand gender relations in the maker movement. *International Journal of Human-Computer Studies, 145*, 102548.

Mamaril, N. A., Usher, E. L., Li, C. R., Economy, D. R., & Kennedy, M. S. (2016). Measuring undergraduate students' engineering self-efficacy: A validation study. *J. Eng. Educ. 105*(2), 366-395.

Martin, L. (2015). The Promise of the Maker Movement for Education. *Journal of Pre-College Engineering Education Research (J-PEER), 5*(1), Article 4.

Thanapornsangsuth, S., & Holbert, N. (2017). Bots for Tots: Young girls' perceived versus actual competency in technology and making. *In Proceedings of the 16th International Conference on Interaction Design and Children*. Stanford, CA: ACM

Learning in an Arts Education Collective Impact Initiative

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Abstract: Collective impact is a well-known approach to changemaking that involves establishing a set of five conditions for change. This mixed methods case study of an arts education initiative combines a longitudinal network analysis of partnership dynamics with a qualitative analysis of situated narratives about learning and partnership to provide a deeper, empirically-based understanding of how and to what extent the conditions of collective impact operate in practice to support changemaking.

Introduction

Collective impact (Kania & Kramer, 2011) is one of a variety of *systems*, *complexity* and *ecological* models of changemaking. The model posits that five conditions for "alignment" should be set for change emergence*: a common agenda, shared measurement systems, mutually reinforcing activities, continuous communication,* and *backbone support organizations* (p. 39). While there has been widespread adoption and funding of collective impact initiatives over the past decade, there have been few empirical studies of how these five conditions for alignment operate on individual or (inter)organizational practice to support collective changemaking. We think the learning sciences can help. The goal of this ongoing study is to apply contemporary sociocultural and sociomaterial conceptualizations of learning as a relational, distributed and situated phenomenon for an empirically-grounded and programmatically helpful analysis of the dynamics and mechanisms of change in a collective impact initiative. We will show how individuals, groups and organizations learn in ways that reconfigure the networked collective and contribute to its impacts.

Framework and method

This is a mixed methods single-case embedded study (Yin, 2014) of the ecosystem of schools and arts education providers assembled via Southtown's (pseudonym) arts education collective impact initiative, the Learning and Arts Collective (pseudonym). The study combines a six-year longitudinal network analysis (Carolan, 2014) of arts education partnerships with a qualitative narrative analysis (Czarniawska, 2004) of partnership types, conditions and dynamics of formation. A cultural-historical activity theory (CHAT) framework (Engeström, 2008) and related sociomaterial concepts of *competence* in *assemblage* (Callon, 1990) and learning as a process of relational *(re)configuration* (Suchman, 2007) are employed to examine how the network is enacted over time at multiple levels (individual to social) per a variety of objects (goals, objectives, projects), and via subjects (partners and schools), communities, tools, rules, norms and roles. This framework helps us examine collective goals and activity as dialogic and multivoiced, and provides a systematic and theory-based way of identifying and interpreting the *contradictions* that schools and non-school arts education partners must grapple with in partnership. From a CHAT perspective, it is these contradictions that drive learning and change in the ecosystem.

Data is drawn from three primary sources: (1) an annual inventory of arts partnerships at all schools in the district collected from 2013 through the 2018 academic year; (2) semi-structured narrative interviews with a purposive sample of schools and arts partners; and (3) digital artifacts of partners and partnership activities (e.g. websites and social media posts). Our analytical approach involved an initial characterization of partners in the district's partnership inventory based on digital artifact data. We tagged partners and partnerships in the inventory according to the apparent *object* (Engeström, 2008) of their partnership activity. Next, we transformed all six years of the partnership inventory into a network graph for longitudinal visualization and quantitative characterization in R using *igraph* and related packages for network analysis. We then developed a purposive sample of partners and schools for interview, selecting participants based on their ability to provide historical narrative accounts of specific network *neighborhoods*, *change trends*, and *objects* revealed in the network analysis. Interviews were used to "provoke the telling of stories" (Czarniawska, 2004) about who partners are, why and how they do what they do, and how partnerships form and evolve. Interviews were transcribed, and our CHAT framework was used to surface and analyze key contradictions emerging within and among individuals, organizations and assemblages in the collective. The stories collected through interviews bring a first-hand *logical* and *narrative* sense (Bruner, 2009) to structural visualizations of network dynamics.

Findings and discussion

Here we present and discuss some preliminary data and findings, and demonstrate how our analytical approach can link diverse, situated achievements of individual and organizational learning to observed network dynamics.

Learning as networked reconfiguration

Overall, we find the arts partnership network to be large and diverse (Figure 1a), comprised of over 778 distinct schools and arts partners and over 10,444 partnership interactions across all years. We see evidence of network-level learning in the form of high-level reconfiguration over time, for instance in the gradual emergence of clusters of school-to-school partnerships (Figure 1b). We also see learning at the level of the individual arts partner, for instance in how the Metro Theater reconfigures and grows its network neighborhood from year to year, embedding itself more broadly and deeply in the arts education ecosystem (Figure 1c).

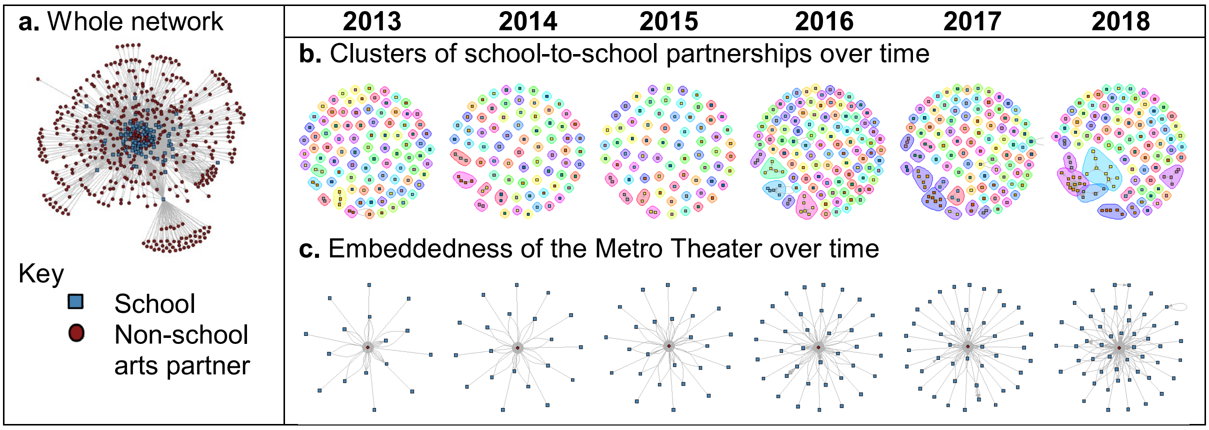

Figure 1. **a.** All partners and partnerships from the 2013 to 2018 academic years. **b.** Clustering over time of school-to-school partnerships (per multi-level modularity optimization algorithm in *igraph*). **c.** Snapshots of the Metro Theater's (pseudonym) network, showing increases in total individual partners and frequency of engagement.

Diverse mechanism of learning

Employing the CHAT framework to analyze narratives of partnership activity, we surfaced a variety of developmental *contradictions* and related learning responses that help explain observed reconfigurations of the network. Some of this learning was supported by the *five conditions* of collective impact. The Metro Theater, for example, reported that the *common agenda* set by the Learning and Arts Collective facilitated the difficult work of justifying and initiating partnerships by reinforcing the fundamental legitimacy of arts education work. The theater also employed the Learning and Arts Collective's *backbone organization* to develop a more synoptic and strategic sense of the overall network of schools. While Metro Theater's early growth in the network depended on passive "word of mouth" relationship-building and the more-or-less random movement of teacher champions from school to school, the backbone organization helped them better detect and strategically select partnerships in ways that minimized what they perceived as unproductive competition, and helped them maximize their impact.

Going forward, we aim to document learning mechanisms and link them to network dynamics.

Conclusion

By combining longitudinal structural descriptions of the arts partnership network with situated narratives of learning and changemaking, this study reveals a bit more of the *social* in a *dynamic* social network, and gives us a better sense of how received concepts and principles of collective impact (Kania & Kramer, 2011) play out in day-to-day practice. We think this can help advance and adapt the collective impact model in theory and practice.

References

Bruner, J. S. (2009). *Actual minds, possible worlds*. Harvard University Press.

Callon, M. (1990). Techno-economic networks and irreversibility. *The Sociological Review*, *38*(S1), 132–161.

Carolan, B. (2014). *Social Network Analysis and Education: Theory, Methods and Applications*. SAGE.

Czarniawska, B. (2004). *Narratives in social science research* (1st ed.). SAGE.

Engeström, Y. (2008). *From teams to knots: Activity-theoretical studies of collaboration and learning at work*. Cambridge U. Press.

Kania, J., & Kramer, M. (2011). Collective impact. *Stanford Social Innovation Review*, *9*(1), 36–41.

Suchman, L. (2007). *Human-machine reconfigurations: Plans and situated actions* (2nd). Cambridge U. Press.

Yin, R. K. (2014). *Case study research: Design and methods* (Fifth). Sage.

Scaffolding Debugging That Uses Tinkering

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Abstract: We designed scaffolding for debugging that uses tinkering. The scaffolding was implemented in a context for teacher learning of computing education. Data included responses to scaffolding prompts, pair debugging processes recorded through video screencast recording, and interviews. We studied how debugging processes differ where the quality of the rules written to justify debugging success (or unsuccess) differ. Findings are organized around the two paired groups who generated different quality of rules in response to the scaffolding.

Introduction

Central to creating culturally responsive computer science (CS) classrooms is a need to prepare teacher candidates to teach CS. Some recent efforts have attempted to identify and strengthen methods of preparing teacher candidates to program (e.g., Kim et al., 2018). But little is known how to facilitate their learning to teach CS in culturally responsive ways. The present study researched methods to do so, through scaffolding for abductive reasoning while tinkering.

Our research question was: How do participants engage in debugging when scaffolded through abductive reasoning?

Theoretical foundation

We used abductive reasoning as a theoretical lens. Abductive reasoning is a process of thinking while attempting to figure out a way of describing a perplexing phenomenon. The process of abduction begins with the best possible guess at the moment and moves to subsequent guesses when the presently tested guess does not explain the phenomenon of investigation (Magnani, 2009; Peirce, 1931-1935).

Method

Paired debugging sessions were recorded using video screencast software. In addition to debugging screencast recordings, pairs' responses to scaffolding prompts were recorded. Our scaffold design for abductive reasoning aimed to (a) leave tinkering as a natural process of debugging and (b) guide rule discovery and refinement. This design was grounded in our prior research in which teacher candidates (a) tinkered through abduction and (b) exhibited reflective debugging, but (c) did not notice a rule across cases (Kim et al., In press). Thus, our scaffolding provided prompts to help them discover a rule that may explain what they were seeing as a result of their tinkering. Artifact-based individual interviews were done after the debugging tasks were completed.

Our analytic strategy involved using conversation analysis (ten Have, 2007) and open and axial coding (Miles et al., 2013) done through the lens of ethnomethodology (Garfinkel, 1967).

Findings and discussion

We present findings from two groups who generated rules of varying quality in response to the scaffolding (e.g., Table 1). As described above, participants were asked to write down a rule that could explain what they just saw during tinkering. The design rationale was to help them (a) connect the change they made in the code to the result they were seeing, (b) reflect on what they guessed as a cause for the buggy code, and (c) notice relations between previously guessed causes and actual results. Such design aimed for reflective abstraction (Abrahamson, 2012) and "plausible abductive generalization" (Rivera & Becker, 2007, p. 140), which would in turn create a collection of potentially relevant rules to be used in abductive reasoning during future debugging.

The following themes were uncovered as to how the debugging processes of these two groups differed.

Reading before (re)writing the code

The initial reading of the given buggy code was rather quick for Group 1. Group 2 read the code line by line also while paying attention to the repeat while block. This finding is interesting because the total time Group 1 spent debugging (38.13 minutes) was longer than that of Group 2 (21.86 mins). Both groups questioned the meaning of "iteration" in the code but Group 1 searched for the term online and read out loud its definition and Group 2 figured out it was a label for a variable. When asked to guess what the code was making the robot do during the initial reading of the code, both guessed incorrectly yet: Group 1 guessed a star shape and Group 2 guessed a pentagon shape. As such, both groups' initial reading of the buggy code was imperfect, but different processes of initial reading, quick versus thorough, were observed between the two groups.

Table 1: Example responses of Group 1 and Group 2 to prompts related to rule generation

	Group 1	Group 2
Final rule	When you put the wrong number in the distance, it will not complete the right shape.	If you program the robot to move forward 50 mm and then have it rotate 45 degrees, it will create one side of an octagon
Rule use plan	We plan on playing around with the numbers in order to make sure we are doing it right.	When considering how many sides we need for a shape, we need to remember to divide the number of sides by 360 to get the angle we should set it to.

Follow-through guesses

Still without information about the programming goal, participants were asked to run the buggy code and guess how the robot would travel. Their guesses were not correct yet: Group 1 guessed a pentagon and Group 2 guessed a hexagon and then a pentagon. But the two groups differed in that Group 2 tinkered through the numeric values in the turn angle in line with their guess but Group 1 did not revisit their guess later.

Parsing the code and robot movement

Group 2 broke down the code in relation to the specific behaviors of the robot whereas Group 1 did not. During such parsing, Group 2 noticed which part of the code worked to lead to a desired behavior of the robot, whereas Group 1 did not notice the misfunctioning of the angle value and ended up changing the correct distance.

Conclusion and implications

The unique contributions of this study are (a) the asset-based scaffolding in which tinkering through abduction among teacher candidates is respected and utilized, and (b) the potential lessons on how tinkering through abduction can be valued and supported among youth learning to program. This in turn has the potential to invite teachers and youth from diverse backgrounds to identify with and engage in programming.

Acknowledgments

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References

Abrahamson, D. (2012). Rethinking intensive quantities via guided mediated abduction. *Journal of the Learning Sciences*, *21*(4), 626–649. https://doi.org/10.1080/10508406.2011.633838

Berland, M., Martin, T., Benton, T., Smith, C. P., & Davis, D. (2013). Using learning analytics to understand the learning pathways of novice programmers. *Journal of the Learning Sciences*, *22*(4), 564–599. https://doi.org/10.1080/10508406.2013.836655

Garfinkel, H. (1967). *Studies in ethnomethodology*. Englewood Cliffs, N.J. http://hdl.handle.net/2027/uc1.-b3986101

Kim, C., Belland, B. R., Baabdullah, A., Lee, E., Dinç, E., & Zhang, A. (In press). An ethnomethodological study of abductive reasoning while tinkering. *AERA Open*.

Kim, C., Yuan, J., Vasconcelos, L., Shin, M., & Hill, R. B. (2018). Debugging during block-based programming. *Instructional Science*, *46*(5), 767–787. https://doi.org/10.1007/s11251-018-9453-5

Magnani, L. (2009). *Abductive cognition: The epistemological and eco-cognitive dimensions of hypothetical reasoning* (Vol. 3). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-03631-6

Miles, M. B., Huberman, A. M., & Saldaña, J. (2013). *Qualitative data analysis: A methods sourcebook*. SAGE.

Peirce, C. S. (1931-1935). *The collected papers of Charles Sanders Peirce* (C. Hartshorne & P. Weiss, Eds.; Vols. 1–6). Harvard University Press.

Rivera, F. D., & Becker, J. R. (2007). Abduction–induction (generalization) processes of elementary majors on figural patterns in algebra. *The Journal of Mathematical Behavior*, *26*(2), 140–155. https://doi.org/10.1016/j.jmathb.2007.05.001

ten Have, P. (2007). *Doing conversation analysis*. SAGE Publications, Ltd. http://srmo.sagepub.com/view/doing-conversation-analysis/SAGE.xml

Designing Artificial Intelligence (AI) in Virtual Humans for Simulation-Based Training with Graduate Teaching Assistants

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Abstract: In this case study, we explored the design and usability of an AI virtual human design architecture. Data from 50 hours of project meetings and 35 hours of user-testing and prototyping sessions contributed to the preliminary results. The study findings indicated the potential of using AI-integrated virtual humans to support conversational and interactive training for student instructors in an open-source virtual reality environment. Moreover, the AI student prototyped was found to be authentic and semantically meaningful.

Introduction and theoretical background

Teaching is complex problem solving. Prior research demonstrated that authentic simulation-based learning can facilitate knowledge application and skills practice for learning to teach (Chernikova et al., 2020). However, designing virtual humans with artificial intelligence (AI) to convey naturalistic interactions with student instructors in virtual reality is still a challenge. Furthermore, empirical research is lacking on how to design AI virtual humans using an interdisciplinary and systematic approach.

According to Hayes-Roth and Thorndyke (1985), AI typically manipulates multiplex architectures to represent ill-structured problem-solving solutions. To represent the AI architectures for educational purposes, understanding human behaviors and modeling human cognition and character traits are integral parts of virtual human design (Johnson & Lester, 2018). To this end, Nye et al. (2014) used semantic analysis with a discourse framework to create natural language dialogues to promote learners' (i.e., graduate teaching assistants in our study) knowledge application and problem-solving skills development. Essentially, *expectations-misconception* mechanism was used to tailor natural language dialogues that model student knowledge and individual differences so that the virtual students can be designed to stimulate preservice teachers' practice with the targeted activities (e.g., Nye et al., 2014; Paladines & Ramírez, 2020). However, it remains a challenge to design such natural-language-enactive virtual humans in 3D virtual environments that utilize low-level implementation programming languages such as Linden Scripting Language (LSL) (Ke et al., 2020). Nevertheless, an open-source, multiuser virtual reality (VR) platform like *OpenSimulator (OpenSim)* is usually more customizable and accessible and hence are more likely to be scalable and equitable for a larger population. The current study is an ongoing exploration of designing AI in the virtual world. The following question is explored: *How does an AI-integrated virtual human design architecture and process come about in a VR simulation-based learning environment?*

Method

As part of an ongoing design-based research project on simulation-based training of student instructors, we documented three iterative cycles of virtual humans (or virtual students, in this study) design in a simulation-based environment in *OpenSim*. We employed a case study approach to investigate the design experience and artifacts in situ. Each iterated design cycle, including its design activities and artifacts, works as a design case that is bounded in a twenty-five-week design period. Interactions and behavioral data elicited in the iterative design process was collected from a total of 50 hours of project meetings, 22 hours of paper prototyping sessions, and 13 hours of functional virtual human prototyping. The paper prototype was made via Microsoft excel sheet with comprehensive syntaxes whereas functional prototypes were created first with RPG Maker MV and then in *OpenSim*. We triangulated the data collected from meeting notes, design documents, design artifacts, screen recordings, and semi-structured interviews with the in-field test users. In the following sections, we present the preliminary results from the open coding analysis of the current case study.

Results

Process and architecture of the AI virtual human design

To develope dynamic, conversational, and interactive AI-integrated virtual humans (see Figure 1, left), we developed an architecture that utilizes both high- and low- level programing languages and external knowledge database with text mining techniques (see Figure 1, right). For agent modeling, we first reviewed the literature on learning and individual differences to outline salient traits and characteristics of virtual humans. Next, we finalized seven individual differences with either a three-point or two-point scale for the machine to interpret as the default characteristics of the virtual students. For example, motivation (0=low; 1=medium; 2=high) or cognitive fixedness (0=no; 1=yes). These characteristics result in four main categories of virtual student states: affective, cognitive, metacognitive, and behavioral. These states are dynamic and changeable from the interactions with the graduate teaching assistants and the teaching contexts (i.e., global rules). The states transition is engineered with external knowledge database and the communications between high-level programming languages and LSL.

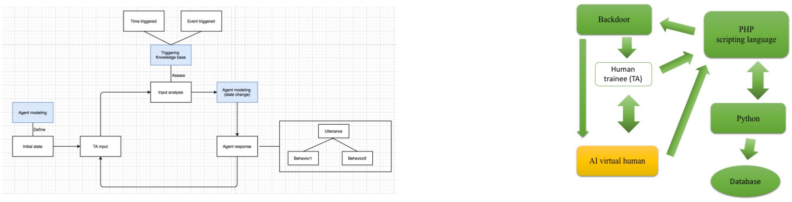

Figure 1. The virtual humans architecture designed for virtual reality using *OpenSim*.

Virtual humans' usability

The preliminary results with front-end users (i.e., expert instructors and designers) and college students (i.e., the population of the agent being modeled) suggest that the design of the virtual students is authentic and semantically meaningful. All participants provided positive feedback. For example, being asked if the virtual students design prototype is naturalistic, Mateo (pseudonym) responded, "*Yeah, I can see that happening.*" The design of challenging teaching situations also reflected what college students experienced in daily life: "*I know there was one student that was annoying that I've come across in all the classes I've taken so far…she would asked questions that…don't really applied to what he* (re: the professor) *was teaching*" (Mateo). Moreover, Shelly (pseudonym) revealed the important role of psychology and agent modeling in the AI virtual human design: "*it's good to know how people work when you're teaching them."* For disruptive student agent behavior design, Shelly commented: "*some students are very extroverted and they're very vocal about how they feel…(their complaints) makes me uncomfortable, like the conflict between a teacher and student.*" These comments suggest that the current virtual student agents were associated with a balanced design between the behavioral and affective states as well as the cognitive and metacognitive states.

Conclusion and Implications

This current study demonstrates the potential of designing and using intelligent virtual humans in a virtual environment (Ke et al., 2020). Specifically, the proposed design architecture consists of state-of-the-art mechanisms and has the potential to tailor natural language dialogues (Nye et al., 2014; Paladines & Ramírez, 2020) between the graduate teaching assistants and virtual students in a 3D virtual world based teaching simulation. Current user-testing data indicate that the designed virtual students are perceived as authentic and semantically-meaningful. This design-based research should foster conversations between and reflections of interested stakeholders in virtual human design and development for teaching and learning in a virtual world.

References

Chernikova, O., Heitzmann, N., Stadler, M., Holzberger, D., Seidel, T., & Fischer, F. (2020). Simulation-based learning in higher education: A meta-analysis. *Review of Educational Research, 90*(4), 499-541.

Hayes-Roth, B., & Thorndyke, P. W. (1985). Paradigms for intelligent systems. *Educational Psychologist, 20*(4), 231-241.

Johnson, W. L., & Lester, J. C. (2018). Pedagogical agents: back to the future. *AI Magazine, 39*(2).

Ke, F., Dai, Z., Dai, C-P., Pachman, M., Chaulagain, R., & Yuan, X. (2020). Designing Virtual Agents for simulation-based learning in Virtual Reality. In R. Zheng (Ed.), *Cognitive and Affective Perspectives on Immersive Technology in Education* (pp. 151-170). Hershey, PA: IGI Global

Nye, B. D., Graesser, A. C., & Hu, X. (2014). AutoTutor and family: A review of 17 years of natural language tutoring. *International Journal of Artificial Intelligence in Education, 24*(4), 427-469.

Paladines, J., & Ramírez, J. (2020). A Systematic Literature Review of Intelligent Tutoring Systems with Dialogue in Natural Language. *IEEE Access*, *8*, 164246-164267.

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International Society of
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An Assessment Focused Research-Practice Partnership

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Abstract: In this proposal we present a narrative account of a research-practice partnership focused on creating an assessment that could meet the needs of teachers as an activity they could enact to support their instruction and assessment goals and also meet the needs of researchers as a research measure. We highlight the way the Draw-A-Scientist Task (DAST), a tool for revealing students' images of scientists, was introduced at a teacher professional development institute and adopted by middle school science teachers. By following a co-design approach, we created a strong research-practice partnership. Our findings summarize the nature of the research-practice partnership and outcomes. This work is a critical illustration of the importance of considering teachers as true research partners. This collaboration afforded the development of a tool that they could use to elicit students' ideas about science and also reveal some of their personal identities.

Keywords: Professional Development, Teaching

Introduction and theoretical frameworks

Introduction

This paper describes a research-practice partnership where teachers and researchers co-edited the Draw-a-Scientist task to measure middle school students' identity using the Draw-a-Scientist Task (DAST) (Chambers, 1983). The DAST is designed to measure students' perceptions of scientists and their ideas about the nature of science. In the current work, teachers and researchers worked together across two years to modify and enact the Draw-a-Scientist task for use in middle school science classrooms.

This work builds on the rich history of research-practice partnerships in the learning sciences (Penuel & Gallagher, 2017). The research question driving this work is "What are the outcomes for teachers and researchers who are involved in a research-practice partnership focused on co-creating a student-centered assessment?" Our narrative description of the work provides an account of how teachers and researchers worked together to build trust and create a tool that was beneficial for instruction as well as research.

The Co-Design Process

The co-design process we engaged in aligns with the definition of co-design as a collaborative process involving teachers and researchers/developers working together to create an educational tool by engaging in iterative cycles of design, enactment, and evaluation (Penuel, Rochelle, & Shechtman, 2007). Typically, co-design research focuses on developing new technologies that are classroom innovations This work is unique because it invites teachers to co-design a paper-and-pencil based assessment as a classroom "innovation".

Methodology

Research Context

Our research took place across two years as part of a larger project being enacted in four middle schools with diverse students and families from rural, suburban and urban communities. In this study we focus on the teachers across two academic years and summers. They participated in summer professional development meetings to learn about the social learning environment, Flipgrid (Flipgrid.com). At these meetings they were also introduced to approaches to create culturally responsive learning experiences that invite students and parents to make connections between their everyday lives and the science being covered in their classes. A major facet of our research is to measure students' science identity. This paper focuses on our effort to include teachers as collaborators in this particular aspect of the project. We selected the draw-a-scientist task to measure student identity and included teachers as partners to modify the task to fit their instruction needs as the researchers also considered how it would meet their research goals.

Data Sources
Teacher focus groups were conducted at the end of each summer professional development (PD) institute. Follow-up focus groups were hosted during the academic year Individual teacher interviews were conducted at the end of each academic year.

Findings

The co-design process: Modifying the DAST
Our collaboration centered on a desire to make sure that the task would be developmentally appropriate, culturally responsive, and gave us insights into students' identities. Teachers were able to create instructions and versions of the task that were most appropriate for their classes. Some also included reflection questions to elicit details about students' drawings and to prompt them to further reflect on their STEM identities and interests in STEM careers. During the year two professional development meeting, teachers collaborated to create a single approach for administering the task and standardized the reflection questions.

The redesigned DAST in action: Research and pedagogical goals
During both professional development meetings, teachers and researchers agreed on the need to better understand students' science identities. Working together, they were able to co-design a tool, the modified DAST that met multiple goals. In Year 1, although teachers administered four different versions of the task, they eventually agreed that one standardized version, along with a reflection question worksheet one teacher created, would be more appropriate for their students as well as provide more information about how students' are situating their own science identities with the images of scientists they drew.

The impact for professional development: Shared goals and trust building
Co-designing the modified DAST helped the research team to understand teachers' goals of developing something that would serve as a class activity as well as a measurement tool. In most cases, their priority was providing students with an opportunity to share their ideas and reflect on their identities. Some teachers used the task as a graded homework assignment and others presented it as a way to get to know their students.

Teachers and researchers discussed the way that the instrument would be introduced, and modified the reflection questions together. To further meet the needs of the researchers, teachers agreed to administer the instrument to their students during a particular week of the fall semester.

Discussion
Our partnership illustrates the power of a relationship built based on a shared goal of eliciting students' ideas about science and also reveal some of their personal identities. Teachers are being asked to make evidence based decisions at the same time as researchers are being asked to develop authentic assessments to measure the impact of interventions that affect difficult to measure constructs such as identity. Co-design activities can serve practical goals to create useful tools. During the co-design process, teachers and researchers can develop critical relationships that advance research and enhance pedagogy.

References
Chambers, D. W. (1983). Stereotypic images of the scientist: The Draw-A-Scientist Test. *Science Education, 67(2),* 255–265. Retrieved from http://kbsgk12project.kbs.msu.edu/wp-content/uploads/2011/02/draw-a-scientist-test.pdf

Penuel, W.R., Roschelle, J., & Shechtman (2007). Designing formative assessment software with teachers: An analysis of the co-design process*. Research and Practice in Technology Enhanced Learning. 2(1)*, 51-74. https://doi.org/10.1142/S1793206807000300

Penuel, W. R., & Gallagher (2017). *Creating Research Practice Partnerships in Education*. Harvard Education Press. 8 Story Street First Floor, Cambridge, MA 02138.

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Designing Effective Automated Feedback for Modeling Tools

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Abstract: This poster reports the results of design experiments exploring the effects of two forms of automated feedback in modeling tools on eighth-grade students' understanding of chemistry (Study 1) and life science (Study 2). Eighth-grade students in each classroom were randomly assigned to receive either Elaborated-Visual (EV) or Reflective-Visual (RV) feedback during modeling activities. Although both forms of feedback significantly improved all students' science learning, the results revealed mixed effects of EV and RV feedback on students' performance on the explanation and modeling items.

Keywords: automated feedback, modeling tools, chemistry, life science

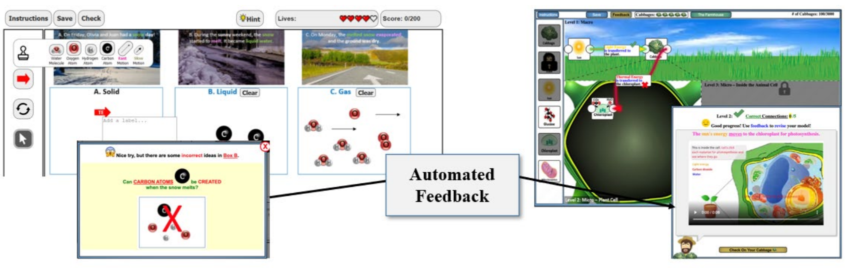
Introduction

Recent developments in automated scoring and feedback technologies allow modeling tools to analyze student-generated visual representations of complex scientific systems and provide real-time feedback based on individual student performance (Luckie et al., 2011; Pei et al., 2019). Although several studies have shown that the use of automated feedback can lead to improved learning outcomes (e.g., Linn et al., 2014; Van der Kleij et al., 2015), there are inconsistent findings about which forms of automated feedback can be most effective for developing and revising visual models of scientific phenomena. For instance, research has revealed mixed benefits of elaborated feedback (e.g., accurate explanations) and reflective feedback (e.g., hints) for different learning tasks (e.g., Ryoo & Linn, 2016; Shute, 2008; Wojcikowski & Brownie, 2013). In addition, recent studies have shown conflicting evidence about the value of providing additional resources or examples in feedback (e.g., Finn et al., 2018). To address the gap in the current literature, this study explored how Elaborated-Visual (EV) and Reflective-Visual (RV) feedback in modeling tools helped eighth-grade students improve their understanding of unobservable scientific phenomena in chemistry and life science.

Study 1

Study 1 explored the effects of EV and RV feedback in a modeling tool on eighth-grade students' understanding of chemistry. Students in each classroom were randomly assigned to either the EV (N = 62) or RV (N = 65) feedback condition. Within each condition, students received visualization-rich inquiry instruction in pairs to explore what happens to energy and matter during a phase change. Prior to and after the study, students individually completed identical pre- and post-tests consisting of open-ended modeling and explanation items.

On days 3-4, pairs were asked to develop visual representations of the relationship between energy and molecular behaviors when snow melts and evaporates by using stamps, arrows, and labels (see Figure 1). Upon submission, they received either EV or RV feedback based on specific non-normative ideas (e.g., molecules breaking up) and the presence of key concepts (e.g., spacing between molecules) represented in their work. Both forms of feedback informed students about the location of the error in the submitted model. Next, the EV feedback provided an elaborated explanation about a key scientific concept with a visual resource, while the RV feedback provided the same visual resource with a reflective question to facilitate discussion about the target concept. Students revised their models using the received feedback multiple times. After the activity, students rated and commented on the usefulness of the feedback.



(a) (b)

Figure 1. Interface of modeling tools with automated feedback used in Study 1 (a) and Study 2 (b).

Analyses of pairs' log data showed no significant differences between the two feedback conditions in the number of model revisions and students' perceptions about the usefulness of feedback. 53% of the EV group found the feedback helpful or very helpful because its specific information helped them understand what they "need to add or what you are missing." 48% of the RV group commented that the feedback "led us down the right path in order to fix our mistake" and provided "suggestions on how we could fix it."

The results from the individual pre- and post-tests showed that both EV ($p < .001$) and RV ($p < .001$) feedback forms significantly improved students' understanding of the target concepts. Interestingly, the RV group demonstrated significantly higher learning gains on the explanation items ($p < .05$), compared to the EV group. However, no significant difference was found between the two conditions on the modeling item.

Study 2

Study 2 examined the effects of EV and RV feedback in a life science modeling tool on eighth-grade students' understanding of photosynthesis and cellular respiration. The procedure was identical to the one used in Study 1. Students in each classroom were randomly assigned to either the EV (N = 48) or RV (N = 46) condition. During the inquiry instruction, pairs developed and revised visual representations of how energy flows between plants and humans at the macro and micro levels by making connections among icons and assigning labels to describe the target concepts (see Figure 1).

The results showed that both groups, on average, revised their models six times, and 70% of each feedback group rated the feedback as helpful or very helpful. Students in Study 2 particularly appreciated having feedback with visual resources, stating that "the videos showed what happens to energy when it enters the chloroplast" and "it really helped visualize the functions of cellular respiration." Consistent with Study 1, both EV ($p < .001$) and RV ($p < .001$) groups demonstrated a significantly enhanced understanding of the target concepts on the post-tests, compared to the pre-tests. However, the results did not show any differences in students' learning gains between the two feedback conditions.

Conclusions

This study extends the current literature by demonstrating the significant effects of EV and RV forms of automated feedback in modeling tools on middle school students' science learning in chemistry and life science.

The results revealed that both forms of feedback led to an increased number of model revisions and significant learning gains from individual pre- to post-tests. Students in both conditions found the received feedback helpful in revising their work. However, the significant advantage of RV feedback, compared to EV feedback, was only found in students' explanations in Study 1. Given the conflicting results, more research is needed to better understand under what conditions EV and RV feedback can support student learning across different modeling tools and various science topics.

References

Finn, B., Thomas, R., & Rawson, K. A. (2018). Learning more from feedback: Elaborating feedback with examples enhances concept learning. *Learning and Instruction, 54*, 104-113.

Linn, M. C., Gerard, L., Ryoo, K., McElhaney, K., Liu, O. L., & Rafferty, A. N. (2014). Computer-guided inquiry to improve science learning. *Science*, *344*(6180), 155-156.

Luckie, D., Harrison, S. H., & Ebert-May, D. (2011). Model-based reasoning: Using visual tools to reveal student learning. *Advances in Physiology Education*, *35*(1), 59-67.

Pei, B., Xing, W., & Lee, H. S. (2019). Using automatic image processing to analyze visual artifacts created by students in scientific argumentation. *British Journal of Educational Technology*, *50*(6), 3391-3404.

Ryoo, K., & Linn, M. C. (2016). Designing automated guidance for concept diagrams in inquiry instruction. *Journal of Research in Science Teaching, 53(*7), 1003-1035.

Shute, V. J. (2008). Focus on formative feedback. *Review of Educational Research*, *78*(1), 153-189.

Van der Kleij, F. M., Feskens, R. C., & Eggen, T. J. (2015). Effects of feedback in a computer-based learning environment on students' learning outcomes: A meta-analysis. *Review of Educational Research*, *85*(4), 475-511.

Wojcikowski, K., & Brownie, S. (2013). Generic reflective feedback: An effective approach to developing clinical reasoning skills. *Journal of Computer Assisted Learning*, *29*(4), 371-382.

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The Human-Interpreter Problem in Youth Encounters with AI

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Abstract: Artificial Intelligence's impact on society is increasingly pervasive. While innovative educational programs are being developed, there is yet little understanding of how pre-college aged youth engage with and construct understanding of core AI concepts and strategies. In this paper, we discuss emerging findings from a cognitive interview study with middle school and high school students to better understand how students learn AI concepts. This research was supported by the National Science Foundation under Grant 1842385.

Introduction: The human interpreter

When a novice programmer encounters a debugging problem in computer science, the novice sometimes imbues the program with a human's ability to interpret ambiguous instructions (Spohrer & Soloway, 1986). This may be especially common where the correct interpretation is obvious, or incorrect interpretations are exceedingly unlikely (Van Someren, 1990). The implicit expectation is that there is a human interpreter between the computer and the code mediating implementation of the code. Across a set of extended cognitive interviews with middle and high school aged youth, we observed evidence of an AI variation on the human interpreter problem: when a novice works to figure out how an AI system might solve a real-world problem, they sometimes imbue the system not only with computational capacity, but also with capacity to infer and reason about human motivations. We hypothesize that youth may begin with a working theory of AI that assumes general intelligence for the system, including the capacity to recognize and reason from human motivations.

Methods

We conducted cognitive interviews with a convenience sample of eight students (12 to 17 years old) from a private school located in the western United States as they worked through five AI problems. As youth worked through the problem set, the cognitive interview employed a semi-structured protocol to elicit student thinking as each student initially encountered each problem, attempted to solve the problem, and in reflection after they had settled on a solution. In-the-moment scaffolding was provided throughout each interview to enable students to reveal thinking across each step of the solution, surface and test emerging ideas about why a student might be stuck, and to disambiguate between superficial challenges and conceptual difficulties (see, Greenwald, Leitner & Wang, 2021, for a full description of methods). The sample was racially and ethnically diverse and also higher-resourced than that of the average public school. Given persistent inequities in computer science academic and career pathways, as well as broader questions of access and privilege across society, the sample presents limitations for generalizability that will be important to address in future studies.

To analyze the video-recorded interview data, we created excerpts of each student's work on each problem, and applied codes directly to the video excerpts according to the problem type using Dedoose (2018), a mixed methods data analysis tool. We then completed two passes through the data. With the first pass we viewed each interview in sequence, generating and applying a set of broadly applicable codes (e.g., problem type, challenges, scaffolds); then, we compiled the excerpts by problem type and viewed the variety of student responses on each problem together. In this second pass through the data, we drew from the principles of grounded theory (Glaser, 1992), to iteratively introduce new codes as themes emerged, which we then added to and revised through successive passes through the data, continually comparing the emergent codes against the data. These initial codes were revised for consistency, then applied systematically across the data.

Initial findings: Insight into students' working theories of AI systems

As previously reported, students in our sample were unfamiliar with parsing the world in terms an AI system can operate on (Greenwald, Leitner, & Wang, 2021). A challenge for all students interviewed, including those with advanced mathematical skills, was recognizing how a problem in the world could be made amenable to the computational power of an AI system. That is to say, students needed support in conceiving a problem space in a way that would enable an AI system to solve it. Students' initial uncertainty, however, did shed light on possible working theories students brought into the AI problem solving tasks.

For the decision tree problem, students were presented with a data table about past behavior and tasked with helping a friend decide whether or not they would wait to get a seat at a restaurant. With this problem, multiple students approached the task of finding patterns in the presented data set by first speculating on the underlying motivations that may have led to the data itself. For example, when presented with the data table and the overarching problem of imagining how an AI system might leverage the data to make decisions, students typically began by inferring from their own experiences and intuitions about eating out to propose reasons that a family might wait or not wait at a table. The dialogue excerpted below occurs after the variables and values in the data table were explained by the interviewer:

> Interviewer: If the goal is to predict whether or not the family is going to wait, how could this data table be used to make that prediction?
>
> Student: All the ones that waited, said that they were hungry; they had a reservation, and it was a pretty expensive restaurant, so they waited And it was a short wait, so they probably...and they were hungry, so they wouldn't want to leave their reservation; same with this one, they also had a reservation and they were hungry, and there was no alternative, so they probably would...they waited as well.

Similar student responses across the interviews suggest that when considering how AI systems use data to make decisions, students begin by drawing on prior experience to suggest underlying motivations within the decision space, rather than attending to features of the data themselves. A possible interpretation is that the student was attempting to understand the family's motivated reasoning for waiting or not waiting as a path to devising an AI solution that could leverage that reasoning. While building understanding by drawing on prior experience is often a productive move, we note that each of the student's conjectures in the excerpt above (hunger level, reservation, price) conflicts with the data as presented in the table. For multiple students, we also observed that this reasoning about diners' motivations as a path for AI system decision-making often persisted after explicit call-backs to the observable features of the data table.

Discussion: A call to explore working theories of AI among youth

Findings suggest that students may be including notions of intent and motivation in their working theories of AI systems: that because *human* intelligence includes the capacity to infer and make use of one's reasoning behind a decision, perhaps then artificial intelligence shares this capacity. The version of AI common in science fiction and popular culture is often that of an intelligent system more or less similar to (or advanced beyond) the intelligence of a human: a yet-to-be realized instantiation of artificial general intelligence, or artificial super intelligence. Evidence across several interviews suggests that students may be drawing on these models of AI when encountering AI problems. It is also likely that students' initial focus on the rationale behind the data dovetails with long-documented difficulties students have analyzing and interpreting data more broadly (Curcio, 1987).

Further research is needed to better understand students' working theories about AI systems, and how those theories may mediate students' developing understanding within the learning experience. Interviews suggest a related need to support students toward a more generalized understanding of how AI systems can be applied to problems, and how problems can be reimagined to be solvable by AI systems. This finding adds weight to efforts aimed at promoting "explainable AI" (Gunning & Aha, 2019) that makes the decision-making of AI algorithms transparent to users. Through its transparency, explainable AI can create opportunities to make AI concepts accessible, in part by supporting youth in developing working theories about how such systems function.

References

Curcio, F. R. (1987). Comprehension of mathematical relationships expressed in graphs. Journal for research in mathematics education, 382-393.

Dedoose (2018) Version 8.0.35, web application for managing, analyzing, and presenting qualitative and mixed method research data. Los Angeles, CA: SocioCultural Research Consultants, LLC www.dedoose.com.

Glaser, B. G., & Strauss, A. L. (1967). Discovery of grounded theory: Strategies for qualitative research. Routledge.

Greenwald, E., Leitner, M., and Wang, N. (2021). Learning Artificial Intelligence: Insights into How Youth Encounter and Build Understanding of AI Concepts. Proceedings of AAAI-21, February 2-9. AAAI Press, Palo Alto, California USA

Gunning, D. & Aha, D. W. (2019). DARPA's explainable artificial intelligence program. AI Magazine, 40(2), 44-58.

Spohrer, J. C., & Soloway, E. (1986). Novice mistakes: Are the folk wisdoms correct?. Communications of the ACM, 29(7), 624-632.

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Grounded and Embodied Proof Production: Are Gestures and Speech Enough to Produce Deductive Proof?

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Abstract: This study investigates the associations of spontaneous *dynamic gesture* and *transformational speech* with the production of *deductive proofs* in participants' reasoning about geometric conjectures (N=77). Although statistical analysis showed no significant association, the result suggests that purposefully including directed actions and pedagogical language in interventions could promote the production of deductive proofs.

Keywords: Geometry, Proof, Dynamic gesture, Transformational Speech

Nathan and Walkington (2017) developed the Grounded and Embodied Mathematical Cognition (GEMC) model (Figure 1) based on the Gesture as Simulated Action framework (Hostetter & Alibali, 2019) and the Action-Cognition Transduction hypothesis (Nathan, 2017). They showed how the activation of both the sensorimotor system and the language system is necessary, but perhaps not sufficient, for a learner to produce a mathematically *valid proof-with-insight*, a conceptual understanding of a conjecture that is correct, logical, and generalizable. The GEMC model posits that *dynamic gestures* and *transformational speech* – both the embodiments of simulated mental action – are reliable predictors of valid proofs-with-insight for mathematical conjectures (Nathan et al., 2020; Pier et al., 2019). *Dynamic gestures* (DG) depict transformational operations on mathematical objects (e.g., rotation or dilation; Figure 2). *Transformational speech* (TS) verbally articulates transformational operations (e.g., "You can increase or decrease the lengths of the sides and still have the same angles."). However, further investigation is needed on the extent of DG or TS's role in generating *deductive* mathematical proofs. Therefore, the research question for this study is: *When students produced valid proofs-with-insight, is there an association between their utilization of DG and TS and the production of deductive proofs?* A proof is *deductive* when it (a) is generalizable and holds for all cases under consideration, (b) utilizes clear logical inferences, and (c) exhibits goal-oriented thinking – where the prover progresses systematically with goals in mind and correctly anticipates the outcomes of the proposed operations (Harel, 2007). This study examined the role of DG and TS in the production of deductive proofs. We expect that the participants who utilized both DG and TS simultaneously while proving would produce more deductive proofs than those who did not.

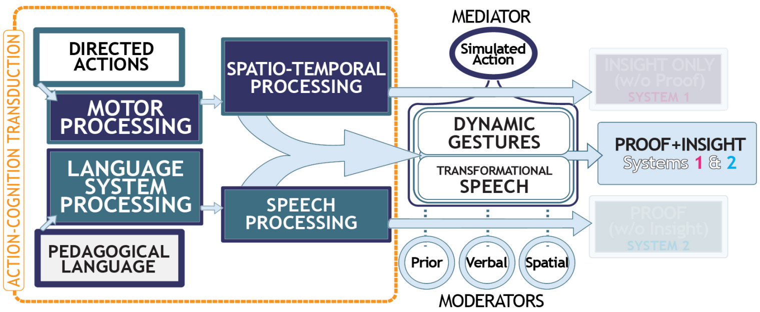

Figure 1. Grounded and embodied mathematical cognition (GEMC) model (Nathan and Walkington, 2017).

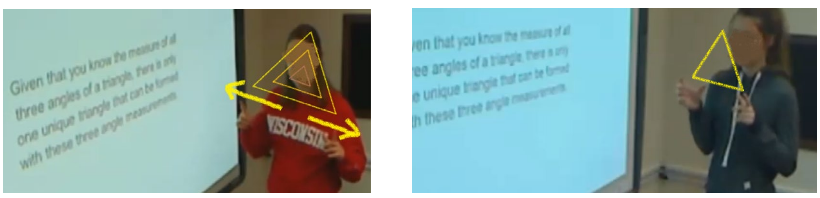

Figure 2. Dynamic gesture (left) and non-dynamic gesture (right).

This study is a post-hoc analysis of the data of 77 valid proofs-with-insight from college students who were recruited to prove four geometric conjectures. Participants were asked individually to prove the four conjectures projected on a screen. Figure 2 depicts students' gestures in response to one of the conjectures, 'Given that you know the measure of all three angles of a triangle, there is only one unique triangle that can be formed with these three angle measurements.' Their responses were video recorded and transcribed.

For this study, a *valid proof* was coded as a correct judgment on the given conjecture's truth value and *insight* as including key mathematical ideas of the conjecture. Then, each transcript of 77 valid proofs-with-insight was binarily coded (i.e., 0/1) in three categories: *DG*, *TS*, and *deductive*, then categorized into four groups by their utilization of DG and TS (Table 1). This random sampling of mutually independent observations satisfied the assumptions for a Fisher's exact test through which we tested whether there was an association between the utilization of DG and TS and the total number of deductive proofs produced.

Table 1: The contingency table of deductive proofs in the four groups by the DG/TS utilization

	DG & TS	DG	TS	None
Deductive	46	19	4	4
Non-deductive	2	1	0	1

Although the raw numbers seem favorable (Column 1, Table 1), statistical analysis showed no significant association between the DG/TS utilization and the production of deductive proofs ($p = .442$) and no significant difference in deductive proof production between the group who used both DG and TS and the groups who did not ($p = .629$). These null results contradict our hypothesis that DG and TS combined would induce more deductive proofs.

Nevertheless, we maintain that this anecdote is inconclusive to refute GEMC model for three reasons. First, multiple previous studies in the same line of research have shown significant associations of the concurrent occurrence of directed actions and transformational language with improved proving practices (e.g., Pier et al., 2019; Williams-Pierce et al., 2017). Second, the GEMC model posits DG and TS as necessary but not sufficient contributors. Third, the small sample size and low statistical power may have resulted in the high p-values. Consequently, we argue that our analysis suggests that spontaneous expression of transformation may be insufficient in generating deductive proof, a more rigorous proof form than valid proofs-with-insight. In turn, the result may hint at the need for interventions to include directed actions and transformational pedagogical language, as predicted in Nathan and Walkington (2017). Future research will investigate other possible contributors to deductive proof production.

References

Harel, G. (2007). Students' proof schemes revisited. In P. Boero (Ed.), *Theorems in school: From history, epistemology and cognition to classroom practice* (pp. 65–78). Sense Publishers.

Hostetter, A. B., & Alibali, M. W. (2019). Gesture as simulated action: Revisiting the framework. *Psychological Bulletin & Review*, *26*, 721–752. https://doi.org/10.3758/s13423-018-1548-0

Nathan, M. J. (2017). One function of gesture is to make new ideas: The action-cognition transduction hypothesis. In R. B. Church, M. W. Alibali, & S. D. Kelly (Eds.), *Why gesture?: How the hands function in speaking, thinking, and communicating* (pp. 175–196). John Benjamins Publishing Company.

Nathan, M. J., Schenck, K. E., Vinsonhaler, R., Michaelis, J. E., Swart, M. I., & Walkington, C. (2020). Embodied geometric reasoning: Dynamic gestures during intuition, insight, and proof. *Journal of Educational Psychology*. https://doi.org/10.1037/edu0000638

Nathan, M. J., & Walkington, C. (2017). Grounded and embodied mathematical cognition: Promoting mathematical insight and proof using action and language. *Cognitive Research: Principles and Implications*, *2*(1). https://doi.org/10.1186/s41235-016-0040-5

Pier, E. L., Walkington, C., Clinton, V., Boncoddo, R., Williams-Pierce, C., Alibali, M. W., & Nathan, M. J. (2019). Embodied truths: How dynamic gestures and speech contribute to mathematical proof practices. *Contemporary Educational Psychology*, *58*(January), 44–57.

Williams-Pierce, C., Pier, E. L., Walkington, C., Boncoddo, R., Clinton, V., Alibali, M. W., & Nathan, M. J. (2017). What we say and how we do: Action, gesture, and language in proving. *Journal for Research in Mathematics Education*, *48*(3), 248–260.

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How Does Students' Perception Of The Main Point Of A Unit Relate To The Quality Of The Final Argument?

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Abstract: Learning about science from an inquiry question across a unit is challenging. We examined whether students with more appropriate goals and plans for a science investigation (i.e., task models) wrote more complete culminating arguments. Students who perceived the unit was about reasoning had less evidence in their essays than those that did not. This suggests that some students need supports to understand the role of reasoning to guide inclusion of evidence in their final arguments.

Keywords: argumentation, explanation, task model, science learning

Introduction

U.S. students are increasingly engaging in inquiry tasks to learn about disciplinary core ideas, science and engineering practices, and crosscutting concepts (Achieve, 2013). By interweaving these three dimensions to answer a question about an authentic anchoring phenomenon (e.g., why were Mesosaurus fossils found in both South America and Africa and how did they get so far apart?), students should begin to develop scientific thinking by engaging in both the construction of explanatory models and argumentation (Achieve, 2013; Osborne, Erduran, & Simon, 2004). Argumentation in science entails the development of claims, the collection of supporting evidence, and the use of key scientific principles and core ideas to reason from evidence to claims (Berland & Reiser, 2009; McNeil & Krajcik, 2012; Osborne & Patterson, 2011). Inquiry learning in 7th grade often involves engaging in argumentation and reasoning across multi-week units. In this situation, it would benefit students to understand how all the individual investigation subtasks contribute to the overarching goal of the unit. Students must know what they are being asked to do for each subtask (i.e., goal state) and how they can do this (i.e., strategies), in order to then assign value to each goal (i.e., interest and motivation for doing the work). We define this regulatory structure as a task model (Britt, Rouet, & Durik, 2018), which is the students' representation of the task during learning. In the current study, we explored students' task models about the point of the unit and the important content they gained from the unit. Then we examined whether students' task model content predicted what they included in their final arguments. In general, we expected students' task models would help explain what was included and not included in their final essay.

Methods

Fifty-seven students participated from three 7th grade science classes taught by the same teacher in Chicago Public Schools (n_s = 25,15,17). After obtaining consent, researchers collected data in March of the 2019-2020 school year. The school district used a science curriculum centered around the Next Generation Science Standards (Achieve, 2013). Each unit presented a hypothetical or real-world scenario with a unit investigation question and built toward a culminating argument essay. During instruction, the teacher used several supportive tools including an *Investigation Steps Chart*, that included five questions to help students monitor and guide inquiry activity (e.g., "How will we use the materials like a scientist to answer the investigation question?" "What have we figured out that helps us to answer the investigation question?" "What do we still need to figure out?"). After finishing their second unit of the year, students completed an eight-minute Task Model survey for that unit. In prior work with adults, our task model survey asked participants to reflect on their goal(s) and actions for achieving each goal. To modify this task for a 7th grade population, we asked students two questions to try to capture the goals in the forefront of the students' minds ("What is the main point of this unit?", "Describe the three most important ideas you learned from this unit."). Then two days later, they had 60 minutes to write their unit argument essay. The instructions prompted students to use evidence to support their claim and to explain their reasoning (i.e., the unit's key reasoning concepts). Students had three resources available to could use when writing their essay: a word bank, their completed Investigation Steps Chart, and notes from a reasoning tool activity that guided students to connect claim-evidence-reasoning.

Results

An ideal essay answer was parsed to identify the key arguments idea units: 15 evidence units (e.g., Earthquakes occur in a pattern along the boundary between the South American and African plates), 10 reasoning units (e.g., which tells me that the plates move), and seven possible pairings of evidence and reasoning. Then the student essays were scored for these units. The Task Model surveys were also scored for the same evidence and reasoning idea units and pairings of evidence and reasoning. Scores were computed as proportions since the number of possible ideas varied between the task model survey and the final essay. Interrater reliability revealed high agreement between two of the authors' judgements (Kappa = .84).

In the argument essays, many students included evidence-reasoning pairs (25%), unpaired evidence (30%), and unpaired reasoning (5%). In the Task Model, students included unpaired evidence (26%), and unpaired reasoning (17%). Evidence-reasoning pairs were not used in scoring the Task Model as they were not as common (1%). A multivariate regression was conducted with evidence and reasoning from the Task Model survey predicting the evidence and reasoning and pairings in the final essay. Reasoning in the Task Model significantly negatively predicted the evidence in the essay $F(2,52) = 2.79$, $p = .05$, $\eta_p^2 = .139$. As students included more reasoning in the Task Model survey, the amount of evidence in the final essay decreased by -.327, $p = .005$.

Discussion

This study presents an exploratory investigation of students' task model knowledge and how it predicts the elements that they include in their unit-culminating argument essay. Students who mentioned that the unit was about key scientific principles and core ideas (i.e., reasoning idea units) included less supporting evidence in their essays. Focusing on curriculum-provided reasoning did not help the students include evidence or make evidence-reasoning pairings in their essays. This finding points to the need to emphasize using curriculum-provided reasoning to learn evidence, practices, and how to think like a scientist in inquiry learning scenarios. Otherwise, students may not benefit from learning these practices and other important concepts intended in inquiry learning. Of course, all these observations are tentative as we only have three classes taught by one teacher. Yet, there was variability in the extent to which students saw evidence as the main point of the unit. Future work will include examining these relationships with a larger sample of classes and different units in the curriculum. This is an exciting first step in connecting Task Models to learning outcomes in this age group.

References

Achieve. (2013). *Next Generation Science Standards: For States, by states.* Washington, DC. The National Academies Press.

Britt, M.A., Rouet, J.-F. & Durik, A.M. (2018). *Literacy Beyond Text Comprehension: A Theory of Purposeful Reading*. New York: Routledge.

Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, *93*(1), 26-55.

McNeill, K. L., & Krajcik, J. S. (2012). *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing.* New York, NY: Pearson Allyn & Bacon.

Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, *41*(10), 994-1020.

Osborne, J. F., & Patterson, A. (2011). Scientific argument and explanation: A necessary distinction?. *Science Education, 95*(4), 627-638.

Penuel, W. R., & Reiser, B. J. (2018). Designing NGSS-aligned curriculum materials. *Committee to Revise America's Lab Report*. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_189504.pdf

Yager, R. E. (2004). Science is not written, but it can be written about. *Crossing Borders in Literacy and Science Instruction: Perspectives on Theory and Practice*, 95-107.

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Family-Friendly Teacher Professional Development

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Abstract: This paper examines a professional development model that centers teachers and their families and was intended to deepen teachers' practices and engagement with making. This program was initiated by teachers who wanted to participate in professional development but faced constraints by the need for childcare. This program highlights what is possible when teachers are positioned to learn alongside their family members and are encouraged to draw on multiple roles and identities. A professional development program that invites and honors the multiple roles of teachers can expand existing best practices and offer a creative and meaningful response to the reality of remote learning and teaching during the COVID-19 pandemic.

Keywords: play, teacher education, technology-enhanced learning, best practices

Introduction

The COVID-19 pandemic has brought several new challenges to, and highlighted existing inequities within, the educational landscape. School districts are requiring teachers adopt new models of pedagogy, while also fervently working to ensure that each of their students receive the emotional, cognitive, technological, and social support that they need. In many states, teachers are expected to pursue additional professional development opportunities, while, at times, still being expected to care for themselves, children, and family members that live in their homes. The tiilt (technological innovations for inclusive learning and teaching) Fellows Program, which began in 2019, examines the challenges and possibilities for teachers who are caretakers and participants in professional development. At a high-level, the program supports teacher professional development experiences that engage teachers alongside their family members to surface pretty good practices (Erickson, 2014) and highlight ways that family members can be assets to teacher learning.

The tiilt Fellows Program is designed to acknowledge the responsibilities and opportunities associated with caring for and learning alongside family members. Cohorts start during the summer and participate in a one-week synchronous experience alongside other teachers from their school district and any available family members. After the one-week session, for at least a year, participants are invited to regularly meet with the program facilitators and receive support as they implement their ideas from the program. A central objective of the first instantiation of the program was to introduce teachers and their family members to some of the tools found in the Maker Movement and support teachers as they designed new activities for their learners. The teachers that participated in the program expressed clear interest in developing their skills and knowledge of technology based making, and how to incorporate it into their teaching. However, when a summer workshop was suggested, teachers assumed that they could not participate because of their responsibilities as primary caretakers for their children. In response to this, the research team designed a program that would incorporate and encourage intergenerational learning and participation. The program features connections to research on teacher professional development best practices. These practices include being content focused, incorporating active learning, supporting teacher collaboration, using models and modeling, providing expert support, including opportunities for feedback and reflection, and being of sustained duration (Darling-Hammond et al., 2017). We utilize these practices as a base for developing our model of practices for intergenerational teacher professional development experiences. Details about the program design can be found in Perez, Jones, Lee, and Worsley (2020).

Discussion

Within these different practices, there are a few challenges and opportunities that are important to highlight. Specifically, the power of play, which created a low-stakes environment for teachers and their families to learn alongside each other; bridging formal and informal spaces so that participants could workshop their ideas with family members; and, finding opportunities to work with the competing identities of teacher and parent.

The power of play

Play created a low-stakes environment that benefitted the group as they navigated new tools and tested out their ideas. It contributed to general levity that offered moments of meaning and consequence (Hall and Jurow, 2015). Play was characterized by structured or unstructured moments when participants and researchers engaged with each other to maintain interest and productively move ideas forward. At the same time, spontaneous moments of play made group discussions challenging. Some parents felt like their children were too distracting for other participants and would have liked clearer delineations to signal when and where play was appropriate. Play has implications for how teachers might think about learning in the context of home, where the rules of school are less dictated, and students have access to materials that are familiar to them. While the home is different for many, it can be the space where students play and have fun with what they are learning in school. In a time of remote learning, moments or postures of play can offer teachers an opportunity to engage their students and expand what they see as possible for making.

Teacher professional development goes home

We often talk about the importance and value of students being able to explore their learning across contexts, but sometimes forget that this holds true for teacher learning, too. In interviews, some teacher participants shared that having family members participate in the program helped them prepare for in-school implementation in part because ideas and practices in the program crossed over seamlessly into conversations at home. This consideration was factored into the design of the program through assignments and materials given to families to take home and complete before returning for the next in-person session. Furthermore, teachers shared ways they sought to incorporate non-participant family members of the program into the experience. Finally, teachers talked about how the experience was meaningful; having the artifacts at home served as a valuable reminder for the children and teachers of their shared making experience.

Complementary and competing identities

The program filled an immediate need that teachers had as primary caretakers and as teachers interested in making. The opportunity for participants to bring in and enact these two identities together proved invaluable. Teachers emphasized that many existing professional development experiences neglect the different roles that they hold—especially as a caretaker. Hence, there is a need for teacher professional development experiences that intentionally make space for teacher participation and their multiple roles or identities (hooks, 1994). Reconciling these roles, however, presents its own unique challenges. One teacher described her process as constantly having to switch between roles. This may point to an important opportunity for future teacher professional development: providing space for teachers to explicitly discuss their different roles or identities, and how they would like for a given professional development experience to incorporate those roles or identities.

Conclusion

Broadly speaking, the program is an instantiation of what is possible when we reposition something that would traditionally be viewed as a constraint, as an opportunity in teacher learning. We find this a useful paradigm shift in the context of making and the maker movement but suggest that this change might be beneficial across several inquiry- and problem-based learning contexts. The COVID-19 pandemic is forcing the world to deal with a new reality where many of our assumptions are no longer met. Instead of running from these different constraints, we can consider how they might advance new forms of expansive and meaningful teacher professional development.

References

Perez, M., Jones, S., Lee, S., & Worsley, M. (2020). Intergenerational Making with Young Children. *In Proceedings of the ACM 2020 Fablearn Conference*.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). Effective teacher professional development. Palo Alto, CA: Learning Policy Institute.

Erickson, F. (2014). Scaling down: A modest proposal for practice-based policy research in teaching. *Education Policy Analysis Archives*, *22*(9), 9. https://doi.org/10.14507/epaa.v22n9.2014

Hall, R., & Jurow, A. S. (2015). Changing concepts in activity: Descriptive and design studies of consequential learning in conceptual practices. *Educational Psychologist*, 50(3), 173–189. doi:10.1080/00461520.2015.1075403

hooks, bell. *Teaching to Transgress: Education As the Practice of Freedom*. 1994. Print.

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From "Authentic Tools" to Authenticity: Using CT to Enable Discovery in Statistics Classrooms

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Abstract: CS Educators pushing to integrate computational thinking (CT) into mathematics classrooms has quickly influenced statistics classrooms where students now analyze data using modern computational tools. Yet while teachers perceive using "authentic tools" in the classroom as providing an "authentic learning experience," the power of computational tools to help reimagine existing content is often overlooked. Our team worked with teachers to co-design two CT-integrated statistics units across two years. We use a model of professional growth to discuss the teachers' changing beliefs over the course of the two co-design projects. We see how the enactment of a programming-focused CT-integrated unit led to changes in teachers' beliefs about the pedagogical impact of CT. These informed the teachers' approach in a second co-design, resulting in a unit that emphasized empowering students to discover statistical concepts via an *authentic learning experience* using authentic computational tools.

Introduction

Prior research has advocated for the integration of CT in K-12 STEM classes with three primary goals. First, the use of computational tools can engage students in authentic inquiry experiences that reflect the work of STEM professionals (Weintrop et al., 2016). Second, prior work shows that students' exploration of computational tools can improve pedagogy and outcomes in STEM as it deepens students' interaction with content (Wilensky & Reisman, 2006; Sengupta et al., 2013; Kelter et al., in press). Third, it broadens access to computing by engaging all students in computational practices within K-12 classes, particularly in the United States, where STEM classes are required and computing classes are often relegated to elective status meaning CT in STEM can reach students beyond those who traditionally take computing courses. Using the interconnected model of professional growth (Clarke & Hollingsworth, 2002), we examine the way that two mathematics teachers make sense of CT within mathematics contexts, and how these conceptions shift through professional development and classroom experience. In this context, we explore the ways that mathematics teachers express their understanding of CT within statistics as they participate in this professional development cycle. How does the enactment of a programming-focused CT unit lead to changes in teachers' beliefs about the pedagogical impact of CT?

Methods

We focus on two participants, both experienced mathematics teachers, from the same high school: Steven and Josh. In the first year of the study, Steven attended CT professional development, called CTSI (Kelter et al., in press), and created a CT-integrated unit with a co-design team. Steven implemented this unit in his class and also recruited and helped his colleague, Josh, to implement the unit with his own students. Steven and Josh both attended the following CTSI where they worked together to build a new unit. It is across these three events, the first PD, the implementation, and the second PD that we examine the changes in the perceived salient outcomes of integrating CT into the classroom for Steven and Josh. We leverage clinical interviews with teachers taken after each CTSI and curricular implementations, classroom implementation video data, and observational field notes collected during the implementations and co-design sessions. We utilize the multiple case-studies method to track the changes in teachers' *personal domain*–their beliefs, knowledge, and attitudes–and how that impacted their involvement in the *external domain* across two PDs centered around co-design and the *domain of practice* (their implementation of the unit). The first two authors coded the teacher interviews according to the IMPG coding scheme, sharing codes and preliminary finds with each other to validate the codes. Video data and field notes from the classroom implementations are used to further triangulate changes in the *domain of practice*.

Discussion and Conclusion

Steven and Josh both originally approached integrating CT for similar purposes of providing students exposure to authentic computational tools (*personal domain)*. They *enacted* this belief system by implementing a computationally enriched lesson focused heavily on the exposure to a new computational tool. Both teachers expressed new ideas about how and why computational thinking should be taught to students (*domain of* *consequence*), suggesting this enactment and subsequent reflection played a large part in updating within their beliefs surrounding CT. They struggled to find a balance between the computational content and the statistics content, first focusing on the computational tool then on the statistics content. They grappled with deciding whether to engage using an authentic tool use compared to using scaffolded computational experiences that more deeply engaged students in the statistics content (see Figure 1). They also noted that these scaffolded experiences did not map to their own conceptions of a math classroom as easily as to the science classroom, suggesting the need for additional scaffolding for mathematics teachers in CT PD. They expressed that it was vital to have the design team present to push back on this statistical focus, and to help frame student engagement around the CT elements (*external domain*). Both teachers expressed a different understanding of CT after participation in the second CTSI professional development but at the time of this work, neither teacher had implemented their second CT-enriched unit, so future work will explore their experiences enacting these new perspectives in the classroom. Broadly, this work contributes to understanding how mathematics teachers conceptualize and approach CT within their domain, with the goal of better supporting computational thinking integration within mathematics and statistics that is more than just exposing students to authentic tools and instead pushes students to engage in authentic practice.

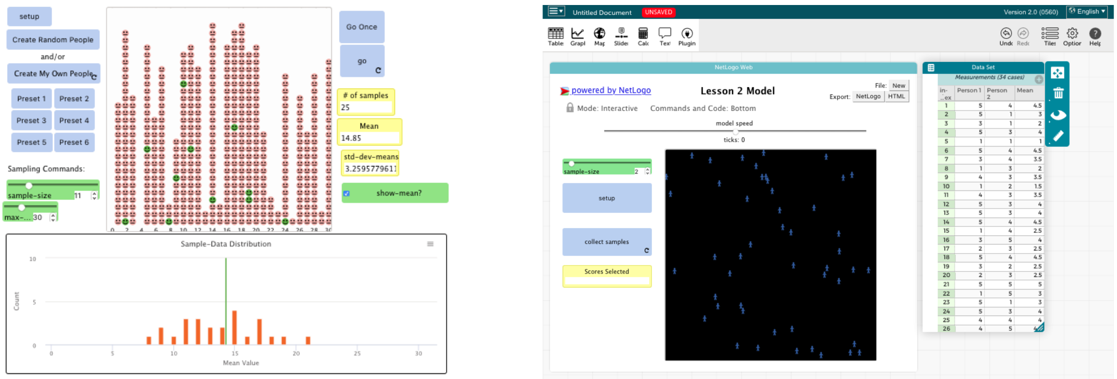

Figure 1. A screenshot from the second unit on Sampling Distributions which uses NetLogo Web with CODAP.

References

Blikstein, P., & Wilensky, U. (2009). An atom is known by the company it keeps: A constructionist learning environment for materials science using agent-based modeling. *International Journal of Computers for Mathematical Learning*, *14*(2), 81–119.

Clarke, D., & Hollingsworth, H. (2002). Elaborating a model of teacher professional growth. *Teaching and Teacher Education*, *18*(8), 947–967.

Kelter, J., Peel, A., Bain, C., Anton, G., Dabholkar, S., Horn M. S., & Wilensky, U. (in press). Constructionist Co-design: A Dual Approach to Curriculum and Professional Development. British Journal of Educational Technology.

Sengupta, P., Kinnebrew, J. S., Basu, S., Biswas, G., & Clark, D. (2013). Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework. *Education and Information Technologies*, *18*(2), 351–380.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2015). Defining Computational Thinking for Mathematics and Science Classrooms. *Journal of Science Education and Technology*, *25*(1), 127–147. https://doi.org/10.1007/s10956-015-9581-5

Wilensky, U. (1999). NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

Wilensky, U., & Reisman, K. (2006). Thinking like a wolf, a sheep, or a firefly: Learning biology through constructing and testing computational theories—An embodied modeling approach. *Cognition and Instruction*, *24*(2), 171–209.

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International Society of the Learning Sciences

Examining Teacher Reflection in a Multimodal Composition about Identity

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Abstract: This study aimed to examine the reflection and development of a multimodal composition exploring the topic of professional identity formation in a teacher education program of teaching English as a Foreign language (EFL). Using a social design experiment, this study examined the process of a key participant. Three themes were identified: (1) iterations through her composition, (2) critical examination of readings, and (3) giving and receiving feedback. This study contributes to a nuanced conceptualization of reflection through multimodal composition when mediating reflection in identity work in EFL teacher learning.

Introduction

Responding to an increasingly digital landscape in recent decades, shifts in pedagogy have called for more expansive notions of text, giving rise to new forms of literacies (Cope & Kalantzis, 2009). These literacies have moved beyond static ideas of text and writing and have been more inclusive of multimodal forms such as visual and audio (Kress, 2010). This view of literacy is characterized by an agentic construction process of text that integrates multiple dimensions, layers, modes, and stages, positioning the writer as "an active designer of meaning" (Cope & Kalantzis, 2009, p. 175). Research in this area has highlighted the affordances of those expansive notions of text to develop learners' voice, creativity, and meaning-making. Notably, a significant subfield has been the studies on digital multimodal composition, especially with language learners (e.g., Anderson, Chung, & Macleroy, 2018). However, few studies have been conducted exploring multimodal composition with teachers. Although it is a tool with the potential to enhance teacher reflection processes necessary to prepare pre-service teachers, most of the extant literature is related to conventional forms of text such as narratives and autoethnographies. Therefore, the goal of this study was to examine the reflection and development of a multimodal composition exploring the topic of professional identity formation in a teacher education program of teaching English as a Foreign language (EFL) in Costa Rica. The present study describes a full semester-long multimodal project in a language teacher education program, focusing on the intricacies of the multimodal composition process and what made it effective for reflection.

Methods

This research is based on a larger study that uses social design-based experimentation (Gutiérrez & Vossoughi, 2010) to design a semester-long intervention. Participants created a digital multimodal composition telling stories about their English learning experience, process of becoming teachers, and feelings of tensions related to identity development. The participants were fourteen pre-service teachers enrolled in a culture course in an EFL teacher education program in a university in Costa Rica. For this study, one participant, Kathy (pseudonym), was selected because she illustrated the major findings. She strategically selected and analyzed everyday and academic elements to make sense of her lived experiences in her multimodal composition. Data sources for this study included: (1) participant artifacts from iterations of the multimodal composition, (2) a 60-minute interview with the participant to dig deeper into the process she followed in her project, (3) field notes and memos from class sessions and the revision process of the participant's drafts. For data analysis, we iteratively examined the data. Through thematic analysis (Saldaña, 2015), the researcher determined patterns and common themes across the multimodal composition process to identify key moments and elements of the intervention that promoted the participant's reflections on her identity.

Findings

Three themes were identified that facilitated the participant's reflection and development of her multimodal composition: (1) iterations through her composition, (2) critical examination of readings, and (3) giving and receiving feedback.

Iteration through the composing process

Kathy found that revisiting her story multiple times and reexamining the modes selected provided opportunities to further elaborate her analyses and gradually build her modes for meaning-making. For example, by revisiting her experiences and looking for modes, she remembered that she had written the Poem "Mi Lengua No Quiere el Inglés" (my tongue does not want English) in one of her college classes. In this part of her story, she was convinced that she was betraying her culture and language by learning English, so her tongue was rejecting English. This poem's title became a central piece in the mode of this chapter, illustrating her frustration and tension. The iteration process was a scaffolding tool for her to gain deeper meanings of what she was gradually constructing and making effective connections among all the elements and the narration.

Building "aha" moments through critical examinations of course materials

Modifications Kathy made to the modes were connected to specific "aha" moments in the course when students critically examined socialization processes and language beliefs in readings and discussions. An example of this was a reading about a critical autoethnography of a Costa Rican author who had learned English in the same context as Kathy. Because of this critical moment, Kathy included a quote from this reading "My journey started much earlier and can be better understood in the context of sociohistorical local and global dynamics" (Solano-Campos, 2014, p. 422). Kathy decided to tell her story from her perspective. She added audio to explain her feelings and thinking rather than describing the events as they happened. Like the article's author, Kathy owned her story and used her voice to uncover the social and cultural factors not analyzed before.

Giving and Receiving Feedback

During the course, students provided and received feedback through peer assessments and formative revisions from professors. In terms of the professors' feedback, Kathy emphasized that the questions received in iterations of her work guided her reflection. For instance, in the second draft, the professors wrote comments about connecting more with cultural aspects. Thus, she described her first contact with English at the age of five through the interest-driven activity of watching cooking shows. She explained how she enjoyed it as she was unconsciously learning words by association. However, she was not making any connections to culture. After adding the videos and the audio to represent what she was thinking when watching the shows, she decided to highlight in the audio the contrast between the "American dream kitchen" with the "cocina de leña" (wood-burning stove) at her grandma's house. Including this cultural aspect helped her reflect on how she was overgeneralizing that all American homes had that "cooking show" kitchen. The opportunity to receive feedback in key moments of her composition allowed Kathy to construct gradual layers of analysis.

Conclusion

The findings of this study indicate that (1) "aha" moments occurred when unnoticed socialization processes and beliefs about language were critically examined through readings and discussions to provide a tool for interpretation of lived experience, (2) an iterative and recursive approach to multimodal composition to foster deep reflection about the self effectively mediates meaning-making of personal narration, and (3) giving and providing feedback provides distributed and collaborative opportunities for gradual improvement and deeper levels of analysis of lived experience. Altogether, these findings demonstrate that these elements of design assembled to produce a multimodal project mediated nuanced and complex understandings of the self rooted in past lived experience. These results show promise for language teacher education programs aiming to integrate identity work to unravel the mediating power of designing a multimodal composition with the elements of critical reflection, iteration, and collaborative feedback for teacher identity development.

References

Anderson, J., Chung, Y. C., & Macleroy, V. (2018). Creative and critical approaches to language learning and digital technology: findings from a multilingual digital storytelling project. *Language and Education*, *32*(3), 195-211.

Cope, B., & Kalantzis, M. (2009). "Multiliteracies": New literacies, new learning. *Pedagogies: An international journal*, *4*(3), 164-195.

Gutiérrez, K. D., & Vossoughi, S. (2010). Lifting off the ground to return anew: Mediated praxis, transformative learning, and social design experiments. *Journal of Teacher Education*, *61*(1-2), 100-117.

Kress, G. R. (2010). *Multimodality: A social semiotic approach to contemporary communication*. Taylor & Francis.

Saldaña, J. (2015). *The coding manual for qualitative researchers*. Sage.

Solano-Campos, A. (2014). The making of an international educator: Transnationalism and nonnativeness in English teaching and learning. *TESOL Journal*, *5*(3), 412-443.

Make with Data: Challenging and Contextualizing Open-source Data with Personal and Local Knowledge

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Abstract: In this poster we describe Make with Data, a two-year project that invites teachers and students from public high schools to work with professional data scientists and open-source data to explore issues important to their local community. While the negotiation of the personal and the quantitative resulted in tensions, Make with Data students found their personal experiences a useful tool for adding context and complexity to the phenomena being studied.

Purpose and significance of the work

In the Make with Data project described here, we engage learners age 16-17, from groups underrepresented in STEM domains, to work together with educators and data scientists in an after-school setting to identify and understand a local community challenge. Leveraging the constructionist design paradigm and research on project-based service learning, the project investigates how framing data science practices as a means of contributing to and improving one's community can impact students' understanding of data and data science practices. By encouraging learners to identify challenges that impact their local community, and supporting them as they use open-source data in collaboration with educators, professional data scientists, and other STEM professionals, students developed a rich understanding of how data can be used to address local needs, which in turn positively impacted their interest in data science related careers.

However, because students have personal experiences related to these local challenges, their exploration of the data inevitably involves negotiating their own perspectives with what they see in the data (Rubel et al., 2017; Wilkerson & Laina, 2018). In this poster we examine how students leveraged their personal experiences in their local community to further elucidate the context and complexity of trends found in open-source data.

Methodology

In the first year of the Make with Data project, teachers were recruited from four boroughs of New York City. Participating teachers were mostly science educators with one pair being social studies teachers. These teachers then selected one to two students from their school to be "student leaders" for the duration of the project.

During this first year, all participants jointly worked through the identification of a locally relevant issue, and in smaller groups set out to explore and find open-source datasets to better understand the issue and propose potential solutions. The teacher and student teams jointly attended approximately 9 sessions with the other teacher-student teams, the project leaders, and professional data scientists. Additional conference calls and meetings between teams and data scientists occurred throughout the year as needed. Full team meetings took participants through a process of brainstorming possible project ideas, learning how to access relevant open-source data, exploring the use of data analysis tools, tinkering with data to explore possible trends, and developing representations and presentations to communicate their findings.

The following year, teacher and student teams implemented a new Make with Data-type project in their own school. Each teacher and student team recruited new students from their school to join their group, developed their own meeting schedules, and—following a structure similar to the one used during the first year of the project—worked with these students to identify and explore locally relevant community challenges. In total, the team (made up of the project leads, data scientists, and students and educators) grew to approximately 50 individuals distributed across four schools.

In this poster we describe the two-year data explorations of two Make with Data students. These cases illustrate the way in which participants' personal experiences with their chosen topic drove their search for data and impacted their interpretation of discovered datasets.

Findings

As expected, students in the Make with Data project took on and explored topics relevant to the experiences and needs of their local community. However, as we will show below, the personal nature of these topics led to an important back and forth between the data, the original research question, and the students' preconceptions.

In the first year of the project, we invited teacher and student participants to consider their own experiences, and those of their community to identify a category of challenges that they would like to explore further. The team from the Bronx chose to focus on student mental health. Speaking about the mental health challenges faced by her and her classmates, Bronx-S (student) stated, “I've experienced mental breakdowns, and I think mental health for students is really important [...] It has affected me because I've had anxiety and stress over school. And that has affected me at home too, my attitude just changes.”

The Bronx team recognized that the geographic layout of their particular borough and school limited access to public transportation so using GIS software, they mapped out the location of mental health facilities, schools throughout the Bronx, and public train and bus lines. However, rather than rely solely on the GIS Data, Bronx-S read her own experiences into the data asserting, “the map and data doesn't tell the whole story” (Van Wart et al., 2020). For example, while there was one mental health facility relatively close to her school, this lone facility served a large number of schools in the area. Furthermore, getting to this facility required overcoming many geographic obstacles—such as moving through areas of high crime—as well as personal ones—like the expectation to come home after school to take care of younger siblings.

Together these life experiences led the Bronx team to build a board game (based on the classic board game “Life”) where players try to make it to the local mental health facility while random events and continually building depression slow their progress. In their project the Bronx team illustrated that access to mental health support is more than just the measure of distance on a map. Rather, their game narrates how a complex interaction of factors—that includes things that can be observed in public datasets as well as factors that are personal, hidden, but no less relevant—impact how students navigate access to mental health support (Wilkerson & Laina, 2018).

Another student, Staten-S, chose to examine marijuana use among teens. While she quickly found relevant datasets, each came with unique challenges and contradictions. For example, when looking at arrest data, Staten-S realized that the NYPD no longer tracks the possession of small amounts of marijuana meaning this data might underrepresent marijuana possession. In Staten-S's words, “not everyone gets caught.” This led Staten-S to examine data on “Stop and Frisk.” She found that incidents of stop and frisk overwhelmingly occurred on Black males (10 times as often as their white counterparts) and showed a miniscule number of incidences resulting in possession charges. Believing this dataset to indicate racist policing policy, Staten-S sought out an alternate dataset, eventually finding a survey on substance abuse. In this survey, more white students reported using cannabis than Black and Latino students. As these results were different than her expectations—expectations that Staten-S admitted were based on problematic stereotypes—she wondered if self-report on a survey could be trusted?

When presenting this work at the end of the second year, Staten-S described the extent of her search and argued that while she had tried to look at this issue from multiple angles using a number of different datasets, “the trends weren't strong enough to come to a specific conclusion.” In the end Staten-S believed the data she was exploring obfuscated things like racist policing practices and data collection methods she wasn't sure she trusted leaving her with “more questions” than answers (Wilkerson & Laina, 2018).

Conclusions

The Make with Data project's central hypothesis is that interest in STEM for underrepresented youth can be substantially impacted by connecting the practice of science with students' personal and communal values and experiences. Through the creation of a learning environment that situates data science concepts and practices in local phenomena and challenges, these two cases show how personal experiences and knowledge about the local context can support data science novices as they make meaning out of complex datasets. While the negotiation of the personal and the quantitative can result in tensions, Make with Data students found their personal experiences a useful tool for adding context and complexity to the phenomena being studied.

References

Rubel, L. H., Hall-Wieckert, M., & Lim, V. Y. (2017). Making Space for Place: Mapping Tools and Practices to Teach for Spatial Justice. *Journal of the Learning Sciences*, *26*(4), 643–687. https://doi.org/10.1080/-10508406.2017.1336440

Van Wart, S., Lanouette, K., & Parikh, T. S. (2020). Scripts and Counterscripts in Community-Based Data Science: Participatory Digital Mapping and the Pursuit of a Third Space. *Journal of the Learning Sciences*, *29*(1), 127–153. https://doi.org/10.1080/10508406.2019.1693378

Wilkerson, M. H., & Laina, V. (2018). Middle school students' reasoning about data and context through storytelling with repurposed local data. *ZDM*, *50*(7), 1223–1235. https://doi.org/10.1007/s11858-018-0974-9

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Teacher Learning as Co-operative Work to Expand Images of Future Classrooms

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Abstract: This paper examines the co-operative action (Goodwin, 2018) of teachers discussing research articles as part of a professional development cycle. We make sense of how the articles become part of the interactional resources teachers use to construct images of their future classrooms and students. This has implications for considering the interactional practices of facilitating teacher learning.

Teacher learning is key for developing meaningful changes in science education. This is important as the field grapples with what it takes to realize changes towards science learning that positions students as "*doers of science* rather than receivers of facts" (Miller et al., 2018, p. 1056, emphasis theirs). This paper proposes a form of teacher pedagogy to develop awareness of what teaching and learning science can look like by focusing on teachers' imagined futures. This kind of professional learning activity is a relatively unexplored avenue for promoting teacher learning in design research with untapped affordances. It provides a flexible medium for teachers to shift their vision of their future work that might not be as readily available from watching video or rehearsing practices. It also encourages partnerships between researchers and teachers (Penuel et al., 2020).

This paper analyzes interactions during professional development (PD) workshops which were shifted to remote, synchronous work due to the COVID-19 pandemic. Analysis focuses on how teachers co-construct imaginings of future classrooms during two conversations about science education research articles. Examining how teachers developed their public representations of their future classrooms offers insight into the possibility for this kind of activity to facilitate teacher learning by developing notions of what their classrooms can look like and what their students can do. This is important for imagining more equitable science spaces for students. Our analysis is centered on the following question: *How do teachers' prior experiences interact with new conceptualizations and images of student learning represented in research articles as they co-construct future visions of classroom teaching and student learning?*

Theoretical framework: Developing substrates to change future classrooms

Crafting a future vision of classrooms and students, collectively, is an important aspect of developing teacher "professional vision" (Goodwin, 2018; Sherin & van Es, 2009). Goodwin (2018) describes co-operative action as the social process of "building something new through decomposition and reuse with transformation of resources placed in a public environment by an earlier actor" (p.3). This paper uses the substrate -- or the complex set of resources that teachers bring, decompose, use, and develop -- as the unit of analysis. The substrate is the "immediately present semiotic landscape with quite diverse resources that has been given its current shape through the transformative sequences of action that culminate" in current action (Goodwin, 2018 p. 39). Reading two STEM education research articles as a PD activity reconfigures the substrate teachers use to develop a discussion of their future classrooms and future students. This includes a perspective on how teachers *laminate*, or deploy across modalities and constructs, particular parts of the stories as resources for further social action.

Context and methods

Data were generated during a four-day summer workshop conducted as part of a professional development (PD) cycle with 13 middle school science and STEM teachers. The purpose of the PD was to help teachers learn about, adapt, and enact lesson sequences that integrate computational activities through the use of sensor technologies (Biddy, et al., 2020). The two activities examined in this paper consisted of discussing two education research articles (Manz, 2019; Hardy et al., 2020). We transcribed recordings of both discussions and selected focal clips during multiple reviews (Jordan & Henderson, 1995). Focal video clips were iteratively reviewed and analyzed through multiple passes together by groups of researchers.

Co-operatively positioning future students and classrooms

In reading the second research article, facilitators asked the teachers to focus on the case study of one student, Hope (p. 115-122). The case study presents a shift in Hope's engagement with data as she used sensors to investigate the relationship between plants and CO_2 levels. Teachers were asked to reflect on guiding questions including: "Where do you see opportunities for students to develop agency as they progress through" a co-designed curricular unit. The day began with a discussion of Hope's story, in relation to the teachers' own practice.

Analysis of the following whole group discussion illuminated the varied perspectives that teachers bring to bear on PD sessions and indicated the local substrates as particular and under construction. Each teacher did not just involve their own context but used the locally available substrate to build towards understanding how their future students might: 1) take part in the type of transitions Manz (2019) proposes, or 2) be a data producer like Hope (Hardy et al., 2020). This activity revealed some of the important resources and narratives that teachers deploy to position their future classrooms and students in relation to the ongoing discourse. These included curricula, disciplinary conceptions of science, past experiences with students, and more. For example, one teacher deftly laminated Hope's story onto her experience with science curricula over the past 8 years, from science kits in a box to inquiry driven investigations that get students outside. Two teachers directly positioned their own future students in relation to Hope. One shared "some of my students would automatically be like hope… others would not… you would need to ask good questions," explicitly laminating Hope's story onto her vision of future students abilities, based on her previous experience. She also characterizes the pedagogical move that would support those who need help getting to the level of independent engagement with the scientific processes: asking good questions. The second teacher rejected such a lamination and characterization of the pedagogical need, instead eventually sharing that students would need "certain background knowledge" to do "correct scientific experiments." This contestation is a familiar narrative in science education that characterizes a particular kind of progression for engaging in critical thinking and experimentation: students need certain knowledge building blocks before they can do the experiment, which limits future visions.

Discussion and conclusion

This kind of social action shows persistent, interactional resources that are – and can be – used to laminate the goals of the PD onto the teachers' classrooms and eventual practice. This analysis brings to the fore that teacher PD is not a neutral activity, but an engagement with teacher future visions of their classrooms that are structured and co-constructed from their prior experiences, in addition to other local semiotic resources. The excerpt above exemplifies the possibility of developing teachers' interactional substrates for collectively imagining different futures for their students and classrooms. It also depicts the various ways that teachers inhabit, decompose, and reuse these kinds of visions of futures through what their students will and will not be able to do. Therefore, as we engage sociocultural and constructivist theories of learning to inform curricula designs that are forward looking (Miller, et al., 2018) we must also apply such theories to facilitate teacher learning towards developing what they can imagine future visions of student learning to look like. This paper describes a possible approach as a beginning for considering how to frame more of teacher development intentionally around an engagement with images of future classrooms and students that leaves room for imagining.

References

Biddy, Q. Gendreau Chakarov, A., Bush, J.B., Hennessy Elliot, C. Jacobs, J., Recker, M., Sumner, T., & Penuel, W. (2021). A professional development model to integrate computational thinking into middle school science through co-designed storylines, *21(1)*. *Contemporary Issues in Technology and Teacher Education.*

Goodwin, C. (2018). *Co-Operative Action* (1st ed.). Cambridge University Press.

Hardy, L., Dixon, C., & Hsi, S. (2020). From Data Collectors to Data Producers: Shifting Students' Relationship to Data. *Journal of the Learning Sciences*, *29*(1), 104–126.

Jordan, B., & Henderson, A. (1995). Interaction Analysis: Foundations and Practice. *Journal of the Learning Sciences*, *4*(1), 39–103.

Manz, E. (2019). Getting a Grip: A framework for designing and adapting elementary school science investigations. Science & Children, 56(8), 1-9.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053–1075.

Penuel, W. R., Riedy, R., Barber, M. S., Peurach, D. J., LeBouef, W. A., & Clark, T. (2020). Principles of Collaborative Education Research With Stakeholders: Toward Requirements for a New Research and Development Infrastructure. *Review of Educational Research, 90*(5), 627–674.

Sherin, M., & van Es, E. A. (2009). Effects of Video Club Participation on Teachers' Professional Vision. *Journal of Teacher Education*, *60*(1), 20–37.

Computational Thinking in Preschool: Bridging Home and School

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Abstract: Computational thinking (CT) has received significant national attention as a key skill for all learners. Our research involved working with preschool teachers and families from underserved communities to co-design home and school learning experiences that integrate algorithmic thinking, abstraction, decomposition and debugging. Findings highlight the promise of bridging home and school learning to promote CT and STEM early in childhood.

Computational thinking

Wing (2006) presented CT as "a universally applicable attitude and skill set" oriented towards solving problems and designing solutions, in ways that make them amenable to being solved with computational systems (p. 33). Earlier notions of CT that focused on programming and procedural thinking (Papert, 1980) have since been expanded to include a broader set of skills and practices (e.g., Dong et al, 2019). National attention on CT has led researchers, educators, and policymakers to design CT resources, curricula, and assessments across grade levels. Much of the attention to date has been focused on middle and high school students, with some emerging CT activities and resources designed for elementary children. However, few studies have examined whether and how CT can be promoted in preschool in ways that resonate with young children's experiences and are consequential for early learning. While studies have found that kindergartners can learn to successfully program robots with support, concerns regarding the developmental appropriateness and level of scaffolding necessary for preschool children to successfully engage in these activities have been raised (Kazakoff, Sullivan & Bers, 2013). Researchers have concluded that young children may benefit from engaging in other CT activities that are better aligned to their abilities and interests. A recent study found that preschoolers benefit from learning important CT skills such as sequence, modularity, and debugging during common classroom activities (Lavigne, Lewis-Presser & Rosenfeld, 2020). Preschool teachers are tasked with promoting children's learning in many areas and adding CT into an increasingly crowded curriculum may be challenging. Identifying how CT can strengthen learning broadly and how it can be embedded into STEM areas, such as math and science, is necessary.

Study design and data sources

Our study brings together public preschool teachers; families from culturally diverse, low-income communities; curriculum and media designers; and researchers to engage in collaborative design and design-based research. As part of the co-design process, all stakeholders shared their unique perspectives and insights; brainstormed whether and which CT skills could be consequential for early learning; and collaboratively developed (and tested) classroom and home activities and digital apps to promote CT and STEM. The study consisted of three phases: (1) identifying target content, (2) co-designing and pilot testing preliminary ideas and (3) conducting a small field study to examine implementation and evaluate the promise of designed resources for classrooms and homes.

Figure 1. Co-Design Meeting

Phase 1: Identifying target content

During this phase, the team of stakeholders first came together to identify target content and discuss co-design processes. Algorithmic thinking, problem decomposition, abstraction, and debugging were selected as the initial target skills for the study. A comprehensive list of math concepts and science practices was also generated so that integration could be explored organically as activity ideas were drafted. Using this information, the team generated the first draft of a learning blueprint that served as an anchor document to guide the development and iterative enhancement of resources, as well as the development of research instrumentation.

Phase 2: Pilot testing and Iterating on Design Ideas

Using the draft learning blueprint as a guide, the research team recruited a larger sample of practitioner partners to engage in co-design (2 public preschool teachers and 4 culturally and linguistically diverse families). The co-design team came together four times. During initial meetings, the research team shared "seed" ideas in order to kick off the idea generation process. Teachers and parents shared insights and feedback about the affordances, feasibility and constraints of the seed activities and were invited to generate alternate or/and additional ideas. As ideas emerged, they were entered into the learning blueprint and tagged with the corresponding CT, math and science learning goals. In between meetings, the team tested activities discussed at subsequent co-design meetings.

A total of 22 classroom activities, 6 home activities, and 2 digital apps (for use across home and school) were developed. While we found robust connections between CT and math concepts, connections to science were not specifically tied to core ideas but rather science practices. For instance, algorithmic thinking activities integrated visual spatial skills and counting, while abstraction activities promoted observation and sorting.

Phase 3: Field Study

The final phase included a small field study in 7 public preschool classrooms; 5 classrooms implemented the CT activities and 2 classrooms served as a comparison group. All children enrolled in the classrooms were invited to participate in classroom activities and a subsample of 2 families in each of the intervention classrooms participated in the home-school component. A subsample of 8 children per classroom engaged in a brief CT assessment. Three observations and debrief interviews were conducted with each intervention classroom/teacher and family.

Figure 2. Digital and Hands-on Activities.

Findings from the assessment analysis indicated that the overall difficulty of the assessment items was relatively high for both pre- and post-assessment, with nearly all items having a proportion correct less than 0.5. Most items, however, demonstrated acceptable levels of discrimination. Cronbach's alpha was also found to be reasonably good: 0.72 and 0.78 at pre and post respectively. Assessment data was used to examine improvement in children's learning from pre to post. While the sample is small, significant improvements were detected from pre to post for children who participated in the home-school connection condition, relative to the comparison condition. Interestingly, a significant effect was not detected for children who participated in the classroom only condition, relative to the comparison condition.

Findings from classroom observations indicate that teachers implemented activities throughout the study and appreciated the formats and connections to STEM. Observers noted over 80% of the activities observed were modified by teachers. While most modifications strengthened activities, more than a quarter of the modifications involved excluding CT activity components. It is possible that teachers gravitated toward STEM content they were familiar, excluding content that was new. Successful integration seemed to have occurred when the CT concepts were integral to the STEM lesson and vice versa. Findings from family interviews indicate that families enjoyed the activities and reported engaging in many of them repeatedly with their children. Families appreciated that the activities included experiences they could easily embed into their routines (e.g., grocery shopping, getting ready for school/bedtime) and involved formats familiar to their family (e.g., book reading, cooking, etc).

References

Dong, Y., Catete, V., Jocius, R., Lytle, N., Barnes, T., Albert, J., ... & Andrews, A. (2019, February). PRADA: A practical model for integrating computational thinking in K-12 education. In Proceedings of the 50th ACM Technical Symposium on Computer Science Education (pp. 906-912).

Kazakoff, E. R., Sullivan, A., & Bers, M. U. (2013). The effect of a classroom-based intensive robotics and programming workshop on sequencing ability in early childhood. *Early Childhood Education Journal, 41*(4), 245-255.

Lavigne, H. J., Lewis-Presser, A., & Rosenfeld, D. (2020). An exploratory approach for investigating the integration of computational thinking and mathematics for preschool children. Journal of Digital Learning in Teacher Education, 36(1), 63-77.

Papert, S. A. (2020). Mindstorms: Children, computers, and powerful ideas. Basic books.

Weintrop, D., Beheshti, E., Horn, M., Orton, K., Jona, K., Trouille, L., & Wilensky, U. (2016). Defining computational thinking for mathematics and science classrooms. *Journal of Science Education and Technology, 25*(1), 127-147.

Wing, J. M. (2006). Computational thinking. Communications of the ACM, 49(3), 33-35.

Transmedia Sensemaking: Working Across Cultural Artifacts to Build Understanding

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Abstract: My research concerns "transmedia sensemaking," how youth work to make sense of phenomena and construct understandings using a variety of cultural artifacts drawn from across multiple platforms and forms of media. I hope to use this poster to invite others to explore this idea and its implication for the learning sciences --- centering the inquiry on a case study of the media-based practices of a young boy over the course of 19 months.

Introduction

Learning sciences researchers have long been interested in what today's rich media landscapes mean for learning. In this vein, my inquiry centers on how youth make sense of phenomena and construct explanations using a variety of cultural artifacts drawn from across multiple platforms and forms of media (e.g., news stories, YouTube clips, films, storybooks), what may be thought of as "transmedia sensemaking." To illustrate the concept, I draw from a case study of the media-based practices of a young boy over the course of several months.

Much of the transmedia research literature focuses on transmedia in entertainment contexts, particularly *transmedia storytelling* (Herr-Stephenson, et al., 2013). I am interested in emergent transmedia collections pulled together into cohesive forms by youth themselves, rather than engineered experiences created by children's media industries. It is possible that these two types may be linked, as youth who are well-socialized into navigating transmedia experiences engineered by children's media industries may be developing a fluency in working across media forms to make meaning. The youth involved in the case study was experienced with popular transmedia experiences, which may have influenced how he used multiple platforms and forms of media for sensemaking.

Context and methodology

The poster centers on a case study of the transmedia sensemaking practices of a young boy, Ronin (pseudonym), over 19 months from ages 9-11. Ronin and I have known each other since he participated in an after-school arts club run by myself and a colleague for local 2nd graders. We re-connected 2 years later and, after learning of his passion for storytelling, I invited Ronin to co-design a storytelling workshop with me. Typically, we meet 1.5 hours/week at either the university or in his family's living room. Both the university and Ronin's home are located in a Northeast urban neighborhood. In our sessions, we explore storytelling through creating our own stop-motion movies, comic books, and other story forms. Over the course of our collaboration, I have been struck by the ways Ronin works across multiple media forms to make sense of phenomena and to construct explanations. In order to begin to understand transmedia sensemaking more fully, I used the audios, computer-screen shots, and field notes across sessions to locate illustrative examples of such sensemaking.

Exploring transmedia sensemaking

In looking across the sessions, a typology of transmedia sensemaking instances has started to emerge. Some of the instances arose as part of our storytelling, some came out of unrelated conversations as we worked together. Below I provide a brief overview of a few transmedia sensemaking types drawn from this initial analysis.

Connecting representations of a concept over time

The meaning making and connections in this example occurred over several sessions, with Ronin raising issues concerning feminist perspectives which he framed in relation to a variety of cultural artifacts. These connections began as we were working on our first story about two friends who are separated then reunited. Ronin underscored the importance of not being like the "typical story" where a prince saves a princess. He told me how, in the animated film *Moana*, the main character saves herself, and that the *The Princess and the Frog* has a very independent princess. He suggested that our story have a boy in distress and a girl saves him. Another day Ronin shared Pixar's *PIRL* on YouTube, where he drew attention to how the relationships between boys and girls "switched." When I asked Ronin what *PIRL* was about, he replied, "Sexism. Because there's 'B.R.O. Capital' and then a girl came." Over time, Ronin has often referred to the need for stories to reflect strong women, which he punctuates with references to Mabel from *Gravity Falls* or showing me a YouTube clip of satirical Disney Princess songs or other relevant YouTube clips. In our planning, Ronin used media forms to back his claims with evidence, and also seemed to be piecing together ideas about gender relations and positioning in narratives.

In-world inquiry into math and science problems

This instance arose with Ronin sharing an interest that he has been developing over time.

Ronin: Do you know for some reason I like, I like these theories. Do you know videogames and, like, movies? They do a bunch of theories on them, there's so much math.

Author: What do you mean math?

Ronin: Like, science and all that, like a bunch of research. Just for, like, videogames and stuff. (Laughs)

Author: So, what's the, give me an example. Like what kind of math?

Ronin: Umm. Like do you know Mario the, like, Tennis Game? …They're seeing if it is actually possible for a tennis ball to break a tennis racquet. And they did it. And it's super dangerous if that actually happened. …And if it was, everyone would die. …So, the ball would move too fast that the air molecules can't move out the way fast enough so there's gonna be an explosion. Same scenario with Sonic, he runs too fast. …If that happened in real life, there'd be explosions everywhere.

In order for me to better understand the reference, we went to YouTube to watch *Game Theory: How to BREAK Mario*! In the clip, the narrator de-constructs the *Mario Tennis Aces* videogame, analysing in-game tennis phenomena through scaling, frame rates, and pixel measurements. The clip is full of sophisticated formulas and computations, which he both deftly and humorously explains through referencing a variety of cultural artifacts (e.g., Sesame Street, real-life TV tennis matches, the Periodic Table) and comparisons to real-life measurement tools. When the clip presented varying computations depending on the type of metal in the racquet, Ronin joked, "He forgot one metal, Vibranium…the strongest metal ever" (a reference to the *Black Panther* movie). The clip engaged Ronin, and scaffolded him in connecting in-world inquiry with problem-solving methods and tools. Although some formulas were too advanced, Ronin had watched the clip numerous times, and followed the reasoning and ways in which math and science could be drawn upon to support investigations.

Co-constructing the Meaning of a Concept

About 8 months into our sessions, Ronin and I worked together to build a shared understanding of "eminent domain." It began with Ronin sharing something he had learned about Disney's *Wreck-It Ralph*: "He was minding his own, if you wait until the very end of the credits, they give you song. It's about eminent domain… It's horrible. It happens to a bunch of real people." We were both familiar with the concept, but did not understand it deeply. Ronin directed me to use Wikipedia, and we read the definition together. He also asked me to find the YouTube channel, *The Film Theorists*, to watch a piece on eminent domain in Wreck-It Ralph that he had found helpful. We also downloaded Pixar's *Up* to see if eminent domain was behind Mr. Fredricksen's loss of property. Not only did the collaboration around the media help in understanding eminent domain, Ronin recognized complexity in a good/bad binary, seeing a character's problematic actions in relation to contexts that felt unfair.

Discussion

Through following his interests in popular media, Ronin is learning how to navigate and build associations between knowledge objects across shared social spaces mediated by digital technology, what Jenkins (2010) refers to as *transmedia navigation*, "the capacity to seek out, evaluate, and integrate information conveyed across multiple media." Ronin's actions in the three examples of transmedia sensemaking indicate that he is developing various epistemic practices and capacities, such as making connections across knowledge objects, pulling together evidence for claims, considering different perspectives, and developing a feel for the use of theories in problem solving. These types of epistemic practices and capacities that Ronin is developing can be seen as assets or resources that may be able to be leveraged into inquiry-based learning. It is important to investigate more deeply the pedagogical implications of making sense in this manner (e.g., Shegar & Weninger, 2010). Further lenses that may prove useful include "objects-to-think-with" (Papert, 1980), learning from multiple sources (Goldman & Brand-Gruwel, 2018), and "conceptual artifacts" in knowledge building (Bereiter, 2002).

References

Bereiter, C. (2002). *Education and mind in the knowledge age*. Mahwah, NJ Lawrence Erlbaum.

Goldman, S. & Brand-Gruwel, S. (2018). Learning from multiple sources in a digital society. In F. Fischer, C. Hmelo-Silver, S. Goldman & P. Reimann *International Handbook of the Learning Sciences*, pp. 86-95.

Herr-Stephenson, B., Alper, M., Reilly, E., & Jenkins, H. (2013). T is for transmedia: Learning through transmedia play. Los Angeles and New York: USC Annenberg Innovation Lab.

Papert, S. (1980). *Mindstorms: Children, computers and powerful ideas*. New York, NY: Basic Books.

Shegar, C. & Weninger, C. (2010). Intertextuality in preschoolers' engagement with popular culture: Implications for literacy development. *Language and Education*, 24 (5), 431-447.

Designing for Home-Based Science Learning: Infrastructuring Within New Openings and Constraints

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Abstract: We describe efforts to use blurred home-school boundaries in the COVID-19 pandemic to co-design learning activities that provide new opportunities for teachers, students, and families to engage with science practices together. This work aims to support the intellectual and cultural resources of home and family life during this pandemic and beyond in ways that draw from and repurpose existing infrastructures**.** We share our design evolution, including commitments, ongoing tensions, and responses to constraints.

Introduction

In this poster, we contribute to work within the Learning Sciences on family-based STEM learning by exploring the opportunities, challenges, and tensions that arise from teachers and researchers co-designing for family learning within formal K-5 educational systems. Specifically, we describe a researcher-teacher team collaboration, within an existing district partnership, that aims to re-imagine a second-grade science curriculum to support opportunities for home-based, multi-age learning that build on families' heterogeneous ways of knowing and learning. We reflect on how the COVID-19 pandemic presented what we took as a set of openings to center relationships, student engagement, and family-based practices as an opportunity for axiological reflection, and potentially innovation, within our work (Bang et al., 2016). Further, we share our design story to explicate how the emerging infrastructure and challenges of remote schooling in our partner district presented stresses, constraints, and tensions that, in turn, led us to refine strategies and structures. We consider this a small-scale case of "infrastructuring," where design includes attention to existing infrastructures and redesigning or repurposing those infrastructures to support new forms of learning and activity (Penuel, 2019). We end by making visible our responses to constraints encountered and our ongoing tensions and questions.

Reorienting our work to new futures

In this poster, we describe how we developed the principles in Table 1 (left column) to orient our team's work and to center learning about the natural and designed world within families, homes, and communities as vital for disrupting injustices in science education (Ishimaru et al., 2015). Our previous work, which focused on co-designing science investigations to center children's resources and ways of thinking (e.g., Manz, 2018), was re-oriented to remote materials development in the summer of 2020 as the COVID-19 pandemic extended school closures. This led to new conversations among teachers and researchers. Teachers found themselves advocating for science to have a continued role in the elementary curriculum, based on their value for student engagement and connection. Researchers, some of us parents, felt called to more explicitly address our commitments to equity and engaging in shifting the narrative of home-based learning from a deficit-based lens towards a partnership between schools and families. Our conversations led us to the left-hand column of Table 1, focusing our design work on the relational aspects of science, increased permeability between school and home environments, family agency, and opportunities for multi-age science engagement.

Constraints and responses leading to new embodiments

As we began to design materials with our team of researchers and teachers and gained buy-in from district partners, our initial design propositions were met with constraints and pushback (Column 2) – stemming, we believe, from the historical infrastructure of elementary schooling and newly emerging pandemic infrastructures of home and school. In response, teachers and researchers have shifted and innovated our practice by repurposing new infrastructures, for example, by utilizing district-wide platforms like Seesaw to invite students and families to share experiences and ideas, rather than using the open-ended menus of optional activities we initially envisioned. In turn, we hope these repurposings will create new infrastructures, such as neighborhood wondering walks and collections of students' photographs that center home experiences for class conversation.

Table 1: Design evolution

Re-Centered Design Commitments	Constraints and Stresses	Embodiment of Commitments in Response to Constraints
Centering the relational aspects of science in our partner district to make science more social, relevant, and connected to students' interests and identities	Teachers have limited time to teach science. There is a district-level discourse around families' limited time and material resources for engaging with science in their home lives.	Teachers utilize morning circle time to create space for science conversations. We prioritize the lessons with the highest pay off for class and family relationality and engagement.
Remote learning increases the permeability between school and home, increasing ways for students' home-based resources to inform instruction and for teachers to see and build on children's various funds of knowledge (González et al., 2005)	Families and teachers are feeling overwhelmed by stresses exacerbated by the pandemic.	We create openings within the pre-existing curriculum for students to share and build upon family-based experiences.
Synthesizing family engagement with scientific practices and learning via optional and fluid activities (Ishimaru et al., 2015)	Teachers, students, and families have a variety of new tools and platforms to navigate. Making activities "optional" is difficult to communicate within existing school infrastructure.	We develop weekly short, open-ended activities, to be shared directly with parents. Recognizing the optional nature of asynchronous elementary-level work, we prioritize activities that are low-stress and high-interest.
Learning in the home environment provides opportunities for families with children of different ages engage in science together, capitalizing on the heterogeneity of families' values and expertise	Schools were hesitant to reorient towards using multi-grade level materials. However, parents have suggested that this is a useful tool for maximizing time and fostering connection.	We design activities such as wondering walks and family conversations that can provide entry points for children of multiple ages to engage with the same scientific phenomenon; including these within the 2nd grade curriculum, rather than the multi-grade materials we had envisioned.

Discussion

We are excited by the way that our work has oriented to newly explicit joint commitments to make science more social, relevant, and connected to students and their families and the opportunity that we (teachers and researchers) have to expand our practices to further recognize and appreciate the resources that students bring to the classroom. We plan to build from these commitments throughout this period of disrupted schooling and beyond. As we explored in this poster, this work to date has involved bringing our commitments into contact with the possibilities of the current system and repurposing the infrastructure for new openings. What we don't yet know is the extent to which our modified designs (e.g., inviting photographs or recorded stories of home objects and practices) will work to disrupt or instead perpetuate inequities within school infrastructures. We hope to engage the community in discussion about the tensions we are facing around the necessity and challenges of working within and repurposing infrastructure to imagine new possibilities for home-based science learning.

References

Bang, M., Faber, L., Gurneau, J., Marin, A., & Soto, C. (2016). Community-based design research: Learning across generations and strategic transformations of institutional relations toward axiological innovations. *Mind, Culture, and Activity*, 23(1), 28–41.

González, N., Moll, L., & Amanti, C. (2005). Funds of knowledge: Theorizing practices in households, communities, and classrooms. Mahwah, NJ: Lawrence Erlbaum Associates.

Ishimaru, A. M., Barajas-López, F., & Bang, M. (2015). Centering family knowledge to develop children's empowered mathematics identities. *Journal of Family Diversity in Education*, *1*(4), 1–21.

Manz, E. (2018). Designing for and analyzing productive uncertainty in science investigations. In Kay, J. and Luckin, R. (Eds.) *Rethinking Learning in the Digital Age: Making the Learning Sciences Count, 13th International Conference of the Learning Sciences (ICLS)* (Volume 1, pp. 288-295). London, UK: International Society of the Learning Sciences.

Penuel, W. R. (2019). Infrastructuring as a practice of design-based research for supporting and studying equitable implementation and sustainability of innovations. *Journal of the Learning Sciences*, *28*(4–5), 659–677.

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Addressing Challenges When Designing NGSS Aligned 3-Dimensional Assessments for Young Learners

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Abstract: The National Research Council (NRC) Framework and the Next Generation Science Standards (NGSS) emphasize that all students, beginning in the earliest grades, must have opportunities to learn science. As science curricula for elementary school is being developed, the need for NGSS-aligned assessments increases. This paper describes three challenges (defining assessment targets, gathering desired evidence, and structuring and scaffolding tasks) when designing NGSS standards-aligned first grade assessments and potential solutions to these challenges.

Keywords: assessment design, Next Generation Science Standards, early elementary

Introduction

The Next Generation Science Standards (NGSS, Lead States, 2013) includes science instruction at the early grades (K-2). Including science in early grades instruction has increased the need for science assessments that are appropriate for young learners' cognitive and language development and provides teachers with information about what their learners know and are able to do in science. We describe 3 main challenges when designing NGSS aligned life science assessments for 1st grade and potential solutions to the challenges.

Background

There are many reasons why early childhood assessment is difficult, including the variable and uneven development of young children, differing opportunities young children have to learn, the range of experiences young children have in the real-world, and the propensity of young children to demonstrate what they know and can do rather than talk or write about what they know and can do (The National Education Goals Panel Early Childhood Assessment Resource Group, 1998). Because of such variability, early childhood assessment is typically a multifaceted system comprised of gathering data using different methods such as observations, interviews, and portfolios (Slentz, 2008). Little literature on design principles (Scott-Little & Niemeyer, 2001) or frameworks to design early childhood assessments can be found, especially in science. Designing for early elementary students should include opportunities for students to engage with science concepts using tasks that are appropriate for students at different developmental stages. Currently there is little guidance on how to design assessments that target science learning, and cognitive or language development of young learners. We describe our approach to addressing challenges in designing a 1st grade science assessment task for performance expectation (PE) LS1-1 "Use materials to design a solution to a human problem by mimicking how plants and/or animals use their external parts to help them survive, grow, and meet their needs".

Challenge 1: Defining measurement targets

The NGSS performance expectations (PEs) are 3-dimensional, with each PE incorporating disciplinary core ideas (DCI), science practices (SP), and cross-cutting concepts (CCC). While the DCI tends to differ between grades, the SPs and CCCs are shared across grade levels. A challenge was identifying the grade level boundaries for these dimensions and developing measurement targets that specify how the SPs interact with the DCI and CCC in a way that was developmentally appropriate for first graders. For example, for PE1-LS1-1, we used drawings and written descriptions to address the CCC and narrowed the DCI to focus on animals that are familiar to first graders. The resulting measurement target for PE 1-LS1-1 was (italics added for emphasis) "Ability to design a solution, through *drawing and/or describing*, to a given problem that is based on *a familiar animal part* that helps that the animal survive, grow and/or meet its needs."

Challenge 2: Gathering the desired evidence

Determining how to gather appropriate evidence can be challenging because 1st grade students have varying levels of oral language competency, word reading ability, and writing proficiency. Additionally, our assessments were limited to the paper and pencil format, making tasks that require skills in designing solutions challenging. Since we decided to allow students to express their understanding by integrating drawing and writing modalities as their responses, gathering student evidence involved examining and interpreting student drawings and determining how well their drawings aligned to the PE. Evidence of proficiency focused on the extent to which the design was related to the animal body part that the students identified and whether or not their design would be an appropriate solution to the human problem. We also analyzed how well the descriptions of their drawings articulated a solution to the human problem. Student textual descriptions were scored for students' intentions behind the description rather than grammar or spelling.

Challenge 3: Determining the structure of tasks and amount of scaffolding

Another challenge was to determine how to structure each task including the degree to which and the type of scaffolding to provide support to students when engaging with the assessment task. In one-on-one administration, alternative prompts are often developed in case students are unable to respond to the initial prompt. This type of structure is not available in an assessment that does not respond to individual students. Our design process addressed this challenge by examining the task and determining 1) the information students need to answer the questions, 2) whether students need all of the information at once or if the information can be broken up to help students focus on the goal of a particular question, and 3) how questions can be organized to walk the students through the question without giving away the responses.

For PE 1-LS1-1, students were asked to design a solution, modeled after an animal body part that can reach an object that was far away (i.e., high above the head). For this task, students were given 3 options of animals: a bird, a giraffe, and an elephant. We used animals that we believed most 1st graders were familiar with and allowed students to pick the animal that could serve as a model for their design solution. Giving students choice increased the chance that students would be familiar with the animal and subsequently design a solution that aligned with the animal. We represented each animal in the motion of reaching for an object that was high in elevation to support students in making the appropriate connections between the animal and their design. The task asked students to draw a circle around the body part that the design solution would be modeled after to help students focus on their design features. We allowed students to provide written responses in addition their drawing to allow multiple opportunities for students to express their developing proficiency.

Discussion

Addressing challenges related to language development, literacy skills, and the developmental stage of students can inform the development of 3-dimensional NGS aligned assessment tasks, the associated rubrics, and the nature of the administration prompts and scaffolds. Developmental characteristics of early learners are attended to throughout the design process in order to ensure the assessment tasks are developmentally appropriate. While this type of process is critical for any grade range, explicitly laying out what is required of students in terms of their language and literacy capabilities is particularly important at the early grades. Recognizing that there is a range of abilities in classrooms and highlighting ways to ensure that everyone can engage with the task will help ensure that students are able to demonstrate their proficiency related to the PE. The resulting assessment scores will be a more accurate portrayal of student's science ability and not a measure of their ability to read and write.

References

National Education Goals Panel Early Childhood Assessments Resource Group. (1998). Principles and recommendations for early childhood assessments. Washington, DC: US Department of Education. www.negp.gov/reports/prinrec.pdf

NGSS Lead States (2013). *Next Generation Science Standards: For states, by states.* Washington, DC: The National Academies Press.

Scott-Little, C., Neimeyer, J. A., & Ahearn, C. (2001). *Assessing kindergarten children: What school systems need to know*. SERVE.

Slentz, K. L. (2008). A guide to assessment in early childhood: Infancy to age eight. Washington State Office of Superintendent of Public Instruction.

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Students' Dynamic Framing of Epistemic Agency

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Abstract: Learning environments are socially shared cognitive spaces where students can act as *epistemic agents*. This case study explores how students mutually frame opportunities to enact epistemic agency in a group-based laboratory setting. We show how an undergraduate student group frames epistemic agency within course constraints but maintains ownership of the collective group frame's negotiation and reproduction via individual discursive and active contributions. Results suggest students can maintain a collective group frame of epistemic agency in a learning environment, even when students offer distinct frame contributions.

Theoretical background and methodology

Scientific inquiry learning environments allow students to collectively and actively engage in scientific experimentation to generate new knowledge through a socially shared cognitive context. In these contexts, students are meant to act as *epistemic agents*, or "individuals or groups who take, or are granted, responsibility for shaping the knowledge and practice of a community" (Stroupe, 2014). Epistemic agency is thought to exist inseparably between the individual and the utilized mediational means, such as discourse, apparatus, and sociocultural norms (Wertsch, 1993). As learners experience significant shifts in learning environments that now expect greater levels of enacted epistemic agency, it is essential to understand how learners generatively perceive and interpret their learning environment as a shared space to enact their epistemic agency. This study focuses on how students collectively contribute to a group's framing of epistemic agency within a socially shared setting. Specifically, we present a case study of four students engaging in a group-based physics laboratory investigation, exploring their mutual framing of epistemic agency within the course structure's constraints and expectations.

This study focuses on four students, Lacee, Ethan, Mika, and Caroline (pseudonyms), who engaged in an undergraduate introductory physics for life sciences (IPLS) laboratory course. This course's primary learning goal is to productively engage students in complex scientific practices while interacting and sensemaking with interdisciplinary concepts. The course in question emphasizes epistemic agency by: a) giving students freedom to develop their own investigative questions and experimental methods; and b) training teaching and learning assistants (TAs and LAs) to empower students to be epistemic agents in their investigations. The presented data comes from the group's third multi-week investigation in the course; each student previously worked with at least one of their current group members. To investigate students' framing of their epistemic agency through a mediated lens, we employ frame analysis (e.g., Goffman, 1974) to study: a) the discourse and associated action involved in student investigation and how this contributes to the development of a collective group frame in light of larger sociocultural processes; and b) how continuing discourse and action from participating individuals sheds light on their contributions to and changes of the collective group frame. We first sought to identify the collective group frame's outer boundaries and thereafter explore individual student contributions to the group frame (Steinberg, 1998). We note our view that frames exist between individuals, rather than within them individually, with each individual uniquely but mutual-dependently contributing to the collective frame. (Medvedev and Bahktin, 1978).

Dynamics of and within collective group frame

Via initial introductory material and direction from the TA, the course structure sought to impose a preliminary framing of epistemic agency (e.g., TA: "These are just possible options… we definitely want your groups to come up with something unique and something specific that you want to study."). The course and instructors "primed" students to frame their investigation as an opportunity to enact epistemic agency without assessment/criticism from TAs/LAs but within the larger course structure (i.e., consistency with scientific topics and experimental apparatus). In response, the group mutually developed a collective group frame within these implicit constraints; for example, through discursive moves, the group explored potential research questions that accounted for the lab's guiding prompts and available apparatus. During this discourse, students incorporated external scientific phenomena that resided outside the course material rather than attempting to unearth and utilize conceptual or procedural information from lab documentation, a common practice in laboratory settings. When interacting with the TA, the group asked clarifying questions about apparatus and course requirements but did not ask for prescriptive steps or affirmation of their methods, suggesting they were framing the learning environment as permitting them to be the main epistemic agents in their experiment. This highlights how the group collectively developed a collective group frame that resided within the course's implicit constraints on epistemic agency.

Though a collective group frame was developed, distinctions between student involvement arose; for example, while Lacee, Caroline, and Ethan engaged in active dialogue to develop potential research questions and experimental plans, Mika asked questions more dependent on other group members' enacted epistemic agency (e.g., "So what's gonna be our [research question]?"). Mika's framing of the group's ability to enact epistemic agency resided within the constraints defined by the course structure and initial introduction and maintained by the group, in that she understood the need for the group to enact its collective epistemic agency to conduct their experiment but seemed reluctant to personally enact her epistemic agency within the group. Though this and other distinctions arose, they did not significantly impact the group's experimental trajectory, instead potentially providing additional opportunities for the group to enact its collective epistemic agency to initiate experimental progress. The discourse resides between Mika and her group members and mutually benefited both parties; Mika gained further understanding of the experimental methods, and the collective group having additional opportunities to enact epistemic agency by discussing experimental details and future progress.

During formal experimentation, additional distinctions arose between group members. For example, Lacee gravitated towards the procedural aspects of experimentation, making decisions on setting up and using experimental apparatus to generate experimental results. In contrast, Ethan consistently brought conceptual topics and questions to the group to explore what conceptual knowledge was necessary to connect their experimental results to external scientific phenomena. These examples suggest that Lacee and Ethan both framed the learning environment as providing significant freedom to enact epistemic agency, though they individually chose how to enact it. Caroline and Mika exhibited more passive perceptions of their opportunities to enact epistemic agency. For example, Caroline framed her role as one of support and revoicing of Ethan's conceptual ideas and Lacee's experimental methods, and Mika frequently asked self-clarifying questions about experimental methods and concepts. Noteworthy in their contributions to the group's experimentation is that, though they did not often enact their own epistemic agency explicitly, they maintained (and even sometimes bolstered) the group's collective epistemic agency. This is in stark contrast to potential alternative outcomes, such as a clash in individual perceptions of the learning environment, which could result in reformation of the collective group frame away from epistemic agency and towards authoritative dependency, as often occurs in laboratory settings.

Discussion

The above vignette shows how a group of undergraduate students in a group-based physics laboratory course developed and maintained a collective group frame that resided within the course's intended framing of epistemic agency, even when students maintained unique roles and individually contributed distinct, and sometimes contested, discourse and action to the collective group frame. These results suggest that students can effectively maintain a collective group frame of epistemic agency and learning within an agentic instructional approach, even with distinct and unaligned individual contributions. This study adds to literature suggesting inquiry-based STEM environments can enhance student enactment of epistemic agency, but results show the nuance of individual distinctions in student contribution to the group's collective framing of epistemic agency (Miller et.al., 2018).

References

Goffman, E. (1974). *Frame analysis: An essay on the organization of experience*. Harvard University Press.

Medvedev, P. N., & Bakhtin, M. M. (1978). *The formal method in literary scholarship: a critical introduction to sociological poetics.*

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the next generation science standards. *Journal of Research in Science Teaching, 55*(7), 1053-1075.

Steinberg, M. W. (1998). Tilting the frame: Considerations on collective action framing from a discursive turn. *Theory and society, 27*(6), 845-872.

Stroupe, D. (2014). Examining classroom science practice communities: How teachers and students negotiate epistemic agency and learn science-as-practice. *Science Education, 98*(3), 487-516.

Wertsch, J. V., Tulviste, P., & Hagstrom, F. (1993). A sociocultural approach to agency. *Contexts for learning: Sociocultural dynamics in children's development, 23*, 336-356.

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Investigating Teacher Data Needs In Terms of Teacher Immediacy and Nonverbal Behaviors

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Abstract: Teachers play a crucial role in students' learning. Therefore, it is important to support teachers in their teaching practice. In particular, it is important to support teacher immediacy which is essential to improving learning and creating a positive classroom environment. We describe an exploratory study aimed at understanding teachers' immediacy data needs. Teachers showed interest in such data about themselves and their students. We discuss how teacher immediacy data can help teachers in their practice.

Introduction

Teachers are crucial in supporting students' learning, making it essential to support teachers in their practice and help them improve their teaching. Professional development (PD) is a typical way to provide such training. PD is highly effective (i.e., Avalos, 2011) but can often be repetitive, not personalized, not scalable and infrequent (Hill, 2009). PD also often overlooks teacher immediacy, an important aspect of teachers' classroom skills. Teacher immediacy involves the nonverbal behaviors that reduce physical and/or psychological distance between teachers and students and increase their interpersonal closeness, with the ultimate goal of enhancing student learning (Andersen & Andersen, 2008). Examples of nonverbal behaviors include location, movement, eye gaze, smiles, nods, posture, gestures, etc. Prior work has shown that teacher immediacy and nonverbal behaviors have a positive impact on teaching, learning and on creating a positive and inclusive classroom environment (i.e., Andersen & Andersen, 2008; Witt et al., 2004). It has been extremely challenging to collect data on such features (i.e., teacher gaze during class or students' gaze over the semester) to use in PD, even with professional observers. Recent advances in instrumented classrooms (i.e., Ahuja et al., 2019) enable opportunities to easily collect a variety of nonverbal immediacy data and provide teachers with personalized and scalable feedback. Literature shows that when teachers view classroom data, it helps their practice and they significantly change their teaching practices (i.e., Xhakaj et al., 2017 a; b). Here, we report on an exploratory study to investigate teacher data needs in nonverbal immediacy behaviors as a step towards supporting teachers' classroom practice.

Methods

We recruited 8 instructors and collected video data for 3-9 classes per instructor using the EduSense instrumented classroom (Ahuja et al., 2019) during the Summer 2019 semester at an American university. We then scheduled a 1-hour semi-structured interview with instructors; they were compensated $15/h. We paired the interviews with PD modules on immediacy, and visualizations (Figure 1) that presented teachers with a subset of data collected from their course with EduSense. The visualizations aimed to start a conversation with instructors and engage them in a discussion around immediacy, nonverbal behaviors, and data they could envision wanting or needing. We transcribed the interviews and conducted a thematic analysis.

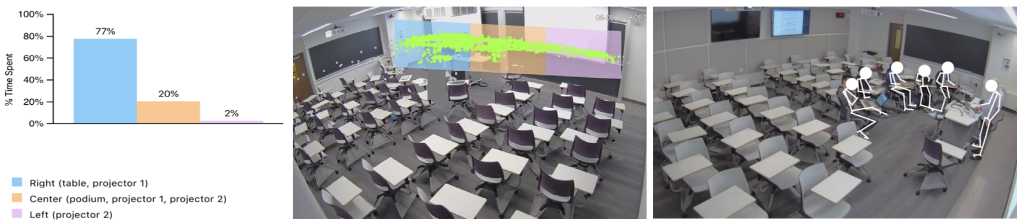

Figure 1. Examples of the visualizations shown to teachers.

Findings

All teachers expressed interest in various immediacy and nonverbal behavior data. Teachers expressed strong interest in their own data. They wanted to know location and movement data including what activity they were conducting at the front of the class, i.e., were they writing on the board, lecturing in front of the projector, etc. (1). Teachers also wanted to know their distance from the board (1), were they sitting or standing (1), their proximity to students (1), and how students were distributed in class, to determine where they need to spend more time (2). Half of the teachers (4) were interested in their eye contact and gaze. For example, one teacher was interested in how often they face their class, while another was interested in having egalitarian eye contact with students. Teachers were also interested in posture data such as were they standing straight and showing enthusiasm (1), how their body language differed based on the activity (1), and whether they had egalitarian physical engagement with students (1). One teacher was interested in how much they smile, and another was interested in gesticulation synchronized with speech. Lastly, two teachers were interested in metadata such as gender or age: how this plays a factor on whether they stood behind the podium or in front of the class (1), and the other, on how this differentiated the kind of interactions they have with students or indicated any biases in those interactions.

Further, all teachers were interested in student data. Specifically, they were interested in different aspects of student engagement, attentiveness, and focus during class. For example, 3 teachers were interested in students' engagement in relation to devices, such as phones or laptops. Teachers thought these devices sucked students' attention from class. Another teacher was interested in the "back and forth" they had with their students, while two teachers were interested in student eye contact data. Two teachers wanted to know about students' body position, as a proxy for engagement. Specifically, they wanted to know if students were slouching or if they were leaning forward on their computers, if they were writing and how much they were taking notes, especially when it was unprompted by the instructor. One teacher wanted to see student leg positions as a way to tell if any of the students were completely closed off in their physical interactions.

In addition to student data, teachers were interested in "student reaction data", namely how students react to teacher actions in class. Teachers thought that this kind of feedback could help them gauge how effective their own practices were. For example, if they stood at a certain location or if they used certain gestures, would that help them reach their goal of increasing student engagement? Two teachers were interested in how student attentiveness, engagement and gaze is relative to where the teacher is standing in class, and how students' body positions change when the teacher moves around in class. Another teacher was interested in how the imbalance in their position in class affected their students, in particular if that caused them to be less focused and inattentive. Similarly, another teacher was interested in the effects of smiling on student attentiveness. Lastly, one teacher was interested in knowing how different students react differently to their actions

Discussion and conclusion

In this paper, we describe an exploratory study to investigate teacher data needs regarding immediacy and nonverbal behaviors, and to better understand how such data can support teachers in their practice. Findings showed that teachers valued immediacy and nonverbal behaviors and were interested in data to support their instruction and improve on their practices in these areas. Teachers were interested in data about themselves, their students and how their actions affect their students in class. In particular, teachers wanted to use this data to keep and increase student engagement and to create a more equitable classroom environment, by sharing their time and attention equally among all students. These results show that there is value in providing teachers with data and feedback on both teacher and student classroom behaviors. In our future work, we aim to design technologies that will help teachers reflect on their immediacy and nonverbal behavior data to support their classroom practice.

References

Ahuja, K., Kim, D., Xhakaj, F., ... & Agarwal, Y. (2019). EduSense: Practical classroom sensing at Scale. Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies, 3(3), 1-26.

Andersen, J., & Andersen, P. (2008). Teacher immediacy. The International Encyclopedia of Communication.

Avalos, B. (2011). Teacher professional development in teaching and teacher education over ten years. Teaching and teacher education, 27(1), 10-20.

Hill, H. C. (2009). Fixing teacher professional development. Phi Delta Kappan, 90(7), 470-476.

Witt, P. L., Wheeless, L. R., & Allen, M. (2004). A meta-analytical review of the relationship between teacher immediacy and student learning. Communication Monographs, 71(2), 184-207.

Xhakaj, F., Aleven, V., & McLaren, B. M. (2017a). Effects of a teacher dashboard for an intelligent tutoring system on teacher knowledge, lesson planning, lessons and student learning. EC-TEL (pp. 315-329).

Xhakaj, F., Aleven, V., & McLaren, B. M. (2017b). Effects of a dashboard for an intelligent tutoring system on teacher knowledge, lesson plans and class sessions. AIED, (pp. 582-585).

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International Society of the Learning Sciences

Early Childhood Cross-Topic Interest Development in STEM

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Abstract: Research is needed to examine ways in which young learners explore and develop interests in everyday environments. This study applies Azevedo's lines of practice research to conceptualize Mihir's (pre-K to grade 1) participation in 'A Bedtime Curiosity' (ABC) with his mother, during which he asked questions and expressed topic interests, then co-explored possible answers and engaged in discussions. 162 questions were coded for interest topics to highlight patterns of cross-topic questioning. Results offer preliminary insights into what interest topics emerged as dominant or were backgrounded, residual, transitory or potentially unexplored by Mihir, contextualized by qualitative researcher memos of the ABC experience.

Introduction

Models of interest development have emerged as a way to encourage learner exploration of science topics (e.g., Hidi & Renninger, 2006) but such models of interest and motivation may not account for the complexity of a young learner's cross-topic exploration, particularly as it unfolds in unstructured settings. Research shows children (2-10 years) engage in domain-specific inquiry and engagement through everyday family activities (Keifert and Stevens, 2019). Given the paucity of research on young children in the learning sciences, further research is needed on how to encourage and assess early childhood interest development in informal learning settings (Tippett & Milford, 2017). We attend to these gaps by examining a family engagement routine involving scientific thinking and content. Shah and her son Mihir (pseudonym) participated in 'A Bedtime Curiosity' (ABC) (designed by Shah) a nightly activity in which he expressed an idea he was curious about, asked a question, co-explored possible answers by watching a short video, followed by a discussion if requested. We examine, *"In what ways did a child's cross-topic interest in STEM develop over time (preK-grade1) as he engaged in a bedtime reading and inquiry routine?"* This research applies Azevedo's (2011) research on lines of practice as a way to understand the complexity of interest development that manifested in Mihir (pseudonym) over time as he chose topics of inquiry as part of his nighttime ABC routine. The lines of practice framework provides theory-driven language to contextualize Mihir's within-topic and cross-topic trends of interest development.

Methods

When the author's (Shah) son Mihir was almost 5 years old, she began *a bedtime curiosity* (ABC). During ABC, the pair read two books, and then Mihir was encouraged to express an idea he was curious about, ask a question, and explore possible answers with his father or mother (Shah) by watching a short video (3-7 mins), followed by discussion if requested. For details on ABC, see Shah and colleagues (2020). During ABC, every question Mihir asked was logged chronologically, amounting to 162 questions across two data collection periods: Pre-K (November 2018-September 2019) and Grade 1 (September-November 2020). Shah created memos to document question contexts, such as descriptions of holidays, current events or recent activities that may have shaped Mihir's inquiry. Memos also recorded resources accessed and discussion topics that emerged from each inquiry.

We conducted a thematic analysis (Corbin & Strauss, 1990) of the questions to generate codes that represent the topics in which Mihir expressed interest: chemistry, zoology, meteorology, geology, paleontology, biology, history, games, anatomy, engineering, and astronomy. Questions were then coded for the presence (1) or absence (0) of a topic for each content using social moderation across two raters (Herrenkohl & Cornelius, 2013). Results are presented as a qualitative case study structured by Azevedo's (2011) lines of practice work, including: a) interest *dominance* (more frequent engagement), b) interest *backgrounding* (less frequent engagement as other topics take prominence), c) *residual* lines of practice (topics he has exhausted but returns to periodically) d) *transitory* lines of practice (i.e., one topic that is subsumed another, larger topic), and e) *potential* lines of practice that he might explore if social norms and designed features of the ABC routine were different.

Results

Mihir asked back-to-back questions regarding bodily processes (i.e., how is pee formed?) in the first few weeks of ABC, suggesting *dominance* in anatomy in biology. Dominant interests then shifted toward how different items were engineered or manufactured (i.e., colored pencils, houses). Memoing regarding these processes revealed that Mihir mostly asked biological questions about processes he regularly experienced, and engineering questions about interest objects he noticed in his household or at school. Questions related to astronomy on the other hand, which were initially more *backgrounded* in comparison to engineering, quickly rose in dominance as a topic he returned to more frequently and with increasingly detailed inquiries. Astronomy interests also manifested in the choices noticed by Shah, including viewing space-related media and creating relevant stories, art, and 3D models.

Mihir's engagement with engineering may serve as an example of a *residual* line of practice; memoing revealed a point at which he could no longer think of questions related to how objects were manufactured or engineered. At Shah's encouragement, Mihir began exploring more diverse lines of questioning but would often return to the occasional "how is this made" question as new contexts inspired them. For example, Mihir asked how monster trucks were made after his mother described a local monster truck event. Several topics in Mihir's inquiry remained *background* lines of practice, such as questions about geology and meteorology. These topics might serve as examples of *transitory* lines of practice that were subsumed by the more dominant topic of astronomy; forays into geology and meteorology were often related to processes happening on Earth, which may have connected to Earth in the wider context of space. At one point, Mihir asked "how hot is lava?" followed by "what is the biggest star there is?" suggesting he may have seen connections between these topics.

Zoology and paleontology topics remained *backgrounded* throughout Mihir's exploration. A question coded for games ("what is the weakest Pokémon?") offered insight into a *potential* line of animal-related inquiry that might have been further explored under different circumstances. Shah reflected that Mihir would routinely engage in activities outside of ABC that suggested interest in fantastical animals, including scheduling virtual discussions about Pokémon with his friends. Shah noted that Mihir asked her a few questions about Pokémon but ceased after she explained her lack of expertise. Perhaps as a result, Mihir's ABC questions about animals were restricted only to animals that once existed or currently exist. Unconscious social norms of the household may have encouraged Mihir to emphasize real-world science and engineering questions, as both parents are scientists.

Discussion and Conclusion

Results highlighted the complexity of Mihir's cross-topic interests over time, such as how topics emerged as dominant over time (i.e., biology first, astronomy later), how he residually returned to others (engineering), and others were potentially subsumed under astronomy (i.e., geology) or remained as potential only (fantastical animals). This routine also shows how a mother fostered her child's engagement in structured lines of practice. The National Research Council reports on science education have discussed how children of preschool and elementary school age demonstrate readiness for science (2012), but further research is needed on mechanisms and practices that can promote deep curiosity, and how interests and motivations shift as a result. Potential limitations include the design of ABC and Mihir's social context, which may have encouraged the exploration of some topics over others. Future work will qualitatively describe and analyze Mihir's questions and consider the potential role of daily events, including Mihir's activities when ABC was not in place.

References

Azevedo, F. S. (2011). Lines of practice: A practice-centered theory of interest relationships. *Cognition and Instruction, 29*(2), 147-184.

Herrenkohl, L. R., & Cornelius, L. (2013). Investigating elementary students' scientific and historical argumentation. *Journal of the Learning Sciences*, *22*(3), 413-461.

Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational psychologist, 41*(2), 111-127.

Keifert, D. & Stevens, R. (2019) Inquiry as a Members' Phenomenon: Young Children as Competent Inquirers, *Journal of the Learning Sciences*, *28*(2), 240-278.

Koh, E., Cho, Y. H., Caleon, I. S., & Wei, Y. (2014). Where are we now? Research trends in the learning sciences. In *Proceedings of the 11th International Conference of the Learning Sciences*. Boulder, CO (Vol. 1, pp. 535–542).

National Research Council. (2012). Discipline-based education research: understanding and improving learning in undergraduate science and engineering. Washington DC: The National Academies Press.

Shah, M., Barany, A. & Siebert-Evenstone, A. (2020). What would happen if humans disappeared from Earth? Tracing and visualizing change in a pre-school child's domain-related curiosities. In A. R. Ruis and S. B. Lee (Ed). *Proceedings of the 2nd International Conference on Quantitative Ethnography* (232-247).

Tippett, C. D., & Milford, T. M. (2017). Findings from a pre-kindergarten classroom: Making the case for STEM in early childhood education. *International Journal of Science and Mathematics Education, 15*(1), 67-86.

Integrating Immersive Technology into Small Group Learning Environments

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Abstract: The goals of this study were to explore (a) whether students learn critical STEM content through group activities that integrate immersive virtual reality (VR) with more traditional digital simulations, and (b) whether choosing to use VR affects students' learning and their perceptions of the activity. The results indicate overall improved pre-post learning outcomes for students in multiple sections of a college astronomy course who participated in the multi-device activity.

Introduction

Technologies such as large multi-touch display surfaces have been shown to be effective for facilitating collaborative learning (e.g., Mercier & Higgins, 2013), but immersive technologies such as augmented reality (AR) and virtual reality (VR) are assumed to have more utility for individual learners and have been used less frequently for collaborative tasks. Numerous studies in recent years have shown that using immersive technologies to alter student perspectives with digital overlays and simulated environments can improve individual learning outcomes in a range of learning domains (Checa & Bustillo, 2020; Concannon et al., 2019; Ibáñez & Delgado-Kloos, 2018). What has been less explored is whether single-user immersive technologies such as VR can be integrated productively into a small group learning activity involving other technologies with different students adopting different perspectives and taking on different roles.

In the current study we looked at a collaborative learning task situated in an undergraduate introductory astronomy course. Students who worked on this task were given many resources including tablet computers and a single VR headset that all tapped into the same set of star models, but with each technology having different affordances for exploration and perspective-taking. The goal of this preliminary study was to understand: (1) Do the individual students participating in this task learn the desired content? (2) Is the amount of time spent using the VR related to the subsequent learning outcomes? (3) Is the amount of time spent using the VR related to the students' attitudes toward the learning task?

Software environment and the tasks

The software enables group members to share observations and annotations of the night sky across both VR (Oculus Quest headsets) and tablet PCs (Microsoft Surfaces) while maintaining a consistent interface and representation of the night sky. Three main views are provided within the software: star view, horizon view, and Earth view (see Figure 1). Horizon view allows for the observation of the night sky from a specific location, date, and time. Earth view allows observe the Earth from above while dropping pins to change their location and obtain latitude and longitude coordinates. Star view provides an explorable view of the full celestial sphere and catalogued western constellations.

The task "Lost at Sea" has students using their observations of the night sky to determine the location of a crewed space capsule that has splashed down at night somewhere on Earth. Groups of students must first identify features of the night sky to determine which hemisphere the capsule is located in (Task 1), then identify familiar constellations to use as reference points (Task 2), then refine their location estimation through the calculation of both latitude (Task 3.1) and longitude (task 3.2) using the night sky.

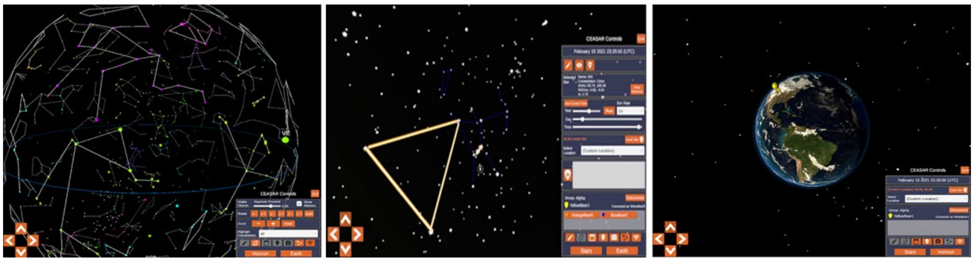

Figure 1. Star view (left), Horizon view (center), Earth view (right)

Participants and measurements

The participants were 33 college students recruited from a subject pool at a community college in the mid-western United States. All students were taking the same introductory astronomy class and were asked to voluntarily form a group of three to four students to work on the tasks collaboratively. Most of the groups spent about 60 minutes to solve the tasks together. One VR and two tablet devices were provided to each group and a pre/post-test and post-questionnaire were completed individually by all participants in the study.

The paper-based materials consisted of a pre/post-test and post-questionnaire. Pre/post-tests were conducted to measure changes in students' knowledge of the procedures involved in calculating latitude and longitude based on the night sky. The question asked in both tests was the same: "Write as much as you know about the steps for calculating latitude and longitude based on the stars visible in a given location." The tests were scored for correctness and complexity on a 0 - 2 scale. All scores were calculated independently by two research personnel and the results were exactly consistent with each other. In addition, the post-questionnaire asked students to make self-ratings on a 5-point scale of statements of perceived difficulty for each task and statements of evaluating the VR simulations. It also contained a short-answer question about how long they had used VR.

Results

For the *first research question*, Wilcoxon signed rank test was conducted on the pre- and post-test scores of each student and the result shows that there is a significant difference in the means from pre- to post-tests, with gains for both latitude ($W = 153$, $Z = 4.07$, $p < .01$, $r = 0.71$) and longitude ($W = 45$, $Z = 2.99$, $p = 0.01$, $r = 0.52$). For the *second research question*, a one-way ANOVA revealed no significant differences for both latitude and longitude, but weak negative correlation has been found for latitude (-0.22). In addition, a simple linear regression was calculated to predict perceived difficulty based on the time spent on VR found that the longer students used VR devices, the more difficult they perceived Task 1. For the *third research question*, a simple linear regression was conducted. As summarized in Table 1, the results showed that the longer students use VR, the more positive they evaluated the VR simulation experience.

Table 1: Students' rating of VR simulation

Post-Questionnaire Item	F	*p*	Correlation
"The VR simulation was useful in completing the task goals"	3.97	0.06	0.34
"I would like to learn with VR in the future"	3.98	0.05	0.34
"I felt happy while using the VR simulation"	6.83	0.01*	0.42
"I felt excited while using the VR simulation"	7.37	0.01*	0.44
"I felt bored while using the VR simulation" (reverse scored)	7.09	0.01*	0.43

Discussion

We acknowledge that having a small number of participants and the absence of a control group are limitations. However, the evidence of overall positive learning outcomes measured via the pre- and post-knowledge assessment indicate that individual students extended their existing astronomy knowledge while engaging with novel technologies and modes of interaction. Significant correlations of time in VR with self-reports of positive affect support the role of VR as an engaging tool in the learning process for this set of astronomy tasks. In addition, the perception of increased difficulty for Task 1 for those spending more time in VR, but not for Task 2 or 3 may be an indication that acclimating to the novel technology environment could be impeding initial learning. To address this, revisions of both the task and the software to provide appropriate and timely scaffolds that assist the learner with using the immersive environment will be critical to ensure productive collaboration and learning.

References

Concannon, B. J., Esmail, S., & Roduta Roberts, M. (2019). Head-Mounted Display Virtual Reality in Post-secondary Education and Skill Training. *Frontiers in Education*, 4.

Checa, D., & Bustillo, A. (2020). A review of immersive virtual reality serious games to enhance learning and training. *Multimedia Tools and Applications, 79*(9), 5501-5527.

Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers & Education, 123*, 109-123.

Mercier, E. M., & Higgins, S. E. (2013). Collaborative learning with multi-touch technology: Developing adaptive expertise. *Learning and Instruction, 25*, 13-23.

Peeking into the AI Hype: Investigating Research Trends and Collaboration Dynamics in Artificial Intelligence in Education

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Abstract: This project presents an in-depth analysis of the dynamics of the International Artificial Intelligence in Education (IAIED) Society through co-authorship networks and keyword analysis, discussing its implications to the larger research community. In addition, this study provides methodological contributions to the analysis of author and topic networks within multidisciplinary communities such as the Learning Sciences.

Introduction

With the growing attention to Artificial Intelligence (AI) in recent years, the application of AI technologies to education followed: AIED has been developing rapidly as an interdisciplinary research area (Feng & Kirkley, 2020). But the development of AI-powered content delivery systems, personalized learning management software, and adaptive testing platforms has been much faster than the growth of the research community (Zawacki-Richter et al., 2019). Now propelled by the global pandemic and remote learning, the AIED technologies might impact millions of students, teachers and schools all over the world at an unprecedented speed. Such significant implications of AI in Education (AIED) leave researchers and research communities with greater responsibility than ever to examine strengths and weaknesses, risks and opportunities, and costs and benefits of implementing AI in various learning scenarios. As the AIED field was growing, so were the calls for closer examination of issues of ethics and social justice around AI (Zuboff, 2015; Berendt et al., 2020). In particular, the International Artificial Intelligence in Education (IAIED) Society, as one of the earliest and more well-defined research communities in this area, has been viewed as an important leader in conversations around AIED. Given such a context, this paper aims to present a bird's-eye view of the recent research in this field through social network analysis on co-authorship networks in the community. The study is guided by the following research questions, which attempt to examine how the field is prepared to navigate itself in a world in which it has a critical social responsibility:

1. What are the major topics and interests in the IAIED research community (2013-2020)?
2. Is the IAIED research community open to new topics and new members, and attuned to new societal concerns?

Methods

To address our research questions, we analyzed time-evolving co-authorship networks and keyword usage trends of conference full papers from the International Conference of Artificial Intelligence in Education (ICAIED) and journal papers from the International Journal of Artificial Intelligence in Education (IJAIED) published from January 2013 to October 2020. The data were retrieved from Springer and the IJAIED official website. We collected the links of the web pages of target papers, automatically accessed the website's source code, stored the source code as text files, and then used *BeautifulSoup* library to extract data from the source code. The dataset contained 949 articles from 1915 authors from 2013-2020, and included the following fields: article title, author names and affiliations, publication year, keywords, abstract, and references. Full body texts of articles were also retrieved for further research.

In our data analysis, we examined the overall trends of topics from 2013 to 2020 through the most frequently used keywords, ascending keywords, and descending keywords over time. Additionally, we built time-evolving coauthorship networks with a two-year sliding window and utilized them as a proxy for the evolving collaboration network of the IAIED community. Core members of the community were identified using degree centrality. Keywords produced by core members and big sub-groups in the co-authorship network were further classified into distinct conceptual groups to reveal different ideas and research foci of those major contributors.

In the end, newcomers in the research community were identified through publishing patterns, and their keyword usage was analyzed.

Preliminary findings and implications

There are 2136 keyword stems presented in a total of 949 publications. The ten most frequently mentioned keywords are Intelligent Tutoring Systems (n=167), Natural Language Processing (n=46), Machine Learning (n=39), Student Model (n=35), Education Data Mining (n=32), Learning Analytics (n=31), Metacognition (n=26), Affect (n=24), Learning (n=24), and Collaborative Learning (n=23). The number of keywords grows from 507 in 2013-2014 to 593 in 2015-2016, 825 in 2017-2018, and 804 in 2019-2020, possibly indicating novel ideas being regularly introduced to the IAIED society.

The IAIED co-authorship network demonstrated a right-skewed distribution in the number of authors by degree of centrality. More than 50% of the authors (1046 out of 1915) in our IAIED dataset possessed a degree of zero to four (i.e., they have zero to four co-authorship ties in total in the period of 2013-2020). We identified 35 core members, who had more than 20 total co-authorship ties and analyzed their collaboration and publications. A majority of them (n=29, 83%) have published work on Intelligent Tutoring System. For the rest of the core members (n=6, 22.9%), all of them study Educational Games. The analysis of core members' publications reveals Intelligent Tutoring Systems and Educational Games being two major research topics in the IAIED society. In addition, the integration of new community members is vital to the growth and vitality of a scientific community. In attempting to measure such integration, we proposed five categories of authors in terms of their publishing patterns from January 2013-October 2020. The large size of the Joined Recently group (n = 542) shows the growth of the IAIED society from the perspective of membership. Additionally, the keyword analysis shows an increase of more than two hundred keywords during this same period of time (2019-2020).

Research topics of the IAIED society can also be investigated by analyzing the most frequently used keywords in large co-authorship cliques. The largest sixteen cliques were inspected, and they consist of nearly half (49.3%) of the authors in the IAIED society from 2013 to 2020. Intelligent Tutoring Systems (n=10, 62.5%), Game-Based Learning (n=3, 18.8%), Collaborative Learning (n=4, 25%) and Conversational Agents (n=3, 18.8%) are the major topics in these cliques.

One unexpected finding from our analysis is the use of synonymous but distinct terminologies to describe the same concepts in different cliques. This phenomenon may hinder inter-group communication since multiple terminologies need to be learned and used accordingly. In further research, we would like to investigate how different cliques developed over time.

Besides an in-depth analysis of the IAIED research community, an important contribution of this work, with applicability to the larger Learning Sciences community, is methodological. AIED (and LS) are new, interdisciplinary, and still under construction. Most of the literature we found on bibliometrics was focused on well-defined communities. Many of the methodologies we developed in this paper were created for these types of novel research communities with "fuzzier," "in-flux" keywords. We also developed a novel way of categorizing author participation in a research community based on publishing patterns. In this way, newcomers in the community can be identified, and the integration of new community members can be studied. Our future research will apply the method to other closely related research communities (e.g. Educational Data Mining, Learning Analytics, and Learning at Scale) to validate current findings and explore more emerging trends.

References

Berendt, B., Littlejohn, A., & Blakemore, M. (2020). AI in education: learner choice and fundamental rights. Learning, Media and Technology, 45(3), 312-324.

Feng, S., & Kirkley, A. (2020). Mixing patterns in interdisciplinary co-authorship networks at multiple scales. *Scientific reports*, *10*(1), 1-11.

Zawacki-Richter, O., Marín, V. I., Bond, M., & Gouverneur, F. (2019). Systematic review of research on artificial intelligence applications in higher education–where are the educators?. *International Journal of Educational Technology in Higher Education*, *16*(1), 39.

Zuboff, S. (2015). Big other: surveillance capitalism and the prospects of an information civilization. *Journal of Information Technology*, *30*(1), 75-89.

Productive Anger? Changing Systems Understanding due to Negative Emotions

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Abstract: There is growing interest in the role that emotion plays on learning. Research has revealed that negative emotions sometimes positively effect learning; however, most of these studies focus on individual learning situations. In this pilot study, we explore how anger during collaborative learning affects students' discussion and learning. Result indicate that negative emotions could facilitate potentially productive shifts in student discussion.

Introduction

There is growing interest in the role that emotion plays on learning (Pekrun & Stephens, 2010). While negative emotions (e.g., anxiety, fear, frustration, anger, boredom, and embarrassment) have been shown to have an impact on learning, not all of them have been negative (Rowe et al., 2014; White, 2013; Pekrun & Stephens, 2010). For instance, anger can derive from interruptions of perceived goals, creating a motivation to overcome obstacles. Anger can result in increased attention to goals, others' actions, higher levels of physiological activity (e.g., increased heart rate, breathing) and aggression. However, research on the effects of negative emotions on learning is mostly related to test anxiety and boredom, and there is a lack of research on the effects of other negative emotions on learning (Pekrun & Perry, 2014). In particular, most studies focus on individual learning situations, and research on the effects of negative emotions on collaborative learning is less known. As a pilot study, we explore how anger during collaborative learning affects students' discussion and learning.

Methods

Simulation and study design

City Settlers is a whole-room immersive simulation, in which the room "becomes" (through collective imagination) a fictional shared planet on which groups of participants develop their cities. In *City Settlers*, each group can freely set their goals with given city metrics (e.g., pollution, population, and happiness) and develop strategies to achieve their goals. Four types of resources (e.g., Gold, Steel, Food, and Cotton) and three types of buildings (e.g., Factory, Farm, and Park) are available to players. Buildings are acquired through bidding – a blind auction system on a marketplace which generates random buildings to be acquired and used by the cities for their chosen goals. While students are trying to understand complex interrelationships for their city to prosper, groups inevitably cause pollution (all the buildings except parks generate pollution). If a city's pollution level reaches a certain level, the pollution spreads to nearby cities (i.e., those physically close in the room itself). We expect this unexpected problem (rising pollution caused by neighboring cities) will cause emotional changes in students, especially anger, and allow us to track how the students' group discourse is changing.

The participants were 10 middle school students recruited from a summer camp, in the mid-western United States. Seven girls and three boys of different ethnicities were distributed randomly into four groups, introduced to the simulation, and asked to start playing. They played the simulation over 1.5 hours. As qualitative exploratory analysis is considered an effective approach for developing insights into the range and phenomenology of an individual's emotion (Pekrun et al., 2002), we video recorded all four groups' game playing with the goal of identifying anger and changing discourse. As a preliminary study and with the page limitation, we focus on one group (consisting of three girls) that consistently worked on the simulation.

Coding scheme

To determine when the group of students expressed anger, we adapted Shaver and colleagues' (1987) definition that anger happens when people judge that the situation is illegitimate, wrong, or unfair. This sometimes occurred through raised voices, yelling, or screaming. In addition, to determine changes in their discussions, we also developed a coding scheme for the types of discussion enacted (Table 1). The three authors were all involved in coding and agreement was checked across 25% of the total coded turns and were found to have an agreement rate of 88%, 85%, 82% respectively (1st - 2ed; 1st - 3rd; 2nd - 3rd).

Table 1: Discussion type codes and examples

Code	Definition	Sample dialog from
What to buy	Talking about which building they want to buy.	“I want to buy a factory”
What to run	Talking about what building they want to run for the current round.	“We should stop running this park”
What to trade	Talking about what resources they want to trade with other groups.	“We’ll give you anything for food”
Game state	Talking about their city status including the metrics, resources, and buildings.	“Our happiness is so low”
Other group	Talking about anything related to other groups.	“They are polluting us”
Causal	Talking about what causes what.	“If we don’t buy a park, our happiness will drop”

Findings

Students exhibited angry episodes when pollution suddenly increased (a by-product of building too many factories and farms) and caused their city’s happiness to decline. After noticing that pollution came from another group's city, individuals showed a hostile attitude toward that city (e.g., [Yelling] Red city! Stop it! Stop polluting us!). The results of comparing the discussion codes before and after students start to get angry reveal some interesting contrasts (Table 2). Before becoming angry, more than 50% of the discussion codes were about “What to buy” and “What to trade”. However, after a group was coded as angry, there was a notable increase in “Game state” and “Other group” codes, whereas “What to buy” and “What to trade” codes considerably decreased.

Table 2: Discussion type code count before and after angry

Code	Before angry	After angry
What to buy	32%	19%
What to run	3%	3%
What to trade	20%	11%
Game state	35%	43%
Other group	6%	16%
Causal	5%	8%

Discussion

We acknowledge that there could be other variables (e.g., time, other emotions) that we didn’t control which likely affected students’ discussion type. However, as a preliminary examination of how students' anger could affect their collaborative and strategic discussions, this work lays a foundation for future elaborative research regarding how "negative" emotions could facilitate potentially productive shifts in student discussion. The increase in the “Game state” code and “Other group” code and the decrease in the “What to buy” and “What to trade” code after students become angry, may indicate students tried to understand and analyze the complex situation and establish strategies based on the city's needs, rather than focusing on immediate short-term goals (e.g., buying a building).

References

Pekrun, R., Goetz, T., Titz, W., & Perry, R. P. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educational psychologist*, *37*(2), 91-105.

Pekrun, R., & Perry, R. P. (2014). Control-value theory of achievement emotions. *International handbook of emotions in education*, 120-141.

Pekrun, R., & Stephens, E. J. (2010). Achievement emotions in higher education. In *Higher education: Handbook of theory and research* (pp. 257-306). Springer, Dordrecht.

Rowe, A. D., Fitness, J., & Wood, L. N. (2014). The role and functionality of emotions in feedback at university: A qualitative study. *The Australian Educational Researcher*, *41*(3), 283-309.

Shaver, P., Schwartz, J., Kirson, D., & O'connor, C. (1987). Emotion knowledge: further exploration of a prototype approach. *Journal of personality and social psychology, 52*(6), 1061.

White, C. J. (2013). Higher education emotions: a scale development exercise. *Higher Education Research & Development*, *32*(2), 287-299.

International Society of
the Learning Sciences

A Review of Active Learning within JLS and ijCSCL: What can the Learning Sciences tell Active Learning Practitioners?

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Abstract: Practitioners of active learning have asked us what Learning Sciences research has found that can inform their practice. In response, we are conducting a rapid review of Learning Sciences articles referencing common active learning approaches and strategies. This study identifies inquiry-based learning, argumentation, and problem-based learning as the top active learning approaches researched within the Learning Sciences and includes early summaries based on an ongoing synthesis of findings.

Introduction

Active learning is on the rise in mainstream education, characterized by the adoption of interactive, student-centered activities and technology-enhanced learning spaces. The Learning Sciences has developed predominantly independently of the active learning research community, but the two share some common contexts, learning approaches, strategies, and goals (e.g., real-world contexts, problem-based learning, jigsaw, and technology-enhanced collaborative learning). But what has the Learning Sciences found that could inform classroom enactments of active learning activities? To answer this question, we are conducting a rapid review of Learning Sciences articles that investigate common active learning approaches and strategies. We began this process by focusing on ISLS's two affiliated journals: the Journal of the Learning Sciences (JLS); and the International Journal of Computer-Supported Collaborative Learning (ijCSCL). Our results identify the extent to which active learning approaches are common in Learning Sciences research and offer a few early findings from our ongoing synthesis of the literature.

Methods

This research utilizes a rapid review methodology and follows the stages described by Arksey and O'Malley (2005) to guide this integration of evidence. The guiding research question is: "What empirical findings of the Learning Sciences relate to active learning approaches and strategies?" Search terms of active learning approaches and strategies were sourced from SALTISE, an active learning, research-practitioner community (see saltise.ca). Terms included both active learning approaches (e.g., inquiry-based learning) as well as strategies (e.g., snowball, gallery walk, and jigsaw). In the study selection phase, abstracts were reviewed by two graduate researchers. For this paper, we identified the top 3 search terms found during our abstract screening phase: inquiry-based Learning (N=52), debates (and argumentation; N=40), and problem-based learning (N=20). A brief overview of findings from these approaches are summarized below.

Results and discussion

Search results produced 262 studies from JLS and 236 from ijCSCL. After removing one duplicate study, the remaining 497 underwent abstract screening, after which 115 studies remained eligible for full-text review.

Preliminary findings relating to inquiry instruction emphasize the shifting instructional focus from teacher-based or -led instruction to student-lead inquiry. In our reviewed studies, inquiry-based instruction was found to benefit to student learning, specifically in the flexible application of acquired knowledge to open-ended questions (e.g., Song & Looi, 2012; Lee et al, 2006; Kolloffel et al, 2011; Muukkonen & Lakkala, 2009). The literature showed no detriment to performance in other types of assessment, implying that inquiry-based instruction is effective across multiple assessment mediums. Key to the effectiveness of inquiry learning is the manner of instruction. In Puntambekar et al. (2007) it was found that a teacher's pedagogical style significantly influences the results of inquiry-based lessons. Further they found that by focusing on the goal, rather than the student's journey to that goal, teachers can undermine inquiry instruction rather than support it. Overall, inquiry-based instruction shows robust evidence for the improvement of acquired knowledge across multiple age groups, and learner categories, provided the teacher's instructional practice supports the students' learning journey.

Regarding debates (and argumentation), this review found articles highlighting use of this approach in classrooms with learners from middle school to teacher education. Instructors employed various digital tools to scaffold the debate process and to analyse the argumentation process. Brom et al. (2016) found that debates stimulated positive affect when students developed and articulated their opinions about pressing issues such as immigration policy, stem-cell research, and agricultural quotas. Further, in Schwarz et al. (2011), tools aiding synchronous argumentation activities showed increased conceptual learning as well as uncovered mechanisms for conceptual change - fostered through interactional analysis. The research further shows that argumentation, even in cases of disagreement, provides opportunities to foster collaboration and critical reasoning. In Schwarz et al. (2015) a fusion of inquiry, argumentative process, and teamwork allowed students to see new perspectives and the value of learning to collaborate. Therefore, argumentative activities such as debates promote reflection and evaluation of evidence. It should be noted, however, that the debate approach of active learning is distinct in many cases from the scientific argumentation common to the reviewed literature. This distinction will be examined and further elaborated in future publications of this data.

Problem-based Learning (PBL) was found to describe prescribed sequences of activities and practices, guided by coaches, that create opportunities for students, individually or in a group, to hypothesize solutions for given issues that they may not yet fully understand (Kolodner et al., 2003). As with argumentation activities, students working in PBL groups need to be aware of their collaborators' knowledge, and find ways to externalize their own knowledge, as an explicit way to facilitate team efforts (Engelmann & Hesse, 2010). Lastly, PBL supports professional development, such as teachers who are often isolated, to come together to address ill-structured problems in their practice, enrich conversations through anecdotal lived experiences, or generate hypotheses to expand their understanding on teaching and learning (Zhang et al., 2011).

In conclusion, this paper represents a preliminary report on empirical findings of the top three most researched active learning approaches within the learning sciences: inquiry-based learning, debates (argumentation), and problem-based learning. A future report of findings will fully synthesize eligible papers in the dimensions of interventions, definitions, theoretical frameworks, methods, disciplines, and demographic information.

References

Arksey, H., & O'Malley, L. (2005). Scoping studies: towards a methodological framework. *International journal of social research methodology*, 8(*1*), 19-32.

Brom, C., Šisler, V., Slussareff, M., Selmbacherová, T., & Hlávka, Z. (2016). You like it, you learn it: affectivity and learning in competitive social role play gaming. *International Journal of Computer-Supported Collaborative Learning, 11(3)*, 313-348.

Engelmann, T., & Hesse, F. W. (2010). How digital concept maps about the collaborators' knowledge and information influence computer-supported collaborative problem solving. *International Journal of Computer-Supported Collaborative Learning, 5(3)*, 299-319.

Kolloffel, B., Eysink, T. H. S., & de Jong, T. (2011). Comparing the effects of representational tools in collaborative and individual inquiry learning. *International Journal of Computer-Supported Collaborative Learning*, *6*(2), 223–251.

Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., ... & Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design (tm) into practice. *The journal of the learning sciences, 12(4)*, 495-547.

Lee, E. Y. C., Chan, C. K. K., & van Aalst, J. (2006). Students assessing their own collaborative knowledge building. *International Journal of Computer-Supported Collaborative Learning*, *1*(1), 57–87.

Muukkonen, H., & Lakkala, M. (2009). Exploring metaskills of knowledge-creating inquiry in higher education. *International Journal of Computer-Supported Collaborative Learning*, *4*(2), 187–211.

Puntambekar, S., Stylianou, A., & Goldstein, J. (2007). Comparing Classroom Enactments of an Inquiry Curriculum: Lessons Learned From Two Teachers. Journal of the Learning Sciences, 16(1), 81–130.

Schwarz, B. B., Schur, Y., Pensso, H., & Tayer, N. (2011). Perspective taking and synchronous argumentation for learning the day/night cycle. International Journal of Computer-Supported Collaborative Learning, 6(1), 113-138.

Schwarz, B. B., De Groot, R., Mavrikis, M., & Dragon, T. (2015). Learning to learn together with CSCL tools. International Journal of Computer-Supported Collaborative Learning, 10(3), 239-271.

Song, Y., & Looi, C.-K. (2012). Linking teacher beliefs, practices and student inquiry-based learning in a CSCL environment: A tale of two teachers. *International Journal of Computer-Supported Collaborative Learning*, *7*(1), 129–159.

Zhang, M., Lundeberg, M., & Eberhardt, J. (2011). Strategic facilitation of problem-based discussion for teacher professional development. *Journal of the learning sciences, 20(3)*, 342-394.

Family Resilience during Covid-19: Contrasting Cases of Mothers' Beliefs and Behaviors to Support Child Well-being

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Abstract: The Covid-19 pandemic drastically changed family dynamics and daily routines across the United States. In this poster, we present contrasting cases from a remote diary study showing how two mothers are demonstrating family resilience during the pandemic by developing open or closed communication practices to support their children's psychological well-being during Covid-19. The findings of this study contribute to the development of a spectrum of family resilience communication practices to make sense of uncertain times.

Keywords: communication, family resilience, child well-being, Covid-19, case study

Literature review

Recent reviews of research that document how families cope with natural and human-made disasters predict dramatic variation in adaptations to pandemic-driven social, economic and health related stressors (Holmes et al., 2020). Resilience in the face of these traumas is a dynamic process, with responses ranging along a broad continuum. Research on family resilience in particular shows that adaptation is supported when caregivers and children develop shared belief systems that foster positive outlooks, help make sense of adversity, create a sense of togetherness, and nurture value-driven transcendent perspectives within culturally meaningful frameworks (Walsh, 1996). Family resilience has been studied as an outcome and as interactional practices and routines which involve "organizational patterns, communication and problem-solving processes, community resources, and affirming belief systems" (Walsh, 1996, p.1). In this study, we focus on understanding communication processes caregivers employ related to child well-being, since the well-being of young children is of central concern during the pandemic (Golberstein, Wen & Miller, 2020). We examine the following research question: How do caregivers vary in their communication behaviors to support their child's well-being? In this particular health crisis, the virus is a major source of anxiety for parents and children and it is critical to understand how families are communicating about it.

Methods

Participants were selected from the dscout panel, equally distributed by household income brackets (<\$50K, \$50-99K, and over \$100K). They lived in 28 states, and 55% identified as White, 16% Black, 15% Hispanic/Latinx, 9% Asian, and 4% Middle Eastern/North African. Each selected one child in grades K-5 to focus on in the study (53% were K-2). We selected two mothers, Alice and Tyra, from the larger diary study using the dscout app (Pozos et al., 2021). We took a case study approach (Yin, 2017) and selected two cases which were both similar in parent role (i.e., mothers), child age (i.e., 5-years old), and child gender (i.e., female); however, these mothers represented opposite ends of a spectrum from open to closed communication based on Walsh's family resilience framework. Alice is a 36-year-old white woman who is a homemaker in a high-income household making over \$99K annually. Tyra is a 36-year old African-American woman working as a full-time clinical coordinator in the healthcare industry, making between \$50-99K annually.

Findings

As summarized in Figure 1, Alice expressed a need to protect her daughter's well-being, which she planned to implement by shielding her daughter from harmful information, down-regulating negative emotions, and redirecting attention from Covid-19. In contrast, Tyra demonstrated communication processes for family resilience that were characterized with clarity, open emotional sharing, and collaborative problem solving to validate her daughters' feelings and learn together about Covid-19.

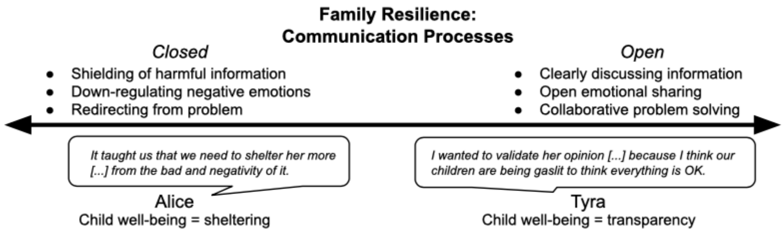

Figure 1: Spectrum of family resilience communication processes from closed to open

Alice decided to protect her daughter Sammy's well-being by not mentioning Covid-19 and not turning on the news to protect her from being frightened by the pandemic. Sammy asked Alice, "What is coronavirus?", "Are people dying?", and "Can kids get it?" Alice's response is described in the quote below:

> We didn't want her to hear all that. You know, the details. I wanted her to know that Coronavirus is out there and people are getting sick and everything like that. But I think a little too much information for her little ears. So it was sad. It was sad that my child had to worry something about the Coronavirus and people dying and everything like that. But it taught us that we need to shelter her more and not talk about Coronavirus around her, and shelter her just from the bad and the negativity of it.

Tyra, on the other hand, is willing to listen to her daughter Tiana's inquiries and answer them as authentically as she can. In this way, she is protecting her daughter's well-being by making sure Tiana feels validated and heard. For example, Tiana asked her mother why China had reopened. Tyra's response is captured in the response below:

> She is coming up with her own novel ideas about how things should work. And I wanted to validate her opinion in that moment because I think even our children are being gaslit in one way or another to think that everything is OK... She's much too young to think that what she has to say and her opinion is crazy because it's not. And just to continue to keep the lines of communication open and I just tell her, you know, if you have other questions just ask me, you know, and I'll try to answer them the best I can.

Overall, Alice and Tyra's contrasting cases demonstrate how sociocultural context and caregivers' experiences may influence their communication practices around child well-being practices. Future research includes examining a broader range of contexts and experiences in the larger sample. During a time when much of the literature has focused on the negative consequences of Covid-19, this work has significant implications by contributing a strengths-based family resilience framework of communication practices.

References

Golberstein, E., Wen, H., & Miller, B. F. (2020). Coronavirus disease 2019 (COVID-19) and mental health for children and adolescents. *JAMA pediatrics*.

Holmes, E. A., O'Connor, R. C., Perry, V. H., Tracey, I., Wessely, S., Arseneault, L., ... & Ford, T. (2020). Multidisciplinary research priorities for the Covid-19 pandemic: a call for action for mental health science. *The Lancet Psychiatry*.

Pozos, R., Martin, C. K., Barron, B., Lam, C., Nguyen, J., Lin, V., Levy, Z., & Garcia, S. (2021). *Before the storm: How families were supported for the transition to distance learning*. Annual Meeting of the International Society of the Learning Sciences (ISLS), Bochum, Germany.

Walsh, F. (1996). The concept of family resilience: Crisis and challenge. *Family process*, 35(3), 261-281.

Yin, R. K. (2017). Case study research and applications: Design and methods. Sage publication.

Expanding the Learning Sciences Toolkit and Reach: A Methodology for the Critical Analysis of Discourse Across Media

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Abstract: We blend Entman's and van Leeuwen's work to advance a novel methodology for the critical analysis of discourse in text media.

Introduction

We add to LS scholarship by pursuing two parallel goals that tackle issues little studied in our field. First, we advance a methodological approach that blends Entman's (2007) framing analysis and aspects of van Leeuwen's (1996) critical discourse analysis (CDA) to distill the relationship between written texts and larger political discourses circulating in society. In demonstrating our methodology, our second, parallel goal is to expand the analytical foci of learning sciences research to consider the discourses of STEM equity that circulate in popular science magazines—*Scientific American*, in this case.

A novel approach to the critical analysis of discourse

We aim to synthesize a simple, yet powerful enough blend of critical CDA tools to facilitate the application and use of these techniques/frameworks to problems directly concerning learning scientists. First, we use Entman's (2007) framing analysis to understand the *content* of a particular text (i.e., what is being said by the author). A frame is the central argument of a text and consist of four elements: *problems*, *causes*, *moral judgments*, and *remedies*. Not all sentences conduct one of the four framing elements, and some sentences may conduct more than one. Researchers proceed by reading all sentences in a text and coding sentences which conduct one of the four framing elements. Once coding is completed, researchers extract those sentences that summarize the frame(s) in a particular text, thus composing a synthetic picture of how the text articulates a problem, its causes, remedies, and moral judgments. At this point, analysis may be deepened by comparing and contrasting frames present within a single text (if at all) or, more importantly, across texts produced by different authors. Extracted sentences are then explored using tools from CDA.

CDA analyzes text at the clause level to identify patterns in language use that reflect societal discourses. Discourses are relatively stable ways of representing the world through language (Fairclough, 2003). To do this, we analyze how *social actors* are represented in texts. Social actors can be any person, group, or even inanimate objects, all of which are capable of doing things or having things done to them. Analyzing social actors entails examining: (a) the *inclusion* or *exclusion* of social actors; and (b) the *activation* or *passivation* of social actors. Included social actors are named in the text, whereas excluded actors are not. Excluded actors are identified by comparing different texts written about similar topics. When social actors are included, they are activated by conducting the action of the verb or passivated by receiving the action of the verb. Researchers proceed by decomposing sentences identified in the framing analysis into clauses, **bolding** social actors (often represented as nouns or pronouns) and <u>underlining</u> verbs. For example, the clause '**Laura** <u>saw</u> **Fiona** in Bochum' has two social actors (Laura and Fiona) and one verb (saw). We code social actors who are included and compare across texts to determine which social actors may be excluded. We examine the relationship between social actors and verbs to code included social actors as either activated or passivated. Patterns in which social actors are included or excluded, and how included social actors are activated or passivated indicate larger social discourses. By iteratively coding social actors within texts and making comparisons between text, we can identify competing social discourses.

Discourses of equity in popular science magazines: Two examples

We demonstrate our methodology with the analysis of two articles (taken from *Scientific American*) that tackle the issue of equity is STEM fields. The first article is titled *Engineering is a man's field: Changing a stereotype with a lesson from India* and it compares enrollment of women in post-bachelor engineering programs in India and the United States of America (Aggarwal, 2013). The second article is titled *Science must clean up its act* and it discusses exclusionary practices in STEM fields, situating that discussion within the author's personal life and an analysis of the 2017 March for Science—a political demonstration where scientists gathered in Washington, D.C. to protest anti-science sentiments growing in the public and government (Metcalf, 2017).

	FA - Problem Definition	CDA - Problem Definition
Metcalf (2017)	"The scientific community, riddled with a history steeped in scientific racism, sexism, and toxic colonialism, has continuously struggled with diversity, equity, and inclusion issues, including systemic bias, harassment, discrimination, and more, all while claiming objectivity." (Paragraph 3)	**(Scientific Community)** (is) riddled with a history (**history**) (is) steeped in scientific racism, sexism, and toxic colonialism **Scientific community** has continuously struggled with diversity, equity, and inclusion issues including systemic bias, harassment, discrimination, and more. **(Scientific Community)** claiming objectivity
Aggarwal (2013)	"We were surprised to find that India has a much lower (better) male-to-female ratio (as compared with the U.S., that is, engineering male-female ratio in India is 1.96 as compared with 4.61 in the U.S. (American Society of Engineering Education, 2009). Interestingly, India does much better than the West on this dimension of gender equity despite being ranked 19th in gender equity among the G20 countries (Thomson Reuters Foundation, 2012)." (Paragraph 2)	**India** has much lower (better) male-to-female ratio, **Engineering Male-female ratio** is 1.96 in India **(engineering male-female ratio)** is 4.61 in the US **India** does much better than **the West** on this dimension of gender equity **(India)** being ranked 19th in gender equity among G20 Countries

Figure 1. The problem definition sentences extracted from FA and prepared for CDA analysis.

We begin by individually reading both articles multiple times, then coding sentences in each according to framing analysis categories of *problem definition* [PD], *causal analysis* [CA], *remedy promotion* [RP], or *moral judgement* [MJ]. This non-linear process involves iterative and collaborative attempts at reading and coding. In the final pass, researchers place a bolded and bracketed code at the end of each sentence, then collaborate to discuss disagreements and to work on a final coding for both texts. Following the coding process, we create a schematic which summarizes each article's frame and contains (one or more) quotes that are synthetic of each frame. We then proceed to the last step in the framing analysis—namely, intertextual frame comparisons aimed at identifying differences between framings of similar social events. To facilitate this process, we place each frame's element side-by-side, as shown in Figure 1. For brevity, here we only show the frames' *problems* identified in each article (Figure 1), leaving treatment of *remedies*, *causes*, and *moral judgements* to an upcoming manuscript.

With framing analysis complete, we have a surface level comparison of the content differences between each of these articles related to how they understand issues of equity in their fields, specifically which issues they consider to be problems. However, we do not yet have a defensible way to identify the discourses that each text relies upon to make their frames and arguments possible—a step that would allow us to pinpoint which discourses circulate the professional STEM world. To do this, we apply CDA to sentences extracted from the framing analysis.

To prepare sentences extracted from the framing analysis for CDA, we break them into clauses, focus analysis on main clauses, **bold participants,** and underline processes. To determine which social actors are *included* and *activated* or *passivated*, we identify the verb, then identify which social actor is conducting or receiving the verb. To determine which social actors are *excluded* we make comparisons between multiple texts, as well as ask questions about what may have been present in the social event that was not captured in the text. Once all social actors have been identified and coded, we draw comparisons between texts to identify divergent or convergent patterns that emerge within or between texts that indicate larger social discourses about equity.

After preparing the sentences extracted from the Aggarwal article, we can identify three participants: India, engineering male-female ratio, and the U. S./West**.** India and the West/U. S. are both mentioned in the text. While 'engineering male-female ratio' is not a person in the typical sense, it is considered a participant/social actor because it conducts the verb "is." Participants represented in parentheses (such as "India") are done so because they are implied by the verb. After preparing the sentence extracted from Metcalf's article, we can see there is only one social actor that is mentioned across the three clauses: **the scientific community**. This comparative exercise thus begins to reveal two competing discourses of equity in STEM. Aggarwal draws on a discourse which represents issues of equity as existing in some places (the U. S.) but not in others (India); whereas Metcalf draws on a discourse which represents issues of equity as existing everywhere in the STEM community and makes no mention of where these issues might be greater or lesser.

Here, we demonstrate this methodology on a single framing element across two texts. The power in this method increases as you analyze all framing elements and make comparisons between multiple texts.

References

Entman, R. M. (2007). Framing Bias: Media in the Distribution of Power. *Journal of Communication*, *57*(1), 163–173.

Fairclough, N. (2003). *Analysing Discourse: Textual Analysis for Social Research* (1st ed.). Routledge.

van Leeuwen, T. (1996). The representation of social actors. In C. R. Caldas-Coulthard & M. Coulthard (Eds.), *Texts and practices readings in critical discourse analysis* (pp. 32–104). Routledge.

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Breadboards and Paper Circuits: Differences in Advanced Circuitry Learning and PCB Layout Design

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Abstract: Most electronic devices have complex circuitry systems embedded in flat and thin structures called printed-circuit boards (PCBs) traditionally to learn at the university level. We systematically compared how 21 youth (ages 15-16) learned basic circuitry concepts and PCB layout design principles using two educational circuitry toolkits, paper circuits or the traditional solderless breadboard for prototyping. Statistical tests of pre- and post-assessments showed large effect sizes (*Hedges' g*) of the score-gain differences favoring paper circuits.

Introduction

Electronic devices, ubiquitous in our fast-paced and interconnected world, are built with complex circuitry systems usually hidden from the users' view and embedded in flat, thin structures called printed-circuit boards (PCBs). PCBs resemble a matrix of layered highways that allow energy to flow in and out of multiple microelectronic components. The different ways learners interact with educational electronic toys and kits, actually do present opportunities to substantially shape learning and participation (Buchholz et al., 2014). However, little research exists on the toolkits' efficacy and how their design features, like the role of materiality, best support learning. In this exploratory study, we sought to explore how each of these toolkits impacted the learning of simple circuitry concepts and advanced PCB design principles by asking: *How do each of these toolkits impact the learning of simple circuitry and advanced PCB design principles? What are the design features of the kits that seem to best support learning?*

Theoretical foundations on learning and materiality in circuitry

This work builds on constructionist theories of learning (Papert, 1980) which perspective asserts that learners construct understandings based on hands-on experiences with tools and materials, particularly through activities that involve the iterative design of personally meaningful artifacts (Peppler & Glosson, 2013). Prior research has demonstrated that the teaching of electric circuitry frequently produces common conceptual misunderstandings, particularly in the areas of *current flow*, *connections*, and *polarity* (e.g., Shepardson & Moje, 1994). Moreover, materials and tools to teach early circuitry can also contribute to erroneous conceptual conceptions (e.g., nonpolar lights, insulated wires) that persist into university level courses (Fredette & Lochhead, 1980).

Methods

For this quantitative study, we held two circuitry workshops in a science museum introducing solderless breadboards and paper circuits (Chibitronics™). The solderless breadboard has been one of the most common toolkits for over 60 years for electrical circuit learning in electrical and computing engineering labs (Figure 1-3). Paper circuits (Figure 1-2) are a recent toolkit that combines paper crafts and arts with circuitry (coin batteries, paper, copper tape, and sticker lights). The workshop participants were 21 youth, ages 15-16 years old, 12 participants for the breadboard group and 9 participants for the paper circuits group. Informed by our prior work (Peppler & Glosson, 2013), we administered one pre- and post-test on basic circuitry concepts (*polarity, current flow, connections*). We performed t-tests using gain scores (post- minus pre-mean scores).

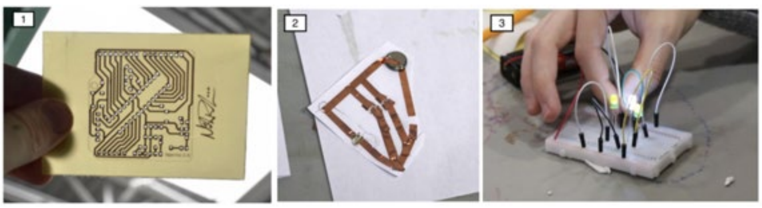

Figure 1. Similar parallel and non-crossing traces in PCB (1) and paper circuit (2) but not in breadboards (3).

For effect sizes, we calculated Cohen's *d* (Cohen, 1988) and its correction for small sample sizes, Hedges' *g* (Hedges & Olkin, 1985). We also analyzed and scored their tests for evidence of appropriate use of the four PCB (see Figure 1-1) layout design principles. Expert PCB designers consider three areas: (1) space allocation or floorplanning, (2) placement of components, and (3) routing or trace positioning (e.g., Wilson, 2018). We narrowed to *polarized component orientation, trace-to-trace spacing, power and ground distribution.*

Findings

We show the results of the comparison of mean gain scores *between* groups (i.e., independent-samples t-tests) in Figure 2. The only statistically significant difference at the .05 level was the mean gain score in the paper circuits for *polarity*, higher than of the breadboard group t(17.817) = -2.458, p = **.024**, and a large effect size Hedges' **g = 1.03**. The mean gain scores were higher in all four principles in the paper circuit group, but only three statistically significant at p < .10 level (see Figure 2-*right*). The results of the independent-samples t-tests indicated the highest mean gain scores were for the paper circuit group for *power distribution*, *trace spacing* and *orientation of polarized components.* We also calculated effect sizes (Hedges' g) for the paper circuit group.

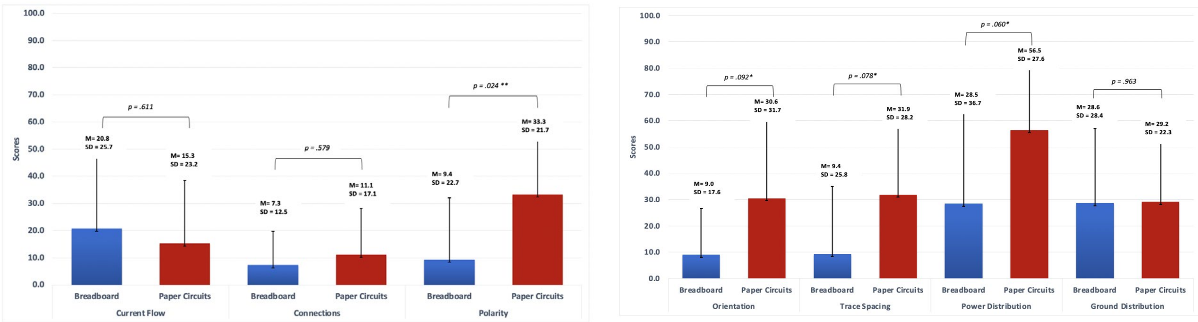

Figure 2. Comparisons of Mean Gain Scores of Basic Concepts (*Left*) and of Layout Design Principles (*Right*). Mean (M), Standard Deviation (SD) and statistical significance (p) at the *p < .10, **p < .05 levels.

Those effects sizes were large for the basic concept of **polarity** (g = **1.03**) and for the layout design principles of **orientation of polarized components** (**.84**), **trace-to-trace spacing** (**.81**), and **power distribution** (**.81**).

Discussion and implications

We encourage educators to carefully select educational toolkits considering the properties of their materials. Breadboards may be a traditional go-to toolkit, but in our study, paper circuits seemed to afford better understanding of some basic concepts, such as polarity, and PCB layout design principles. The familiar nature of the paper circuits materials and their placement in a 2D space offers similarities with the actual space and nature of a 'real' PCB (Fig. 1). Breadboards may cut out problems for novices, such as the use of insulated wires and a grid to temporarily and quickly place components, but also seem to prevent deeper learning opportunities.

References

Buchholz, B., Shively, K., Peppler, K., & Wohlwend, K. (2014). Hands on, hands off: Gendered access in crafting and electronics practices. *Mind, Culture, and Activity*, *21*(4), 278-297.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences.* (2 Ed.) Lawrence Erlbaum Associates.

Fredette, N. & Lochhead, J. (1980). Students' conceptions of simple circuits. *The Physics Teacher, 18*, 194-198.

Hedges, L. V., & Olkin, I. (1985). *Statistical Methods for Meta-Analysis*. New York, NY: Academic Press.

Papert, S. (1980). *Mindstorms: Children, computers, and powerful ideas.* New York, NY: Basic Books.

Peppler, K., & Glosson, D. (2013). Stitching circuits: Learning about circuitry through e-textile materials. *Journal of Science Education and Technology, 22*(5), 751-763.

Shepardson, D. P., & Moje, E. B. (1994). The nature of fourth graders' understandings of electric circuits. *Science Education, 78*(5), 489-514.

Wilson, P. (2018). *The circuit designer's companion.* (4th ed.). Boston, MA: Newnes.

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Emergent Learning Possibilities and Evolving Design Spaces in Students' Redesigning the Pandemic Board Game

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Abstract: We discuss a study on grade 7 students' exploring emergent systems while redesigning the board game Pandemic using mathematics and science topics. We evaluated students' developing ideas and the unfolding learning possibilities through the redesign process. Our findings show how game redesign supported learners' decision making and their evolving conceptions of problems.

This project used a board game redesign approach to learners' engagement with emergent systems using mathematics and science. We follow the concept of learning as an emergent phenomenon that expands learners' capacities to adapt to and participate in novel situations. Complexity perspectives use the notion of enabling constraints: appropriate structures in learning designs free learners from having too many choices, provide shared goals and language, and enable learners' different responses (Davis & Sumara, 2006). We discuss how the board game redesign approach sets structures that enable students' collective decisions, which eventually expand their engagement with math and science topics. We attended to the following questions: How did the learners' co-design spaces evolve through the redesign process? How did learners' decisions frame their designs and use of math and science in creating game systems?

The literature on design similarly signifies constraints as shaping creative pathways (Sternberg & Kaufman, 2010). Constraints could be external such as materials, or self-imposed emerging from designers' ideas and decisions. With every decision, designers impose constraints on their work that not only restrain the next actions, but also become tools to think with and to explore new design spaces. Design space is interpreted as a dynamic conceptual space of possibilities that is constructed as designers go through the design process (Biskjaer et al., 2014). Systemic perspectives describe it as continuously developing through the interactions of designers and design conditions. Designing board games, as models of systems, could engage students in developing and shaping the design space with mathematics and science (Kim & Bastani, 2017; Saxe, 1992). Kim et al. (2020) showed structuring game design projects as re-designing board games, in which learners play a common board game and change its elements to create their own games, enabled learners to creatively engage with disciplinary ideas. The common starting point and physical material supported learners' communication and shared goals. In the iterative process of design, learners' evolving decisions become frames that direct their further inquiry into design problems. Using our data, we will discuss how learners' design decisions developed through redesigning the Pandemic board game and enabled them to expand their ideas and use math and science topics, thus their design space.

Research design and data sources

We conducted this design-based research with grade 7 students in a Canadian school, in Fall 2018. We developed the activities with the math teacher (also a game designer) and focused on the topics of numbers, statistics and probability, and the science topics of interactions and ecosystems. We collected ethnographic data through field notes, video-recordings of students' designs and group interviews. We used the cooperative game Pandemic which models disease spread across the world (Figure1a), as the game to be redesigned. We used it as a model of an emergent global issue. In this game, players work together to treat infected populations and discover the cures. The student groups began by playing the game. Then they brainstormed on design ideas and using learning topics and redesigned Pandemic.

Findings

Our unit of analysis was the critical episodes in which the interaction of learners' ideas, materials and activities transformed their collective design space. Here, we chose one group whose redesigned game was Reverse Pandemic. The group's design decisions enabled them to expand their ideas and use of math and science, thus their design space.

The group developed the idea of reversing Pandemic's narrative, i.e., players would act as diseases spreading around the world, which directed their design process. We observed that the Pandemic's physical materials, e.g., the cubes representing viruses and board map, mediated their discussions on game redesign ideas.

Initially, they tried to implement their idea of reverse Pandemic by defining opposite functions for the original game's components (e.g., cubes representing cures instead of diseases). While this approach might not be helpful in reversing the dynamics of a game system it encouraged them to explore the original game system.

It was important for the group to taking the perspective of bacteria and viruses. In a critical episode, their conversation around Pandemic's and their own game's theme with a science teacher led to elaborating their game backstory through exploring how bacteria and viruses act. They discussed how bacteria develop resistance against antibiotics and mutate and how viral diseases spread with international travels. Discussing cities' defence against diseases, they talked about how vaccines could develop widespread immunity. An intentional interaction between students and teachers mediated by Pandemic's board and other components supported integrating learning topics. The group's work showed that mathematics can become a tool to materialize ideas. The group found to reverse the Pandemic's narrative, they needed to understand the game's system more deeply. They evaluated the infection cards that determine the cities to be infected based on designed probabilities, and the epidemic cards that trigger an outbreak. Their choice of reversing the Pandemic's story became about reversing its logic: i.e., their design problem evolved so as their choices and design space, exploring more possibilities of using math. They created numeric values for players' power (diseases) and adopted probability for vaccination cards (one out ten players' cards were vaccination cards), which made cities' defence dynamic. The group's goal of having playable drafts and playtesting (Figure1b) encouraged them to use mathematics in different design stages from the beginning. Students could experience the problems in context by confronting their own designs (Kim et al., 2019) and could develop more holistic views about this complex system.

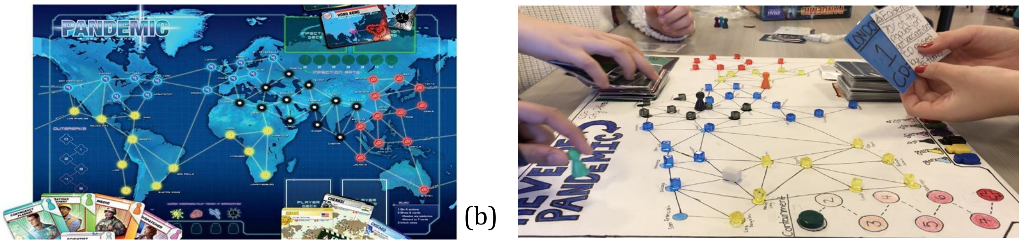
(a)  (b)

Figure 1. (a) Pandemic, Z-MAN Games, (b) the group's redesigned game

Conclusions

We structured this project as a board game redesign to limit the vast possibilities of creating a game from scratch, and support learners' shared conception of their design practices (Bastani & Kim, 2020). Students used the original game's languages and components and shared the goal of reversing its theme. Game redesign enabled collective decision making, through which learners explored novel paths of integrating learning topics: i.e., expanded their design space.

References

Bastani, R., & Kim, B. (2020). Learners' emergent designs for play: Game design as mathematical modeling practices. In *Proceedings of the 14th International Conference of the Learning* Sciences (ICLS).

Biskjaer, M. M., Dalsgaard, P., & Halskov, K. (2014). A constraint-based understanding of design spaces. In *Proceedings of the 2014 conference on Designing interactive systems* (pp. 453-462).

Davis, B., & Sumara, D. J. (2006). *Complexity and education: Inquiries into learning, teaching, and research*. Psychology Press.

Kim, B., & Bastani, R. (2017). Students as game designers: Transdisciplinary approach to STEAM Education. *Special Issue of the Alberta Science Education Journal*, *45*(1), 45–52.

Kim, B., Bastani, R., Rahimi, F. B., & Dadkhahfard, S. (2020). Finding Opportunities to Pursue Interest in the Classroom. In *Proceedings of the 14th International Conference of the Learning* Sciences (ICLS).

Kim, B., Rasporich, S., & Gupta, D. (2019). Imagining the Sustainable Future Through the Construction of Fantasy Worlds. In *Critical, Transdisciplinary and Embodied Approaches in STEM Education* (pp. 61-82). Springer.

Saxe, G. B. (1992). Studying Children's Learning in Context: Problems and Prospects. The Journal of the Learning Sciences, 2(2), 215–234.

Sternberg, R. J., & Kaufman, J. C. (2010). Constraints on creativity. *The Cambridge handbook of creativity*, 467-482.

Z-MAN games (2007). *The world of Pandemic [Board game]*.

Supporting Collaborative Learning About the Nature of Science and STEM Identity Development in a High-School Biology Class in Ontario

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Abstract: Our study conducted in a Grade 11 Biology classroom focused on supporting students' development of the 21st Century Competencies, NOS understandings, and students' STEM identity. A scientific learning community approach, supported by technology, was implemented to improve inquiry-based learning and students' collaboration and thinking processes. Students co-constructed a common knowledge base to make connections across topics. Our findings showed a potential of a learning community approach in helping students develop the competencies of critical thinking about resources, collaboration, and scientific argumentation, and explore their STEM identities.

Keywords: learning community, collaborative learning, STEM identity, Nature of Science

Introduction

Our research study was conducted with a Grade 11 Biology classroom in a diverse urban school located in Ontario, Canada. Students were engaged as a scientific learning community by exploring case studies and datasets, evaluating the credibility of online and published resources, developing scientific argumentation and participating in debates, reflecting in personal journals and working together to explore the Nature of Science (NOS) and STEM-related careers. Guided by a theoretical model of Knowledge Community and Inquiry (KCI - e.g., Fong & Slotta, 2018), we co-designed a curriculum in which students made connections across course units and connected to real-life issues. A substantial research literature has addressed the benefits of a learning community approach (Bielacyzc & Collins, 2006; Slotta & Najafi, 2013), such as developing and advancing a shared community knowledge base (Bereiter & Scardamalia, 2014; Fong & Slotta, 2018). By engaging in a scientific learning community, students develop collaborative skills and become independent problem solvers (Smithenry, Gallagher-Bolos, & Kosnik, 2007).

Our primary research question: How can engagement in a scientific learning community support the development of high school students' scientific competencies, collaboration, NOS understandings, and STEM identities?

Theoretical framework

We applied the KCI model to guide the design of a curriculum in which students work together as a community, developing scientific argumentation and critical thinking (e.g., through discussions and evaluation of source credibility), improving their understanding of the NOS and exploring STEM careers. In the KCI model, students create a common knowledge base which is further used in the activities; they can add new ideas to the base, can edit and improve it (Fong & Slotta, 2018). Students participate in the interactions and scientific argumentation reflecting some practices characteristic of the real scientific community; they make connections within and across instructional units and connect to real-life issues. Along with a deeper understanding of scientific practices and processes, students also build their understanding of the Nature of Science, and how scientific knowledge is generated and validated.

Method

The study was conducted in a diverse urban school located in a large city in Ontario, Canada. A series of lessons co-designed with the classroom teacher used a variety of technology environments and materials (e.g., Google Docs, Google Forms, Google Classroom and Padlet) to support the curriculum and assessments. We developed a KCI curriculum for 11th grade Biology that aimed to address the research question, adding a cross-cutting diet and nutrition theme. Three cohorts of students (60 students in total) participated in the study, examining interesting evidence cases, participating in inquiry activities and engaging around ideas, connections, data analysis and critical thinking about resources. Their culminating activity included a group analysis of a case study "Atkins vs Mediterranean Diet", developed by the Tufts University and adapted by the teacher and researchers. The KCI research method included having students construct a community knowledge base, scaffolded inquiry activities, and accessible learning outcomes. Exploration of the NOS and student epistemology was effectuated through students' scientific argumentation, exploration of their beliefs about the NOS, and critical interpretation of evidence, which includes data reasoning, student-contributed evidence, discussions and debates. Students worked as a class community to address distinction between observation and inference, between scientific laws, theories, hypotheses, principles and facts. A C.R.A.A.P. rubric was used to evaluate primary and secondary resources. The teacher and researchers observed students' participation and collected evidence of their engagement – individually, in groups and as a class. A pre- and posttests of students' epistemological ideas on the NOS, Learning Communities and Career Exploration were developed. The analysis of students' responses included identification of the central ideas and scoring of the complexity of responses. Three levels of students' responses were determined: 'Partial', 'Full', and 'Complex'.

Data sources
The data collected during this study include student replies on pre- and post-questionnaires, tables, documents and journals created by students individually (on Google Forms and Google Docs), in groups and as a class (on Google Docs, Padlet, and Google Classroom), as well as classroom observation notes, audio and video recordings. Co-constructed tables and student contributions represent a community knowledge base built during school year and used by all students for their final case study activity. In scientific argumentation activities, information was collected as claims, evidence, and reasoning statements. Students' replies to the pre-post questionnaire were recorded on Google Forms. In each unit students also worked individually and in groups to build a STEM Identity and Careers common knowledge base which represented students' contributions to a career exploration folder on Google Docs.

Findings
First, our study supported students' understanding of the role of a learning community in science learning and science research, and in communication of results. In students' replies to a post-test questionnaire, students provided high-level responses on the role of a community: among scientists (e.g., contributing to a total knowledge pool, improving the credibility and accuracy of the previous ideas) and in a classroom (e.g., sharing information to peers and learning from them, learning through explanations). Second, our design supported students' communication, collaboration, and critical thinking about primary and secondary resources – through discussing, evaluating and ranking resources. KCI activities enabled student engagement and connected to important learning goals in biology. Third, students' understandings of the NOS were built progressively through all units. Students learned that scientific knowledge is subject to change as new evidence becomes available or old evidence becomes reinterpreted with the advances of technology and new discoveries in science. Finally, through exploring different careers and contributing to the class career folder, students built their understanding of STEM careers. The study demonstrates opportunities of collaborative learning and learning community approach, achieved through student work and discussions in groups and as a whole class, for helping students develop the competencies of critical thinking about resources, collaboration, and scientific argumentation, and explore their STEM identities.
We acknowledge the support of a grant from the Canadian Social Sciences and Humanities Research Council.

References
Bereiter, C. & Scardamalia, M. (2014). Knowledge building and knowledge creation: One concept, two hills to climb. In S. C. Tan, H. J. So, J. Yeo (Eds.), *Knowledge creation in education* (pp. 35-52). Singapore: Springer.

Bielaczyc, Katerine, & Collins, A. (2006). Fostering knowledge-creating communities. In A. M. O'Donnell, C. E. Hmelo-Silver, & G. Erkens (Eds.), *Collaborative learning, reasoning, and technology* (pp. 37–60). Mahwah, NJ: Lawrence Erlbaum Associates Inc.

Fong, C., & Slotta, J. D. (2018). Supporting communities of learners in the elementary classroom: The Common Knowledge learning environment. *Instructional Sciences, 46*(4), 1-29.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In K. Sawyer (Ed.), Cambridge Handbook of the Learning Sciences (pp. 97-118). New York: Cambridge University Press.

Smithenry, D. W., Gallagher-Bolos, J.A., & Kosnik, C. (2007, April). *Student perceptions of community inquiry in the chemistry classroom*. Paper presented at the Annual Meeting of the American Educational Research Association, Chicago, IL.

Slotta, J. D., & Najafi, H. (2013). Emerging technologies for the classroom. In C. Mouza, & N. Lavigne (Eds.), *Emerging technologies for the classroom: A learning sciences perspective* (pp. 93-112). New York, NY: Springer New York.

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Embodied Geometry in Haircutting Practice

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Abstract: We investigate the emergent, interactionally achieved, embodied geometry that two hairstylists collectively enacted during a haircutting session.

Introduction

We investigate the emergent, interactionally achieved, embodied geometry that two hairstylists enacted during a haircutting session. By stepping out of classroom environments and into the world of a professional trade, we shed light on alternative, powerful forms of embodied mathematical practices (Hall & Nemirovsky, 2012), and join efforts that seek to counter epistemological injustices and marginalization (Medin & Bang, 2014).

Theoretical framework

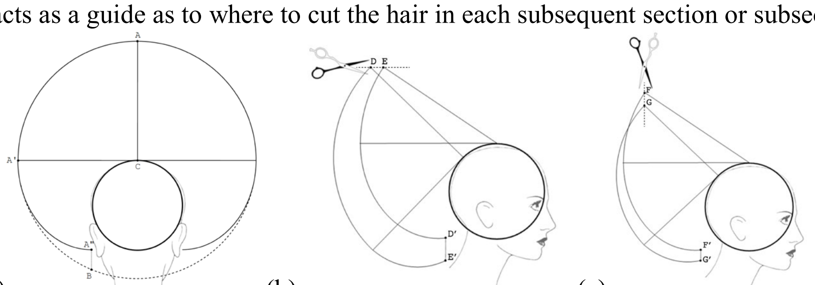
We adopt an *interactionist* perspective (Jordan & Henderson, 1995) and take it that cognition is embodied to the extent that knowing and learning are processes that take place through bodily perception and action, and which unfold within specific material, physical, and social settings (Hall & Nemirovsky, 2012). In this approach, therefore, the body is seen as "a dynamically unfolding, interactively organized locus for the production and display of relevant meaning and action" (Goodwin, 2000) and "concepts… [are] forms of modal engagement in which bodies incorporate and express culture" (Hall & Nemirovsky, 2012, p. 211). We emphasize the coordination of action between participants in a setting, the multifaceted roles that bodies take on during the process, the tool mediated character of the job, and how reasoning and action emerges from the exchanges between participants.

Empirical methods and context

We investigate a single episode of an interaction between two professional hairstylists, Steven and Brooke (pseudonyms), and a client. Steven, a male in his early forties, had specialized in cutting hair for 16 years, while Brooke, a female in her late twenties, had specialized in coloring hair for seven years. Steven and Brooke had arranged to help each other develop their coloring and cutting techniques, respectively. We focus on the session in which Steven guided Brooke through a haircutting job for which the client had requested a layered cut. We video recorded the naturally unfolding exchanges between Steven and Brooke, as they worked at a salon.

Analysis

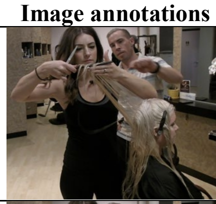
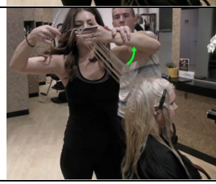
Layers are created by cutting sections of hair so the ends of the hair fall around the head in such a manner that their overall relative lengths appear to be "graduated." In canonical geometry terms, the process rests on the concepts articulated in Figure 1. Key concepts of haircutting operate "on top" of, and in tandem with this geometry basis: (1) *sectioning* is the act of dividing the hair at the scalp to separate the hair into uniform working areas; and (2) a *guideline* (or guide) is a section of hair that establishes the length to which the hair, locally or overall, will be cut—that is, it acts as a guide as to where to cut the hair in each subsequent section or subsection.



(a) (b) (c)

Figure 1. (a) Hair extended from point C to A is free to rotate about point C until it reaches A', at which point the hair is extended in a line tangent to the head and begins to wrap around the curve of the head, effectively "shortening" in length relative to where it would fall if allowed to rotate freely. Thus, upon reaching point A', the hair wraps around the head until it falls to point A'', as opposed to point B; (b) and (c) Notice that even if the length DE is equivalent to length FG, the differences in length D'E' and F'G' differ as the hair wraps around the head, following the *involute* of the roughly circular head shape.

On this background, we pick up the action as Brooke had established the guideline (17:42) and moved to section the hair to be cut into layers. Creating precise layering effects is founded on the formal geometrical concept of *involute of a circle*. If cutting a single strand (Figure 1b), one can see that the hair rotates freely, in a *semicircular* path, until it reaches point A', at which it appears to "shorten" in length as it wraps around the head. When cutting a whole section of hair, then, the angle at which hair are elevated and cut have a drastic effect on the graduation of the layers. For instance, cutting across a section of hair parallel (Figure 1b) and perpendicular (Figure 1c) to the ground creates differences in *lengths* among the strands in the section (compare length D'E' to F'G') and, once an *angle* (parallel or perpendicular) is adopted, one must adhere to it throughout; Stephen and Brooke had decided for a parallel angle. But as Brooke was about to carry out the first cut in the process, an imprecision in cutting angle threatened to violate these principles and to introduce layering inaccuracies:

Turn	Time	Participants' talk and action annotations	Image annotations
1	18:11	Steven: ((Talk unintelligible)) ((Began moving his left hand towards Brooke))	
2	18:12	Steven: Just, watch the arm bend up there ((pointing to her left wrist)).	
3	18:13	Steven: ((Talk inaudible)) ((Grabs Brooke's left arm near the wrist and lifts it so it is parallel to the floor)). Brooke (18:14): The hair? Steven: Yeah.	

As Brooke lifted the hair away from the client's head and neared her first cut stroke (turn 1), she rested her hand on the hair and held her elbow at a depressed (incorrect) angle toward the floor (turn 1, image)—in effect "bending" that hair section, rather than creating a straight line. This action, akin to disregarding a fundamental axiom of geometry, breaks the geometric basis upon which the relevant cutting theory is dependent. Immediately noticing the problem (turns 2-3), Steven directly intervened by grabbing Brooke's left arm and correcting its position and, by implication, her hand's angling and holding of that hair section.

Discussion and conclusion

We found that the geometry of hairstyling is an interactional, embodied accomplishment in that: (1) Body parts were literally operated upon, cut and discarded, according to underlying geometric principles; (2) Bodies were constantly coordinated to obtain meaningful relationships of geometrical nature; and (3) Hairstylists' actions and body posture were founded on, and expressed geometrical concepts. In all, the embodied mathematical practices we reported upon reflect a complex geometry, yet achieved through means quite different from canonical mathematical practice and based on quite distinct epistemological and ontological bases. The complexity of such math and its instantiation in a traditional trade reaffirms the power of alternative STEM epistemologies (Medin & Bang, 2014) and the promise that research on learning out-of-school holds for advancing our field.

References

Goodwin, C. (2000). Action and embodiment within situated human activity. *Journal of Pragmatics*, *32*, 1489-1522.

Hall, R., & Nemirovsky, R. (2012). Introduction to the special issue: Modalities of bodily engagement in mathematical activity and learning. *Journal of the Learning Sciences*, *21*(2), 207-215.

Jordan, B., & Henderson, A. (1995). Interaction analysis: Foundations and practices. *The Journal of the Learning Sciences*, *4*(10), 39-103.

Medin, D. L., & Bang, M. (2014). *Who's Asking? Native Science, Western Science, and Science Education*. Boston, MA: MIT Press.

International Society of
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A Review of Complexity Perspectives in the Learning Sciences

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Abstract: This paper presents a summary of our critical review of complexity perspectives in the learning sciences. We provide a map which helps identify roots of complexity research. Our review identified two strands of research on complexity in the learning sciences namely *complexity as a subject matter* and *complexity as a frame* to study knowledge and learning. We address the main debates within each strand and discuss a possible dialogue between the two.

Complexity discourses have contributed to different domains of research in the learning sciences. Scholars have used complexity views to design school and classroom structures that better fit with their increasingly diverse participants (Doll, 2015). In this poster, we review the scholarly work in the learning sciences that have adopted complexity views. Two main strands of research stand out based on this review: *complexity as a subject matter,* aiming to support learners' understanding of complex phenomena; and *complexity as a frame* to study knowledge and learning conceptualized as emergent phenomena.

Our review shows there has not been much dialogue between the two strands. We conjecture that this gap is the result of disjunctions between fundamental views towards the dynamics of cognition and learning, and towards disciplinary knowledge, even though complexity is the very framework that can cross the bridge between these two threads. To elaborate on this possibility, we trace the roots of complexity discourses in different domains of inquiry and will explore how the two identified strands in the learning sciences build on complexity views.

Complexity research

Complexity research explores how diverse rule-following entities interact and shape a collective whole (i.e., a complex system). These entities, or *agents*, learn, adapt and evolve, and form a system, which shows emergent behaviors and collective patterns, without benefiting from a central controller (Mitchell, 2009). Complex systems have a number of key qualities, such as involving multiple agents, self-organization, and emergent behaviors. For this review, we first conducted a historical review of complexity research in different fields. We mapped contributions of different fields, as well as the development of various concepts which can be accessed on a digital map created by the authors (Bastani & Kim, 2020).

The first row on this map shows the emergence of complexity research, its origins and evolution in mathematics and physical sciences, as well as in life sciences and social sciences. Complexity research in mathematical and physical sciences emerged as a challenge to the deterministic views of modern science and ideal reductionism. As opposed to ideas of prefect predictability (Laplace, 1814), Heisenberg's uncertainty principle in quantum theory and Poincaré's (1908) dynamical systems emphasized the impossibility of complete prediction. Their work discredited the assumptions of the simplicity of nature. Later research on computation contributed to understanding complex systems through processing of information. Cybernetics was significant in using the notion of feedback to explain the adaptation process in complex systems (Alhadeff-Jones, 2008).

In parallel, biological sciences were influenced by evolutionary biology. Informed by the automata theory, McCulloch and Pitts (1943) developed computational models of neural systems to explain the biological processes in the brain as neural networks. These models were later applied to artificial intelligence. Connections between the evolution of living systems and the emergence of cognition were also studied (Bateson,1972).

Early research on complex social systems included Herbert Simon's work on decision making processes in organizations and human problem solving. This along with the work of others such as Bateson led to a constructivist view of complexity. Simon (1962) described complex systems (e.g., societies), as composed of interrelated entities (e.g., families), which themselves are complex and consisted of various complex parts.

Complexity perspectives in the learning sciences

In this review, we aimed to include seminal work and the main trends of using complexity discourses in the learning sciences. Our initial reading of the literature showed key trends shaping from mid-20th century. Importantly, we attended to how this scholarly work were informed by the main historical developments in complexity research and what their areas of focus were.

Our review of complexity research in the learning sciences identified two main strands. The first strand focused on design approaches to support students' understanding of complex systems. Computational modeling and simulation tools are widely used (Bastani, 2016). For example, modelling activities for students through

StarLogo (Resnick, 1991) and NetLogo (Wilensky, 1999), i.e., agent-based modeling platforms, are used to model complex systems. Other examples include participatory activities where students could take the role of systems' agents (e.g., a virus carrier) and follow the local rules for their actions and observe both their role and the system behaviours (e.g., disease spread) in a computational simulation (Colella, 2000; Danish, 2014).

The second strand concerns the design of learning environments based on complexity-informed conceptions of knowledge and learning (Davis & Sumara, 2006). Such design is built on a view that understanding is not instantaneous and linear but emerges through the interaction of multiple arguments and viewpoints (Doll, 2015). Individual sense-making and collective understanding, in this view, are emergent and inter-dependent, thus designing learning environments need to consider agency, creativity and diversity at the individual level as well as collective interaction. The second row of the digital map showcases theories of learning connected to complexity discourses. The third and fourth rows of the map focus specifically on the two strands of complexity research in the learning sciences.

Discussion

The two strands of research we identified in our review, namely *complexity as a subject matter* and *complexity as a frame* to study knowledge and learning stem from different conceptual views towards complexity and the relationship between learners and disciplinary knowledge. The first strand mostly focuses on designing tools and environments to support students understanding about complex phenomena. Therefore, although the subject matter and the curricular aim for students to achieve a better understanding of complex systems (e.g., feedback mechanisms in systems) through individual or collective modeling activities, the computational and non-computational tools and curricula do not necessarily encourage the expression and interaction of learners' diverse perspectives and exploring complex phenomena in context. A more comprehensive complexity view of knowledge and learners would expect learners to create diverse meanings and views about the same phenomena.

The second strand looking at the dynamics of learning and knowledge production, uses complexity discourse mostly to elaborate how individual and collective learning are different but interconnected emergent systems. From this viewpoint, the produced knowledge is not a separate entity from learners. Knowledge is produced as learners interact with the world and expand their horizons of interpreting phenomena. There is, however, a lack of empirical work that examine the proposed design conditions within this strand. We, therefore, argue that each of the two strands has its own merits with limitations. We argue for a possible dialogue between these two strands that could inform a view of education that both enables learners' better understanding of complex issues and allows for diversity and inclusion of different viewpoints, skills and interests.

References

Bastani, R., & Kim, B. (2020). Complexity perspectives in education. Retrieved from: https://bit.ly/35rdZrF

Alhadeff-Jones, M. (2008). Three generations of complexity theories: Nuances and ambiguities. In M. Mason (Ed.), *Complexity Theory and the Philosophy of Education*. New Jersey: John Wiley & Sons.

Bastani, R. (2016). Enhancing children's understanding of complex systems: A study of the design considerations of an effective learning environment. In *EdMedia+ Innovate Learning* (pp. 1348-1353).

Bateson, G. (1972). *Steps to an Ecology of Mind: Collected Essays in Anthropology, Psychiatry, Evolution, and Epistemology*. Chicago, Illinois: University of Chicago Press.

Danish, J (2014). Applying an Activity Theory Lens to Designing Instruction for Learning About the Structure, Behavior, and Function of a Honeybee System. *Journal of the Learning Sciences*, *23*(2),100–148.

Davis, B., & Sumara, D. J. (2006). *Complexity and education: Inquiries into learning, teaching, and research*. Psychology Press.

Doll, W. E. (2015). A post-modern perspective on curriculum. Teachers College Press.

Laplace, P. S. (1814). *Essai philosophique sur les probabilités*. Paris: Mme. Ve. Courcier.

McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *The Bulletin of Mathematical Biophysics*, *5*(4), 115–133.

Mitchell, M. (2009). *Complexity: A guided tour*. Oxford: Oxford University Press.

Osberg, D., & Biesta, G. "Complexity theory and the politics of education." (2010).

Poincaré, H. (1908). *Science and Method* (translated). Paris: Cosimo Incorporated.

Resnick, M. (1991). Animal Simulations with StarLogo: Massive Parallelism for the Masses. In J. A. Meyer & S. Wilson (Eds.), *From Animals to Animats*. Cambridge, MA: MIT Press.

Simon, H. A. (1962). The Architecture of Complexity. *Proceedings of the American Philosophical Society*, *106*(6), 467–482.

Wilensky, U. (1999). NetLogo. Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University.

Interface as an Integrative Framework for Understanding Learning and Knowledge Acquisition in Public Library Contexts

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Abstract: Public libraries are increasingly leveraging both physical and digital space for community learning. In this conceptual piece I build on Björneborn's libraries as "*integrative interfaces*" framework as an analytical tool for understanding the material and relational interactions that impact library patrons' uniquely complex learning experiences across space. I argue that this lens can illuminate structures of power and their impacts on interaction, access, and learning, across physical and digital space.

Introduction

Over the last decade, the Learning Sciences has increasingly recognized the significance of libraries as spaces for community learning and accessing resources, especially for under-resourced communities (Lee & Phillips, 2019; Ito & Martin, 2013). While the physical spaces of libraries are important parts of community social infrastructure (Klinenberg, 2018), digital learning experiences have become increasingly prevalent with the integration of STE(A)M education. As public libraries increasingly mix the digital and physical, it is important to understand embedded and connected learning across space, as well as how inequity translates. In this conceptual poster paper, I build on Björneborn's (2008) libraries as "*integrative interfaces*" framework, as a way to understand sociomaterial activity that impact patrons' learning experiences in libraries. By thinking about physical and digital space through this lens, we can illuminate architectures and structures of power across both types of space, as well as the implications of these structures on interaction, access, and learning.

Conceptualizing interface

The term interface is most often used to describe the visual and structural frames that a user interacts with in digital space. However, interface can also be observed and understood in physical space through architectural design, spatial layout, and the policies and norms that shape behavior and interactions. Media and technology theorist Alexander Galloway (2009) provides two examples of how interface has been considered and conceptualized: as a "surface" (like a screen) to be interacted with, or a portal. Citing French author François Dagognet, Galloway prompts us to consider that the interface, "both separates and mixes the two worlds that meet together there" (Galloway, 2009, p.32). Galloway also conceptualizes interface as being a "process or a translation", rather than a "thing" (2009, p.33).

Putting this conception of interface into conversation with sociocultural learning theory, interfaces can be considered as places of mediated activity. Mediating tools, including "social others and artifacts" (Yamagata-Lynch, 2010, p.2) can be encountered as an aspect of a digital or physical interface. From this perspective, interface could be seen as the activity that occurs at the meeting place between, "biological individual, the cultural mediational artifacts, and the culturally structured social and natural environments of which persons are a part" (Cole & Wertsch, 1997, p. 253). An interface may also be considered as a boundary, or a place where sociocultural differences between two activity systems, "give rise to discontinuities in interaction and action" (Akkerman & Bakker, 2011, p. 139).

Interface in the public library context

Applying the concept of interface to library contexts, Danish information studies scholar Björneborn (2010) developed a conceptual framework of libraries as "*integrative interfaces*" where users can interact with, "a multimodality of human, physical, and digital information resources" (2010, p.143). These three types of information resources support each other as parts of a whole, necessitating the consideration of design across all of the "contact surfaces" a library patron might interact with (Björneborn, 2010, p.144). Specifically, the framework was developed to examine design dimensions that facilitate exploratory (unplanned) information seeking behaviors in library patrons.

Interface as a conceptual framework to inform analysis

Using a socio-cultural lens and drawing on Galloway's conception of interface, I propose an expansion of Björneborn's framework for a power-focused analysis of diverse forms of learning and knowledge acquisition in libraries. Below, I detail how an expansion of this framework might be understood and operationalized.

Based on Galloway's conception, interface is understood as occurring in digital and physical space through encounters with elements of the space or social interactions in the space (what Björneborn (2010) would call “contact surfaces”). Physical “contact surfaces” of the library could include architectural elements, spatial arrangement, and mediating tools such as a book, or a soldering iron in a Makerspace. Digital “contact surfaces” might include the contents and architecture of a library’s Facebook page or website, a digital cataloguing system, or other digital tools. Interfaces tend to be nested, and can be encountered sequentially or simultaneously. Elements of digital space are always encountered *in* physical space, whether in the library, the home, or elsewhere. Social interactions are understood as crossing both physical and digital space.

Looking at the boundaries that occur at interfaces allows for analysis that illuminates issues of equity and access. Boundaries encountered at interfaces can be considered as material or sociocultural, and may be permeable or impermeable. Aspects of the design or social arrangement of learning spaces encountered at interface can allow or disallow participation.

One example of boundaries in action can be seen in the institution of airport-style security checks at Millennium public library in Winnipeg. A study conducted by Millennium for All, a group of concerned community members, found that the screening policy was discriminatory and blocked access to information and shelter for those who relied on those resources most (Selman et al., 2019). As they interfaced with security guards, the threshold of the library became an impermeable boundary for members of the public who’s racial, gender, or class identities made them vulnerable to a culture of surveillance due to experiences of excessive policing or trauma. The interfaces they encountered at the entrance of the public library was not a portal, but a barrier to accessing nested interfaces inside the library that could lead to learning and a sense of safety.

Affordances and possibilities

Conceptualizing interface affords analyzing how institutional power shapes learning experiences through social interactions and as a function of the arrangement of digital and physical space. While libraries are public spaces, they are not necessarily equitable or equally accessible. Public spaces are often contested sites between neoliberal interests and non-dominant communities (Córtez & Gutiérrez, 2019), and racial bias and structural oppression is equally present in the digital landscape (e.g. Noble, 2018).

While the frame of interface can illuminate barriers to participation, it can also surface characteristics of library interfaces that open participation, and facilitate community connection and collaborative learning. It can serve to highlight the agentic moves participants make through their encounters with interfaces, including subversions of the intended usage of a particular tool or design.

The interface frame also has the ability to work across Learning Sciences and Library and Information Sciences. There has been increased interest in bridging the disciplines, (Lee & Phillips, 2018) which may have different ways of understanding the activity in libraries. The framework also necessitates deep engagement with the library context. This is significant, as many LS studies of learning programs in libraries, have treated the library context as incidental to the program being implemented there.

References

Akkerman, S. F., & Bakker, A. (2011). Boundary Crossing and Boundary Objects. *Review of Educational Research*, *81*(2), 132–169. https://doi.org/10.3102/0034654311404435

Björneborn, L. (2010). Design Dimensions Enabling Divergent Behaviour across Physical, Digital, and Social Library Interfaces. In T. Ploug, P. Hasle, & H. Oinas-Kukkonen (Eds.), *Persuasive Technology* (pp. 143–149). Springer Berlin Heidelberg.

Cole, M., & Wertsch, J.V. (1997.). Beyond the Individual-Social Antinomy in Discussions of Piaget and Vygotsky. *Human Development, 39*(5), 250-25*6.*

Córtez, A., & Gutiérrez, K. D. (2019). Socio-spatial repertoires as tools for resistance and expansive literacies. *Transforming Schooling for Second Language Learners: Theoretical Insights, Policies, Pedagogies, and Practices*, 123-142.

Galloway. (2009). The Unworkable Interface. *New Literary History*, *39*(4), 931–955.

Ito, M., & Martin, C. (2013). Connected learning and the future of libraries. *Young Adult Library Services*, 12(1), 29–32.

Klinenberg, E. (2018). Palaces for the people: How social infrastructure can help fight inequality, polarization, and the decline of civic life. Broadway Books.

Lee, V. R., & Phillips, A. L. (2018). *Reconceptualizing Libraries: Perspectives from the Information and Learning Sciences*. Routledge.

Noble, S. U. (2018). *Algorithms of oppression: How search engines reinforce racism*. nyu Press.

Selman, B., Curnow, J., Dobchuk-Land, B., Cooper, S., Samson, J. K., & Kohan, A. (2019). *Millennium for All Alternative Report on Public Library Security* (p. 66). https://osf.io/preprints/lissa/vfu6h/

Yamagata-Lynch, L. C. (2010). *Activity Systems Analysis Methods*. Springer US.

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Anything But Race: Race-Evasion and Color-Blindness in Preservice Teachers' Responses to a Hypothetical Scenario

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Abstract: This paper contributes to the literature challenging color-blind racism in teacher education by presenting findings from a study involving elementary preservice teachers responding to a hypothetical teaching scenario about race. Framed by theoretical perspectives on race-evasive teacher identity studies and color-blind racism, our findings reveal four typical response components—*apologize*, *explain*, *solve*, and *appreciate*. We describe each component and explain how all four can serve to evade race and hide/reproduce color-blind racism.

Background and research purposes

What do elementary preservice teachers (PSTs) know about race and how it influences classroom teaching and learning? What assumptions or previous understandings do PSTs bring to bear to make sense of and address racial situations they might encounter in future teaching? How do we build on—and possibly confront—their prior knowledge? These are the thematic questions that guide our work as teacher educators and researchers as we consider our responsibilities in preparing teachers for diverse classrooms.

The work reported here is part of a larger project improving our home institution's elementary teacher licensure program. One of the broader aims is to incorporate social justice content and learning activities PSTs can engage across their program coursework. To pursue this aim, our signature methodology involves designing and empirically evaluating the use of *hypothetical teaching scenarios* to support teachers learning about diversity, inclusion, and justice in elementary education. This study analyzes a subset of data involving PSTs discussing a scenario in which a 5th-grade student reports a racial grievance (Figure 1). In small groups, the PSTs discussed how they would respond to the grievance and confront their potential racism and biases.

Responding to Student Grievance

Imagine you are teaching a 5th grade class. A student asks to talk with you privately and you agree to meet with them. They start the conversation as following:

Student: **"I don't know how to say this, but... it seems like you only call on the same three white students to show their work at the board. And I have my hand up too! But you never call on me... What's up with that?"**

How would you respond? Please write the next one or two lines of dialogue for what you might say or do.

Figure 1. "Responding to Student Grievance."

Critical whiteness studies, color-blindness, and race evasion in teacher Ed.

Critical Whiteness Studies in education is the broader paradigm in which this study is situated, wherein the theoretical and analytic foci are shifted away from the experiences and achievements of students of color to *Whiteness*. Whiteness is comprised of ideological as well as material forms of racial privilege and advantages for the dominant racial group (Gillborn, 2005; Leonardo, 2013), that is, for people who are born white. Additionally, scholars argue that Whiteness goes "undetected and proceeds as part of normalcy and racial common sense" (Leonardo, 2013, p. 93) in large part through the racial ideology of *color-blindness*.

How can teachers' perceptions be considered racist if there is no direct discourse about race? For this paper, we focus on one of Bonilla-Silva's conceptual tools for analyzing *color-blindness* and how it becomes re/produced in interaction. *Anything But Race* (ABR) is a rhetorical strategy that "allows whites to explain away racial fractures in their color-blind story" (Bonilla-Silva, 2018, p. 86). The overwhelming majority of participants in our study dismissed race as a relevant aspect of the scenario. "[W]hites explain the product of racialized life (segregated neighborhoods, schools, and friendship networks) as nonracial outcomes and rely on the available stylistic elements of color blindness to produce such accounts" (Bonilla-Silva, 2018, pg. 87). This study demonstrates how our PST participants, as a group, employed ABR as a means of making sense of the scenario.

The university and licensure program where we teach and do research is a predominately White-serving institution. There is incontrovertible evidence that, absent any racial awareness or a capacity to engage in race dialogue, White preservice and in-service teachers tend to evade, deny, or minimize the salience of race in classroom teaching and learning (Jupp et al., 2019). Previous research also highlights the challenges teacher educators face as they attempt to inform White teachers' racial understandings and promote race-visible teaching (Hambacher & Ginn, 2020). This study contributes to ongoing efforts in social justice-oriented teacher education and builds on previous research by providing clear and detailed descriptions of preservice teachers' racial sense-making during collaborative engagement with a hypothetical teaching scenario.

Summary of data, findings, and discussion

We analyzed PSTs' written responses and rhetorical moves during small group dialogue. Our main findings reveal a pattern of interpretation across all groups (14 groups; N=46) that reproduces color-blind racism. Furthermore, we have discerned four typical response components from our data—*apologize*, *explain*, *solve*, and *appreciate* (Gutiérrez et al., 2020). Here we argue that the different components serve the same functions, to evade race and reproduce color-blind racism; this paper discusses how each component does so in its own way and how the four combine and work together to explain the racial grievance as "anything but race" (Bonilla-Silva, 2018).

While typical explanations (e.g., "it was an accident"; "I try to choose a variety of students and he might be seeing it wrong"; or "I call on students who raise their hand first") expressly evade race, indirect apologies (e.g., "I'm sorry you feel that way") provide auxiliary support to the race-evasions and carry out the emotive work of color-blindness. Often, apologies came first, before an explanation. We speculate that apologies do the initial work of distancing PSTs from the scenario and begin to undermine the student's claim that a racial disparity has occurred. Some of the groups stated that teachers have to address the situation and (pseudo) apologize to control the situation and move past it. All 14 group conversations reflect an interaction in which PSTs pushed for a color-blind interpretation of the scenarios. Some groups did this implicitly by NOT mentioning race, smoothly and quickly shifting the conversation away from race, and proposing a typical four-component response. Here is a representative example: "This is hard for me to answer, because I know as a pre-service student NOT to only chose the same students to answer {*explain*}. In this situation, I would apologize to the student {*apologize*} and let them know that I appreciate their responses/help {*appreciate*} and promise to call on him more {*solve*}."

In summary, the evasions we observe in our data are performed as an attempt to absolve and excuse PSTs from doing the work of race (Rosenberg, 2004). These evasions also allow PSTs to furnish responses to the student's grievance—i.e., to "*solve* the complaint"—in ways that they perceive are good teaching practices, such as using a random generator to call names, eliciting input from the child, and so forth. However, we maintain that these race-evasive moves, reflected in all the groups, do not challenge racial discrimination or bias and therefore perpetuate it in the everyday practices of classroom teaching and learning. To remove race from the scenario, a PST needs to believe that racial bias is impossible, the teacher plays zero role in discrimination, and, as a consequence, the classroom opportunities they will provide in future teaching will be the same for "all students" so long as they "just do popsicle sticks" and "make sure everyone's participating." All this reinforces racial inequality in education.

References

Bonilla-Silva, E. (2018). Racism without racists. Rowman & Littlefield.

Gillborn, D. (2005). Education policy as an act of white supremacy. *Journal of Education Policy*, 20(4), 485–505.

Gutiérrez, J.F., Dobie, T., Greenberg, K., Francom, R., & Barth-Cohen, L. (2020). Examining preservice teachers' written responses to a hypothetical classroom scenario involving race. In M. Gresalfi & I.S. Horn (Eds.), *"The Interdisciplinarity of the Learning Sciences." Proceedings of the 14th International Conference of the Learning Sciences (ICLS 2020)* (Vol. 4, pp. 2325-2328). Nashville, TN: Vanderbilt University / ISLS.

Hambacher, E., & Ginn, K. (2020). Race-visible teacher education: A review of the literature from 2002 to 2018. *Journal of Teacher Education*, 0(00), 1–13. https://doi.org/10.1177/0022487120948045

Jupp, J. C., Leckie, A., Cabrera, N. L., & Utt, J. (2019). Race-evasive White teacher identity studies 1990-2015: What can we learn from 25 years of research? *Teachers College Record*, 121(2), 1–58.

Leonardo, Z. (2013). Race frameworks: A multidimensional theory of racism and education. T.C.P.

Rosenberg, P. M. (2004). Color Blindness in teacher education. In M. Fine, L. Weis, L. P. Pruitt, & A. Burns (Eds.), Off white: Readings on power, privilege, and resistance (2nd ed., pp. 257–272). Routledge.

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Teachers as Learners in Research Practice Partnerships: A Design Narrative of a Social Design Experiment for Maker-based Learning

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Abstract: This paper offers a comparison of three distinct logics applied to both teacher learning and to modes of research practice partnerships. Further, this paper puts these modes of partnering in conversation with one another, to reveal that in fact, research practice partnerships and participatory design-based partnerships often rely on teacher learning, or change in practice, as an essential component, though this fact is only foregrounded in one mode of partnership: social design experimentation. Keywords: Teachers-as-learners, maker-based learning, social design experimentation, research-practice partnerships

Introduction

When it comes to teachers-as-learners (Russ, Sherin, & Sherin, 2015; Walkoe & Luna, 2019), there is much left to know, despite the fact that entire fields of educational scholarship (like Educational Leadership, Teacher Education, for instance) take the definition of teacher learning as settled knowledge. However, critical theorists point out that "teachers" and "learners" occupy constructed identities which enable schooling to perpetuate the social status quo (Apple, 1985; Bernstein, 1977; Bourdieu, 1984); indeed, the binary identity of teacher vs. learner is unnatural. Therefore, if learning scientists take seriously that learning happens outside of formal structures and recognition via social participation (e.g. Lave & Wenger, 1991; Rogoff, 2003), it stands to reason that teaching does as well. Still, scholars struggle to conceive of teachers-as-learners beyond explicit pedagogical training environments (Russ, Sherin & Sherin, 2015) Teacher learning is often a mechanism of change in RPPs. In this context, epistemological orientations which impact RPP design vary according to the following question: 1) Is the purpose of educator learning to afford systemic coherence, systemic disruption, or some combination of both? 2) What counts as relevant learning for educators? 3) Who counts as a teacher in discussions of teacher learning?

Theoretical analysis: Teachers-as-learners and RPP design methodology

In this brief analysis, I take up the high-level epistemological tensions that arise from differing beliefs about educators and learning produced by three different fields: educational leadership, teacher education, and learning in informal institutions. To be clear, while this analysis draws upon these fields for information, it is not exhaustive.

Tension #1: Educator Learning as Means to Coherence vs. Educator Learning as a Means to Disruption

Teachers-as-Learners: A high level look at the fields of educational leadership, teacher education, and informal learning reveals a discrepancy around the overall goal: is the purpose of educator learning to generate coherence around a central goal or is the goal of educator learning to produce disruption? For instance, in Educational Leadership, the goal of educator learning is ultimately systemic coherence, though educator learning is recognized as a mechanism for iteration upon systems of schooling.While critics might attack this approach as insufficiently responsive to local, or bottom-up, innovation, proponents argue that systematized dynamics of inequity require systematized corrections (Ladson-Billings and Tate, 1995). The field of Teacher Education responds to the notion of teachers as middle managers differently: since educators convene power through praxis, in addition to their role within the system of schooling, their learning process, identity, and goals ought to provide the foundation for systemic change improvement. Informal learning institutions are caught between systemic coherence and disruption, because on the one hand, they view themselves as part of a wider learning ecology, but on the other, the reality of informal learning institutions is that they are working toward curricular collaboration with formal institutions. When it comes to informal educator professional learning, museums and libraries see their job as supplementing learning taking place in formal schools (Allen & Crowley, 2017; Brahms & Crowley, 2016). *RPPs*: This tension is most obvious in the difference between participatory design partnerships (Bang & Vossoughi, 2016), including social design experiments (Gutierrez & Vossoughi, 2010), and more top-down, organizationally-dependent models of partnering, like design-based implementation research (DBIR) (Penuel & Fishman, 2012). Though both social design experimentation and DBIR rely upon teacher learning as a change mechanism, they diverge when it comes to systemic coherence vs. disruption.

Tension #2: Educator Learning as Discovery vs. Educator Learning as Transmission

Teachers-as-learners: Russ, Sherin, & Sherin (2015) take up the question of what constitutes educator learning by categorizing the types of knowledge or skill acquisition that have been proposed as constitutive of teacher learning. In other words, this scholarship seeks to understand what educational scholars are talking about when they mention teacher learning. Their review proposes three different conceptualizations teacher learning: process-product (where teacher knowledge is constituted by individual strategy development), cognitive modeling (where teacher knowledge follows a predictable trajectory that increases in complexity throughout a career), and a situative/sociocultural approach (where teacher knowledge is constituted by situated social interaction). While it is generally unwise to amplify one argument about teacher learning as the truth, the analytical work presented by Russ, Sherin, & Sherin provides a useful "object to think with". *RPPs:* The complexity of this belief cannot be overstated, nor can the effect of one's epistemological orientation regarding knowledge about educators-as-learners for the design of educator learning environments. In the design of RPPs for teacher learning, one's stance on this issue determines whether teachers co-design, or receive, learning.

Tension #3: Educator Identity

Teachers-as-learners: The last tension concerns how one identifies and designates individuals as educators, and further, how educators identify and designate themselves. Given the fact that teaching and learning activities occur outside of formal and informal learning environments as everyday processes of adaptation and participation (Rogoff, 2003; Rogoff and Gutierrez, 2003), it stands to reason that all humans learn and teach throughout the course of participation in social communities. Still, anyone who has ever had a bad teacher in school understands that being a professional Teacher in formal and informal spaces requires specialized skills that transcend content knowledge. This assertion, foundational to the reasons university-based Teacher Education programs exist, is often mobilized in fights related to labor relations for formal Teachers.

There are few opportunities for educators from informal and formal learning environments to share knowledge and expertise, perhaps due to the fact that all educator expertise is systematically devalued in the ways I've outlined. The result of this is a narrowing of "who counts" as an educator, and whose teaching is "real" or "legitimate". *RPPs*: The epistemological orientation one occupies with respect to "who counts" as an educator is crucial to the design of educator learning environments, because it indicates whose expertise and practice counts as a resource for learning.

Implications

This design narrative, combined with the theoretical framing which troubles well-worn assumptions about teacher learning, reveals the need for further research into activity-based inquiries into teacher learning. Whereas the impact of research-practice partnerships has been examined through various lenses, like social change, scalability, and sustainability, there is much to learn about the impact of design-based partnerships as learning environments themselves, for both designers and participants.

References

Apple, M. W. (1985). *Education and power*. Ark edition. Boston, Mass. : Ark Paperbacks, 1985. https://search.library.wisc.edu/catalog/999577533602121

Bang, M., & Vossoughi, S. (2016). Participatory Design Research and Educational Justice: Studying Learning and Relations Within Social Change Making. *Cognition and Instruction*, *34*(3), 173–193. https://doi.org/10.1080/07370008.2016.1181879

Bernstein, B. (2015). Sociology and the sociology of education: A brief account. In *Approaches to Sociology: An Introduction to Major Trends in British Sociology* (pp. 145–159). Taylor and Francis.

Bourdieu, P. (1984). *Distinction* (2nd ed.). Harvard University Press.

Coburn, C. E., & Penuel, W. R. (2016). Research–practice partnerships in education: Outcomes, dynamics, and open questions. *Educational Researcher*, *45*(1), 48–54. https://doi.org/10.3102/0013189X16631750

Coburn, C., Penuel, W. R., & Geil, K. E. (2013). Research-Practice Partnerships. *A Strategy for Leveraging Research for Educational Improvement in School Districts*, *January*.

Gutierrez, K. D., & Vossoughi, S. (2010). Lifting Off the Ground to Return Anew: Mediated Praxis, Transformative Learning, and Social Design Experiments. *Journal of Teacher Education*, *61*(1–2), 100–117. https://doi.org/10.1177/0022487109347877

Gutiérrez, K. D., & Jurow, A. S. (2016). Social design experiments: Toward equity by design. *Journal of the Learning Sciences*, *25*(4). https://doi.org/10.1080/10508406.2016.1204548

Ladson-billings, G., & Tate IV, W. (1995). Toward a Critical Race Theory of Education. *Teachers College Record*, *97*(1), 47–68.

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Learning with Purpose: Orienting Student Agency Towards Community Solidarity in a Secondary Science Curriculum

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Abstract: This study uses a framework, *learning with purpose*, to support the design and analysis of student learning opportunities in science. Researchers and practitioners developed and implemented a secondary biology unit for use across an urban district in the US wherein students engaged in a community-based citizen science design challenge. Results suggest student agency may influence how students experience and assign purpose in their learning.

Keywords: Purpose, Agency, Science Education, Reform, Curriculum

Introduction

Designing formal learning experiences that students see as relevant to their lives and the world outside the four walls of the classroom has proven an enduring challenge in science education (NRC, 2007). In the years since the advent of recent science education reforms (see NRC, 2012), researchers and developers have taken up this challenge with renewed vigor. Yet, even when using innovative instructional models (e.g., Project-Based Learning) and innovative curriculum designed to reflect reforms, meaningful science learning can remain elusive for all students (Pitts, 2008; Priester, 2020). The aim of ensuring students have learning they find meaningful in the science classroom holds particular significance for addressing inequities in science education; learning that fails to prove consequential to all students by ignoring the strengths students bring from outside the classroom serves to reproduce patterns of marginalization experienced by non-dominant students (Lee & Buxton, 2010).

Learning with purpose

Using a sociocultural perspective and ideas from cultural psychology, this study uses a framework, termed *learning with purpose*, to support the design of more meaningful schooling and its analysis. Much as how leveraging the cultural funds of knowledge students bring to the classroom can promote more meaningful and culturally-relevant learning, this framework proposes that the purposes students and their families orient towards can serve as particularly powerful cultural strengths for learning. At its core, a learning with purpose approach seeks to create opportunities for all learners to act in solidarity with and for their communities. Cross-cultural studies have shown how the act of taking initiative to "pitch in" and contribute to a group endeavor appears more prevalent in non-dominant families, such as indigenous and Latinx families (Rogoff, 2014), than in European American families. The prevalence of this practice indexes a shared purpose where individuals' activity arcs towards serving the needs of a collective or group (i.e., a community). Ladson-Billings (2000), when discussing orientations in the Black community in the US, noted how central this purpose can prove to peoples' existence, a notion well-captured in the African saying *ubuntu*: "I am because we are." To conceptualize how students can collectively engage in learning with purpose over time and at various levels (see Smith, 2020), this framework draws on Leontiev's (1978) notion of the structure of activity: learning with purpose requires students always move towards the *motive of their activity* (e.g., protect our ecosystem) through smaller *actions and goals* (e.g., find patterns with species) and yet smaller *operations* (e.g., writing notes). Lastly, learning with purpose requires students have meaningful agency in their learning. Students must have opportunities "to act (not merely to know)" (Eisenhart et al., 1996, p.282), to use their learning to do something they and their communities see as important.

Design and implementation of biology unit

To achieve an inclusive vision of science education where all students have opportunities to engage in learning with purpose—while also meeting the aims of science education reforms—proves no small design challenge, particularly at large scales (e.g., school districts). Through a co-design approach, researchers and practitioners from an urban school district in the US developed an 8-week secondary biology unit on ecosystems aligned to reforms in the US, namely the *Framework for K-12 Science Education* (*Framework*; NRC, 2012). Part of the district's official biology curriculum, researchers and teachers saw the unit as a means for all students across the district to engage in more purposeful learning. The vision of the *Framework* offers areas of convergence with a learning with purpose approach, including having students' learning orient towards a phenomenon and/or problem relevant to students' lives and communities, as well as positioning students with epistemic agency (Miller et al., 2018). The ecosystems unit employs these aspects in a way intended to blur school and community and position students with the agency to act. In response to a pressing threat (i.e., an invasive species about to eradicate trees throughout the city), the unit has students take up a citizen science design challenge. This challenge—where students can wield science *in* practice (Penuel, 2014), while acting in solidarity with and for their community—asks students to use science and engineering practices to decide what tree their class should plant and where to maintain the biodiversity and services of their ecosystem. Community members helping to enact students' solutions included the city's parks department and local non-profits. Twelve teachers from eight schools piloted the unit with approximately 975 students. Latinx students comprised around 56% of students, Black students comprised around 14% of students. One classroom, where 92% of students identified as Latinx and 5% identified as Black, served as a focus of study. Researchers used daily surveys across all schools to collect practical measures of students' experiences for each lesson. In the focus classroom, researchers conducted twelve observations as well as three interviews with two Latinx focus student (FS) participants. A mixed methods approach to analysis, including using rounds of inductive and deductive coding (Emerson et al., 2011), focused on ascertaining (1) whether students experienced learning with purpose and (2) how the unit mediated such experiences.

Results and discussion/conclusion

Students' survey responses across all classrooms indicate that, on average, they saw their learning in the unit as relevant to the community (64%) but less so to their class (39%) and themselves (29%); focal students also saw their learning generally as more aligned with the community's purposes. Interestingly, when students noted on surveys that a lesson connected strongly to the citizen science design challenge, these responses showed a moderate correlation to students reporting their learning as relevant to themselves ($r(1222) = 0.32$, $p<.001$) and to a slight degree their class ($r(1222) = 0.14$, $p<.05$) but not to the community; data from focal students followed this pattern (e.g., "I don't think they'd [community] want to stop and ask why we're planting a tree," FS). Interview data from focal students also indicated that students felt more agency when working on the citizen science design challenge—both in terms of *actions* (e.g., using science and engineering practices) and the *motive for their activity* (e.g., planting a tree to help ecosystem: "…we provided this research, it should be like brought into like action, like how we're doing planting the tree," FS). These patterns suggest that the agency students experienced may have influenced how they saw and assigned purpose in their learning. With more agency, students associated purpose in their learning with more proximal communities (personal and class) than a more distant "community." This work demonstrates the challenges and promise of designing formal curriculum to promote learning with purpose. Future curriculum designs should continue to explore the interplay of purpose, agency, and community.

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References

Eisenhart, M., Finkel, E., & Marion, S.F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal*, *33*(2), 261-295.

Emerson, R.M., Fretz, R.I., & Shaw, L.L. (2011). *Writing ethnographic fieldnotes*. University of Chicago Press.

Ladson-Billings, G. (2000). Racialized discourses and ethnic epistemologies. In N.K. Denzin & Y.S. Lincoln (Eds.), *Handbook of qualitative research* (2nd ed., pp. 257-277). Sage.

Lee, O., & Buxton, C.A. (2010). *Diversity and equity in science education: Research, policy, and practice*. Teachers College Press.

Leontiev, A.N. (1978). *Activity, consciousness, and personality*. Prentice Hall.

Miller, E., Manz, E., Russ, R., Stroupe, D., & Berland, L. (2018). Addressing the epistemic elephant in the room: Epistemic agency and the NGSS. *Journal of Research in Science Teaching*, 55(7), 1053-1075.

National Research Council. (2012). *A Framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press.

Penuel, W.R. (2014). Studying science and engineering learning in practice. *Cultural Studies of Science Education*, 11(1), 89–104.

Pitts, V.M. (2006). Do students buy in? A study of goal and role adoption by students in project-based curricula. (doctoral dissertation), Northwestern University.

Priester, J.L. (2020). Next Generation Science Standards aligned curriculum's impact on students' academic scores and attitude towards science. (doctoral dissertation), Liberty University.

Rogoff, B. (2014). Learning by observing and pitching in to family and community endeavors: An orientation. *Human Development*, 57(2-3), 69-81.

Smith, J. (2020, May 29). *Purpose as a nested structure* [Flash Talk]. New Gen Learning, UC Santa Cruz.

Using Augmented Reality for Biology Learning in High School: A Quasi-Experiment Study

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Abstract: A quasi-experiment was conducted to explore high school students' perception of Augmented Reality (AR) in biology learning and examine the impact of AR utilization on their academic emotion. The findings indicate students' general willingness to use AR applications and confirmed the capacity of AR in stimulating positive emotions towards the subject. This suggested that AR can be leveraged to sustain students' positive academic emotion and engagement in science education.

Introduction

Augmented Reality (AR) refers to a combination of technologies which overlays computer-generated content into the real world (Azuma, 1997). AR-facilitated learning was generally found beneficial for enhancing learning experience across the affective, behavioral and cognitive domains (Akçayir & Akçayir, 2017). In the affective domain, the impact of AR on academic emotions, i.e. emotions associated to learning, is yet to be measured comprehensively. Therefore, a preliminary quasi-experiment study was conducted to explore high school students' perception of AR in biology learning and examine the extent to which AR utilization affects their academic emotion. The findings contribute to the literature by providing empirical evidence on the impact of AR on academic emotions and will also be helpful for informing enhancement of AR applications in learning.

Research methods

The quasi-experiment was conducted in a high school in Southern China. Two Grade-11 classes having no prior experience with AR learning materials participated respectively as the experimental group and the control group. When this study was conducted, they had finished the standard high school curriculum for biology and were preparing for the National University Entrance Examination to be held at the end of Grade 12. The two groups had a lesson that reviewed cell structures. Students of the experimental group were invited to use a 3D vision-based AR learning material in the lesson where they were given a demonstration and a 30-minute usage in groups of four with technical assistance available. They could continue using it at home during the week after.

To understand students' perception of AR, a questionnaire survey was conducted in the experimental group one week after the lesson. The students were asked to report frequency of their after-class usage of the AR material and rate on a 5-point Likert scale their level of satisfaction towards it and experience of sensory immersion. The questionnaire items were adapted from those proposed and verified in Han, Jo, Hyun, and So's study (2015). To measure the impact of AR on academic emotion systematically, two questionnaires adapted from the Achievement Emotions Questionnaire (AEQ) (Pekrun, Goetz, Titz, & Perry, 2002) were administered one week before and after the lesson. The AEQ measures nine discrete emotions (i.e. enjoyment, hope, pride, anger, anxiety, shame, relief, hopelessness and boredom) in three types of academic achievement situations: class-related (triggered while attending lessons), study-related (towards the course or subject), and test-related (towards tests and exams). Focusing on the teaching and learning process, this study examined class- and study-related emotions.

Post-lesson focus-group interviews were conducted. Five sub-groups were selected on a random basis respectively from the two groups. In each interview, students were asked to discuss their perception of the lesson and the subject of biology. Students of the experimental group also discussed their perception of AR learning.

Findings

103 students participated in this study. Valid sets of questionnaires were collected from 88 students, among which 47 students were in the experimental group (26 males and 21 females) and 41 were in the control group (22 males and 19 females). 70.3% of the surveyed students (33 out of 47) in the experimental group reported that they had used the AR material at home. Among them, 11 (23.4%) used it more than once. A median of 3.00 or above was obtained across items, indicating that students were satisfied with the AR learning experience.

To measure the impact of AR on academic emotions, sufficient internal consistency for each emotion construct was confirmed using Cronbach's alpha ($\alpha \geq .690$) (George & Mallery, 2003). A Mann-Whitney U test per emotion was conducted on responses to the pre-questionnaire. The results indicate no significant emotional differences between the groups before the lesson except for study-related hope (p = .001). Therefore, a Mann-

Whitney U test was conducted within each group to compare the ratings on study-related hope before and after the lesson. For other constructs, a post-questionnaire Mann-Whitney U test was conducted per construct to compare the two groups' ratings. The results indicated that students in the experimental group tended to be more positive towards the lesson than their peers in the control group. After the lesson, their ratings of enjoyment (p = .000), pride (p = .006), and hope (p = .000)) were significantly higher than those of students in the control group while those of anger (p = .006) were significantly lower. Their ratings of boredom (p =.055) and hopelessness (p = .075) were also lower than those from students in the control group though at the p = .10 level. As for study (i.e., subject)-related emotions, the findings indicate that AR did not make a significant impact on students' emotion towards the subject (biology) except for enjoyment (p = .05).

Findings from the focus group interviews align with the statistical findings. The perceived novelty of the AR material was found to be a stimulus of positive academic emotions and motivated the usage. Students also tended to find the opportunities of exploration in 3D space helpful for their understanding of the content concerned, making them enjoy the lesson and feeling interested and engaged. It was, however, noted that the technical requirement (both hardware and soft skills) for using AR might have possibly discouraged usage.

Implications and future work

This study confirmed the affordances of AR in helping students understand things that may not be easily seen or not at all present in the real world (Hughes, Fuchs, & Nannipieri, 2011). It found that the use of AR in learning tended to increase positive academic emotions and reduce negative ones, which was partially due to the perceived novelty of the technology (cf. Huang, Chen, & Chou, 2016). It also found that the impact of AR on class-related emotion was more obvious than on study-related emotions. This is possibly because the intervention was implemented as a single instance while belief and attitude tend to change in a slow process (Haberman, 1991). All in all, these findings suggested that user-friendly AR materials can help develop learning interest and sustain learning engagement in science education.

Distinguished by its systematic approach to academic emotion, this preliminary study is a starting point of further research on AR-facilitated learning and its affective effects. First, the intervention of this study was one AR material and one lesson followed by a week of after-class usage. The research design in subsequent studies will be extended with more AR materials and/or longer learner-material contact time to validate the findings. This will also provide an optimized setting to study the relationships between AR utilization, academic emotions, and learning performance. Second, the context of this study was a mixture of formal learning and self-study. User experiments could be conducted to test AR utilization in different learning settings. Third, this study used self-report to collect emotion data, which may lead to concerns of subjective bias. Sensor technology will be considered for psychophysical data collection in subsequent studies to reinforce the reliability of the findings.

References

Akçayır, M. & Akçayır, G. (2017). Advantages and challenges associated with augmented reality for education: A systematic review of the literature. *Educational Research Review*, *20*, 1-11.

Azuma, R. T. (1997). A survey of augmented reality. *Presence: Teleoperators & Virtual Environments*, *6*(4), 355-385.

George, D. & Mallery, P. (2003). *SPSS for Windows step by step: A simple guide and reference. 11.0 update* (4th ed.). Boston: Allyn & Bacon.

Haberman, M. (1991). Can cultural awareness be taught in teacher education programs? *Teaching Education*, *4*(1), 25-32.

Han, J., Jo, M., Hyun, E., & So, H.-J. (2015). Examining young children's perception toward augmented reality-infused dramatic play. Educational Technology Research and Development, *63*(3), 455-474.

Huang, T.-C., Chen, C.-C., & Chou, Y.-W. (2016). Animating eco-education: To see, feel, and discover in an augmented reality-based experiential learning environment. *Computers & Education*, *96*, 72-82.

Hughes, O., Fuchs, P., & Nannipieri, O. (2011). New augmented reality taxonomy. Technologies and features of augmented environments. In B. Furht (ed.), *Handbook of Augmented Reality* (pp. 47-63). New York: Springer-Verlag.

Pekrun, R., Goetz, T., Titz, W., & Perry, R. (2002). Academic emotions in students' self-regulated learning and achievement: A program of qualitative and quantitative research. *Educ Psychol*, *37*(2), 91-105.

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Fostering Students' Argumentation Skills with Game-Based Learning Method: A Systematic Review

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Abstract: This study maps instructional support and learning outcomes of game based learning on argumentation skills. This systematic review report positive effects of game based learning on learning outcomes and instructional supports on argumentation skills. However, the reviewed publications did not report specific instructional support and game elements associated to the learning outcomes. This study provide suggestions on how to design digital games for argumentation skills and learners' learning outcomes.

Keywords: game based learning, argumentation, learning outcomes, instructional support

Introduction

Learners need to learn how to generate valid arguments, reason soundly, and engage in argumentation especially in academic settings (Noroozi et al., 2012, 2016, 2018, 2020). Learning to engage in argumentation is challenging for students due to the complex, non-linear, and ill-defined nature of argumentation. This is striking since the ability to construct valid arguments and exchange them with others in reasoned debate is one of the critically important real-world skills required in the workplace and community life (Latifi et al., 2020; Noroozi, 2018). Liu, Liu, & Lin (2019) reported that most of the high school students had difficulties to engage in argumentation either in collaborative, or individual environment. Students may have difficulties in exploring relevant literatures, incorporating the data to make a generalisable claim, using evidence to back their claims, and rebut an argument in light of evidences. To cope with these challenges, educational technologists have focused on scaffolding students' argumentation. Designing Game-Based Learning (GBL) environments for fostering students' argumentation skills has recently become popular, especially with respect to scientific results for real-world applications. GBL promotes scientific argumentation (Bressler, Bodzin, & Tutwiler, 2019).

Given vast scientific support for the positive impacts of games on various aspects of the learning processes, many researchers from different disciplines are committed to developing GBL to promote students' argumentation skills. Despite various review studies in the field of GBL and their effects on various aspects of learning processes and outcomes in different disciplines such as business, marketing, math, statistics, environmental sciences, biology, and psychology (e.g., Boyle et al., 2014; Dehghanzadeh et al., 2019; Qian & Clark, 2016), no review study has yet been reported for the impacts of the GBL on promotion of students' argumentation skills. Therefore, the main aim of this review is to clarify what empirical evidence exists with regard to the effects of GBL on students' argumentation skills. Therefore, this review follows these questions:

1. Which instructional supports that influence argumentation have been investigated?
2. Which game elements that influence argumentation have been investigated?
3. Which learning outcomes that influence argumentation have been investigated?

Method

A keyword search strategy was used based on the most important concepts of the study, namely GBL, argumentation. First, we identified synonyms and related terms using Merriam-Webster's Online Thesaurus in combination with the reviews of Ke (2016) as well as Qian and Clark (2016). Then, we combined the related terms with the Boolean operators OR and the three concept areas with AND to arrive at the following search string: game* OR gamification OR GBL OR game-based learning OR serious game OR learning games OR educational game OR entertainment game OR video games OR mobile game OR digital game OR edutainment game AND argument. To identify relevant publications, a systematic search strategy was executed in the bibliographic databases such as Scopus, ERIC, and Web of Science. Various inclusion criteria were used to include the most relevant publications which resulted in 18 publications selected for this systematic review.

Results

The most commonly used instructional support for argumentation were modeling (8), interactivity (4), feedback (2), and reflection (2). The most commonly used elements for gamifying argumentation were feedback (18), challenge (9), collaboration (9). The most commonly used learning outcomes for argumentation were improving high level of argumentation skills (6), engagement (5), collaborative learning (3).

Conclusion, limitation and future research

This systematic review presents an overview of the current state of the art on the use of game based learning for argumentation in learning environments. This review intends to contribute to a growing body of knowledge on designing game based environments for argumentation skills learning. It provides interested scholars with information on how to take advantage of potential benefits of game based learning for argumentation and how to design digital environments to improve students' learning processes and their corresponding learning experiences and outcomes. These findings (Table 1) are useful to commercial game developers, because the engagement potential of a game is important for game development, with the goal of establishing a compulsion to play.

We did not report common affordances and hindrances that are inherent to game based learning for argumentation skills. Gamified environments typically provide learners with various affordances that can be used with the help of ICT tools. More research is needed to shed light on the possible affordances and hindrances that are inherent to the use of game based learning for argumentation.

References

Boyle, E.A., MacArthur, E. W., Connolly, T.M., Hainey, T., Manea, M., Karki, A., et al. (2014). A narrative literature review of games, animations and simulations to teach research methods and statistics. *Computers & Education, 74*(1), 1-14.

Bressler, D. M., Bodzin, A. M., & Tutwiler, M. S. (2019). Engaging middle school students in scientific practice with a collaborative mobile game. *Journal of Computer Assisted Learning*, *35*(2), 197-207.

Ke, F. (2016). Designing and integrating purposeful learning in game play: A systematic review. *Educational Technology Research and Development, 64*(2), 219-244.

Dehghanzadeh, H., Fardanesh, H., Hatami, J., Talaee, E., Noroozi, O. (2019). Using gamification to support learning English as a second language: A systematic review. Computer Assisted Language Learning. https://doi.org/10.1080/09588221.2019.1648298.

Latifi, S., Noroozi, O., & Talaee, E. (2020). Worked example or scripting? Fostering students' online argumentative peer feedback, essay writing and learning. Interactive Learning Environments, 1-15. https://doi.org/10.1080/10494820.2020.1799032.

Liu, Q. T., Liu, B. W., & Lin, Y. R. (2019). The influence of prior knowledge and collaborative online learning environment on students' argumentation in descriptive and theoretical scientific concept. *International Journal of Science Education*, *41*(2), 165-187.

Noroozi, O. (2018). Considering students' epistemic beliefs to facilitate their argumentative discourse and attitudinal change with a digital dialogue game. Innovations in Education and Teaching International, 55(3), 357-365.

Noroozi, O., Dehghanzadeh, H., & Talaee, E. (2020). A systematic review on the impacts of game-based learning on argumentation skills. Entertainment Computing, 100369.

Noroozi, O., Kirschner, P.A., Biemans, H.J.A., & Mulder, M. (2018). Promoting argumentation competence: Extending from first- to second-order scaffolding through adaptive fading. Educational Psychology Review, 30(1), 153-176.

Noroozi, O., McAlister, S., & Mulder, M. (2016). Impacts of a digital dialogue game and epistemic beliefs on argumentative discourse and willingness to argue. *The International Review of Research in Open and Distributed Learning, 17*(3).

Noroozi, O., Weinberger, A., Biemans, H.J.A., Mulder, M., & Chizari, M. (2012). Argumentation-based computer supported collaborative learning (ABCSCL). A systematic review and synthesis of fifteen years of research. *Educational Research Review, 7*(2), 79-106.

Qian, M., Clark, K.R. (2016). Game-based Learning and 21st century skills: A review of recent research, *Computers in Human Behavior, 63*(1), 50-58.

A Learning Sciences and Organizational Behavior Framework for Analyzing how College Instructors Learn Inclusive Pedagogies

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Abstract: This study identifies mechanisms that motivate college STEM instructors to learn and adopt inclusive teaching practices. Adaptive Equity-Oriented Pedagogy (AEP) has been shown to improve student learning by over a letter grade (Phuong et al., 2017a). We use van de Sande & Greeno's (2012) perspectival frames (e.g., positional, epistemological, conceptual) to understand how instructors reflect on their values and the values of their university, discipline, and industry. We introduce an emotional frame to examine emotional schemas that promote and inhibit instructors' behavioral changes and learning. We present a conceptual framework that uses these frames to explain what motivates instructors to integrate knowledge about AEP (e.g., eliciting, adding, distinguishing, revising their ideas about pedagogy) (Linn & Elyon, 2011).

Research questions and significance

Research shows that 90% of college students leaving STEM cite poor teaching (e.g., a lack of alignment between instruction and assessment) as a primary concern (Seymour & Hewitt, 1997). High STEM attrition rates persist especially for underrepresented minority (URM) students (Sax et al., 2018). Studies show that STEM instructors applying adaptive equity-oriented pedagogy (AEP) have improved student achievement by over a letter grade (Phuong & Nguyen, 2019). AEP is defined as adapting instructional practices (e.g., productive struggle, modeling key skills, deliberate practice, providing feedback) based on student learning data (e.g., formative assessment, observations, surveys) (Phuong et al., 2017a). The AEP practice elements include 1) Clarify learning outcomes; 2) Align formative assessments with outcomes; 3) Diagnose students' competencies, interests, and equity barriers to meeting outcomes; 4) Adapt teaching based on diagnoses; 5) Iterate: Demonstrate a continuous commitment to adaptation and improvement (Phuong et al., 2017b). For this study, we explore the research question: What are the cognitive, emotional, and socio-organizational mechanisms that facilitate instructors' learning of AEP?

Conceptual framework and methods

To account for socio-organizational factors impacting instructor learning, we use van de Sande & Greeno's (2012) perspectival frames (e.g., positional, epistemological, conceptual) to understand how instructors look outward and inward to reflect on their values and the values of their university, scholarly field, and industry. We introduce an emotional frame to examine emotional schemas that impact instructors' behavioral changes and learning. We offer a conceptual framework that uses these frames to explain what motivates instructors to progress through the knowledge integration cycle of learning AEP (eliciting, adding, distinguishing, revising) (Linn & Elyon, 2011).

The **positional** (e.g., power and community) frame is defined as the content valued by the authoritative figures in the field-- do peers, the scholarly field, the industry, and those I'm serving value the AEP practice? Is there a community of practice around equity-oriented teaching? The **conceptual** (e.g., relevance) frame is defined as the concepts or ideas that one foregrounds in their mind-- is the AEP practice relevant to my teaching and goals that I am foregrounding in my mind? Are these AEP practices relevant to the course content and concepts that my organization and I prioritize? The **epistemological** (i.e., data frame) frame is defined as the kinds of knowledge and data that are important and relevant in an academic and socio-organizational culture-- do I value certain kinds of practices because they are tested using data sources and methods that are important to me or my field? The **emotional** frame is defined as the emotions that arise from engaging in a practice, experience, or reflection-- does the data from implementing these practices help me feel more valued, fulfilled, and connected to my organization and those I'm serving? Is the experience energizing me or burning me out?

We analyze written reflections from a faculty member and a student-instructor case study using the 4 frames to explain changes or lack thereof in AEP competency. We inductively and deductively coded data.

Findings

Here we present two sample analyses of a faculty member and a student-instructor. The faculty member is a white queer male and was a first-generation low-income college student. He has taught at the Computer Science department for 14 semesters or 7 years. The student-instructor, a white male, reported having about 1 year of classroom teaching experience, about 3 years of tutoring experience, and was enrolled in a pedagogy and data analysis course for first-time TAs. These case studies are important because a growing number of faculty, graduate, and undergraduate student instructors are becoming interested in inclusive teaching.

When writing about the values of the department, our analysis suggested that the faculty member relies on emotional framing. Although epistemological framing was present, emotional framing was dominant for this instructor. For instructors like the faculty in this case study who care about equity, finding data that students do not meet learning outcomes is devastating and motivational towards creating better pedagogy. These emotions motivate how the faculty member applies the AEP practice element of diagnosing student learning needs:

Faculty written reflection	*Frame*
I feel **horrible and sad** when **students are not meeting my learning outcomes** when I collect formative assessment and student feedback […] When I **collect data with AEP, I know why students are not learning based on data**. So when I feel **sad or disappointed,** the data from AEP gives me an idea of what the next step should be to adjust appropriately and improve student learning. **I don't feel hopeless and know I have a methodical AEP framework that has helped me make a difference** […] **AEP can help me impact students' emotions especially when I get feedback from students.** I use **formative assessments and student feedback loops** and this will inherently help me understand students' emotions. It's a process that can help me **build stronger relationships so that I can dynamically drive better outcomes**. Because I believe in having a growth mindset, I am always experimenting with new teaching practices, reflecting, and revising my teaching approaches […] I **love teaching more when my students love learning**. I am the happiest when this happens! [bolded for emphasis]	Emotional Epistemological Emotional Conceptual Emotional Epistemological Emotional Emotional

The student-instructor uses a positional frame to explain how authoritative figures and peers reinforce an epistemological value for data that is rooted in the Computer Science department's disciplinary culture. He acknowledges the limitations to data. And, he invokes an epistemological frame related to his discipline to highlight how he came to prioritize data-driven decision making through key concepts and skills in his discipline (e.g., "machine learning"). His thought process is echoed by the Silicon Valley community:

Student-Instructor written reflection	*Frame*
All professors I have had at Berkeley seem to be constantly **asking for feedback and information--data. TAs are always sending feedback forms, GSIs are sending out intro-surveys, mid-semester surveys,** and internal and **University surveys at the end of the semester** […] In general, Berkeley seems to be one of the **major universities in the machine learning field,** which is naturally data-heavy. This, as well as the **data frenzy within nearby Silicon Valley,** creates a **culture within the university of relying on data.** […] However, **data is not all objective**, and can have some major problems[bolded for emphasis]	Positional Epistemological Positional Epistemological Epistemological

Implications and conclusions

These case studies show that the four frames can help researchers and instructor professional developers understand cognitive, affective, and socio-organizational factors that drive instructors' motivations for learning inclusive practices. This framework is important for helping instructors reflect on their values and for instructor professional developers who want to motivate college instructors to promote inclusive teaching and student success, which are important for diversifying faces of success in academia and our workforce.

References

Linn, M. C., & Eylon, B. S. (2011). Science learning and instruction: Taking advantage of technology to promote knowledge integration. Routledge.

Phuong, A. E. & Nguyen, J. (2019). Evaluating an Adaptive Equity-Oriented Pedagogy on Student Collaboration Outcomes Through Randomized Controlled Trials. *Proceedings of 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019,* 496-503. Lyon, France: International Society of the Learning Sciences.

Phuong, A. E., Nguyen, J., & Marie, D. (2017a). Evaluating an Adaptive Equity-Oriented Pedagogy: A Study of Its Impacts in Higher Education. *Journal of Effective Teaching*, 17(2), 5-44.

Phuong, A. E., Nguyen, J., & Marie, D. (2017b). Conceptualizing an adaptive and data-driven equity-oriented pedagogy. *Transformative Dialogues: Teaching and Learning Journal*, 10(2), 1-20.

van de Sande, C. C., & Greeno, J. G. (2012). Achieving alignment of perspectival framings in problem-solving discourse. *Journal of the Learning Sciences*, 21(1), 1-44.

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Zone of Proximal Self: A Sociocultural Framework for Examining the Development of Possible Selves and Social-Emotional Competencies

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Abstract: This study introduces a conceptual framework called the zone of proximal self which conceptualizes how interactions within a higher education learning ecology support students' progress towards their possible selves and the development of both academic and social-emotional competencies. Employing a case study approach with semi-structured interviews and surveys, the study presents findings on how the zone of proximal self impacts the experiences of undergraduate computer science mentors and students at a U.S. public, research-one university on the West Coast. Findings show how feared selves highlight inequities and reveal the importance of community. Additionally, mentors' socialization impacted their mentorship practices. This framework has significance for understanding the learning mechanisms and processes of mentors, which can inform equity-oriented programs that support all students.

Conceptual framework and literature review

In higher education university settings, students' future goals become salient, and students develop their academic and social-emotional competencies in pursuit of these goals. This study introduces a zone of proximal self (ZPS) framework to contextualize how students work with others to pursue their vision for their future. The ZPS framework draws upon Lev Vygotsky's (1978) sociocultural theory of human learning which emphasizes how learning is a social process. Vygotsky (1978) described how children's learning exists within a zone of proximal development, or "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem-solving under adult guidance, or in collaboration with more capable peers" (Vygotsky, 1978, p.86). Since higher education is a time where students are thinking about future opportunities, ZPS synthesizes the zone of proximal development with possible selves, i.e., the selves that we could become, and also the selves that we are afraid of becoming (Markus & Nurius, 1986). ZPS also acknowledges how academic and social-emotional competencies are developed in a learning ecology, defined as "the set of contexts found in physical or virtual spaces that provide opportunities for learning," which in higher education can include classrooms, programs, residential/dorm spaces, and peer groups (Barron, 2006).

Research questions

To study the conceptualization of ZPS, this paper examines the following research questions within a computer science mentorship context: 1) How do computer science undergraduate student mentors and mentees frame their possible selves? and 2) How do mentors' socialization of the computer sciences field impact their own future pathways and the way they mentor different mentees?

Methods

This study employs a qualitative case study approach (Yin, 2007) to unpack examples from a real-world computer science context. Undergraduate student mentors were recruited from a computer science graduate-level teaching course. 5 undergraduate student mentors participated in the study. 14 undergraduate computer science students were recruited from a student success program. The program selects students with little to no exposure to computer science that identify as a member of one or more of the following groups: first-generation, low-income, historically underrepresented in the field (i.e., Black/African American, Chicanx/Latinx, and Native American), and/or female. Two mentors were Chinese American, one Korean American, one Japanese American, and one

Chinese Australian. Three of the mentors identified as female, while two identified as male. Of the fourteen students in the program, 71.4% were female and 64.3% were first-generation. Their race/ethnic background was 42.9% Latinx/Chicanx, 14.3% Southeast-asian, 14.3% South Asian, 14.3% East Asian, 7.1% Middle Eastern, and 7.1% White.

Five undergraduate mentors were paired with two mentees: one in the student success program and one not in the program. The mentors were not given instructions on how to mentor their respective mentees. The mentors met with their mentees for at least eight times each in a 14-week-long semester. At the semester's end, the mentors participated in a semi-structured interview virtually on Zoom about their mentorship beliefs, practices, and experiences. Students from the student success program took an online survey via Qualtrics which had a total of 26 questions with Likert-scaled and open-ended response options about their current academic and social-emotional competencies, possible selves, social networks, and future goals. The mentor interviews were audio-recorded and transcribed. To analyze the interview transcripts and survey responses, deductive and inductive thematic coding was done using a codebook with common definitions to guide a ZPS analysis (Saldana, 2015).

Findings

When describing their possible selves, students described their ideal selves in terms of their dream occupation and desire for financial stability. A topic emerged, however, within feared selves that did not come up for ideal selves: the role of social environments and communities. Students described social-related concerns including gentrification, leading a team, and familial obligations. A student in the success program wrote in the survey, "I don't want to be a gentrifier, ESPECIALLY in my community/communities like mine." Another student in the program expressed the following: "[I have concerns with] confidence in myself and nervousness during interviews/while leading a team." Similarly, in the mentor interviews, Esther and Colette (pseudonyms) expressed concerns with the support they would receive from the social environment in their future workplace. Esther described how she wanted a working environment with "no one picking on your ideas and asking questions without being ridiculed." Esther's word choice focuses on what she does not want, which sheds light on a feared possible self in relation to interactions with others. Colette also hints at similar thoughts in her interview when she says, "I don't think I'm looking for a place that's cut-throat, a lot of companies with reputations for being not so great for being working there..." The findings show how feared selves reveal stories of what students fear not only for themselves, but for their immediate family, community, and workplace culture. Feared selves reveal issues of equity within higher education STEM structures and institutions. Students' feared selves are connected to the messages they receive about computer science being cutthroat, unsupportive, and technically focused.

Based on their socialization, the undergraduate student mentors' mentorship practices varied on a spectrum of non-adaptive to adaptive academic and social-emotional practices. Academic mentorship practices focused on the development of academic competencies, such as problem solving and technical skills. Social-emotional mentorship practices are defined as those where mentors focus on the development of mentees' social-emotional competencies such as building social networks and confidence in one's strengths. The degree to which mentors adapt does not seem to be related to the quantity of interactions they have within their learning ecology; rather, it is impacted by the quality of the interactions they had with perceived legitimate figures in their field. Therefore, mentors have been culturally shaped within a zone of proximal self and actively shape the zone of proximal self for other students. This research has significant implications, including the contribution of a conceptual framework that college administrators, mentors, and faculty can use to understand FLI and URM students' experiences and development in novel ways that guide equity-oriented programs.

References

Barron, B. (2006). Interest and self-sustained learning as catalysts of development: A learning ecology perspective *Human development*, 49(4), 193-224.

Markus, H., & Nurius, P. (1986). Possible selves. *American Psychologist*, 41(9), 954-969.

Saldaña, J. (2015). The coding manual for qualitative researchers. Sage.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes (M. Cole, V. John-Steiner, S. Scribner & E. Souberman., Eds.) Cambridge, Mass.: Harvard University Press.

Yin, R. K. (2017). Case study research and applications: Design and methods. Sage publications.

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