Course Syllabus

SE 413: Engineering Design Optimization

Tuesday/Thursday 3:30-4:50 pm

Tuesdays: Synchronous Lectures | Thursdays: Synchronous Discussion Session

Location: 106B8 Engineering Hall (students in online section access lecture via MediaSpace)

Office Hours:

Instructor (Prof. James Allison): In-person, Tu 10-11 am W 3-4 pm, TB 313 | Virtual, by appointment, Zoom

[jtalliso@illinois.edu, (mailto:jtalliso@illinois.edu,) systemdesign.illinois.edu (https://systemdesign.illinois.edu/) , youtube.com/@designimpact2178] (https://www.youtube.com/@designimpact2178)

TA (Elena Fernandez): In-person, Th 11 am-noon, TB 406 [elenaf3@illinois.edu]

TA (Dhritiman Roy): In-person, Fri 3-4 pm, location TBD [dr31@illinois.edu]

Virtual Office Hour: M 5:30-6:30 pm, Zoom. Held by one of the TAs.

UIUC Course Description

Application of optimization techniques to engineering design problems. Emphasis on problem formulation, including applications in structural, mechanical, and other design domains. Important theoretical results and numerical optimization methods. Matlab programming assignments to develop software for solving nonlinear mathematical programming problems. 3 or 4 undergraduate hours. 3 or 4 graduate hours. **Prerequisites: MATH 241 and MATH 257/415.**

1-page course description: Spring 2024 (https://canvas.illinois.edu/courses/45087/files/11193362?wrap=1) (https://canvas.illinois.edu/courses/45087/files/11193362/download?download_frd=1)

Course Summary:

This course focuses on the interface between practical engineering design problems and mathematical optimization. In particular, design optimization methods are covered that apply to the design of engineering artifacts or systems that involve physical elements. Students will learn how to model engineering systems in a way that is appropriate for design optimization, formulate engineering design problems as optimization problems, and how to solve and analyze these optimization problems.

practice. This course is open to both undergraduate and graduate students. An optional intensive project can be completed for an additional credit hour (choose the 4-credit option when registering). This option is provided primarily for graduate students who are looking for a deeper experience and who need a four-credit course, but is also open to ambitious undergraduate students with deep interest in design optimization.

General Note About Course:

SE 413 is an intensive course. It involves significant mathematical depth (but is not proof-based), lengthy MATLAB programming assignments with increasing complexity, and an integrative semester project. It is **important not to get behind with topics in class**. This class is targeted specifically for senior undergraduate students, but is also an excellent practical introduction to design optimization for graduate students and practicing engineers.

While SE 413 requires significant effort, students who complete it and master the material will be in a strong position to use design optimization techniques in actual engineering practice. It encompasses not only optimization theory and algorithms, but a practical knowledge of how to formulate design optimization problems and an understanding of what to do when things go wrong with design optimization efforts.

See **this page (https://canvas.illinois.edu/courses/45087/pages/advice-for-se-413-success)** for general advice on how to be successful in SE 413.

Prerequisites:

While the only formal prerequisites are Math 241 (multivariate calculus/calculus III), Math 257/415 (linear algebra), it is important that students are able to model and analyze some type of physical engineering system to be designed. For example, students having taken basic courses in statics, dynamics, solid mechanics, or other engineering analysis domains will have the physics-based modeling background needed for this class. Quantitative analysis experience in many other domains will work equally well (e.g., electrical engineering, fluid dynamics/aerodynamics, chemistry, materials science, heat transfer, physics majors, etc.). Students interested in participating in the optional intensive course project will need to have strong background in analysis for their domain of interest so that they can rapidly construct more involved design-appropriate models (i.e., models that can predict how system behavior changes when system design is adjusted) and successfully construct and iteratively refine Engineering Design Optimization (EDO) problem formulations that accurately represent domain design intent.

MATLAB and Programming:

Many SE 413 assignments and the project will involve a significant amount of MATLAB programming. These assignments go beyond interactive command-line use of MATLAB, requiring a moderate level of

We will review the basics of MATLAB programming at the beginning of class. Elementary examples will be provided in lecture, and Chapter 2 of the SE 413 Course Notes [**EDO Allison (https://canvas.illinois.edu/courses/45087/files/11184035?wrap=1)** **(https://canvas.illinois.edu/courses/45087/files/11184035/download?download_frd=1)** , please note that updated versions will be available periodically] is a resource tailored to the needs of SE 413 students in learning MATLAB. This basic assistance is intended to help students who have programming experience in another language and need to learn MATLAB syntax and programming conventions, as well as to help students who have learned MATLAB but have not used it for some time. Students who do not have recent experience with MATLAB should plan to devote significant time early in the semester to ramping up MATLAB programming skills. In addition to completing programming assignments, you should spend time doing your own exploration and learning until you feel comfortable with basic MATLAB programming, as well as how to debug/solve coding problems, and learn on your own how to code new things as the need arises. Student feedback from previous years indicates that even if a student does not have previous experience with MATLAB programming, it is worth the investment to learn MATLAB because the available documentation, examples, and other resources help students learn how to use numerical optimization more efficiently than with Python or other candidate languages.

Students who have no programming experience at all should not take this course. Assignments in this course will start small with simple programming assignments and then will build up to implementing your own optimization algorithms and solving practical engineering design optimization problems.

Practical note regarding using MATLAB via Citrix: If you are having difficulty moving files from Citrix to your local computer, please see **this page (https://answers.uillinois.edu/illinois/page.php?id=105140)** for more information.

MATLAB Local Installation: UIUC no longer provides a free option for students to install MATLAB locally on their own computers (**MATLAB virtual application is available for free (https://webstore.illinois.edu/shop/product.aspx?zpid=4587)** to students). Given this reality, students are encouraged to consider purchasing their own **student license of MATLAB (https://www.mathworks.com/products/matlab/student.html)** so that they can install it locally on their own computers. It is similar in price to the cost of a textbook, and SE 413 does not require the purchase of a traditional textbook. If you purchase MATLAB, the MATLAB and Simulink Student Suite ($99) includes the optimization toolbox. It is recommended that you also include the Global Optimization Toolbox for an additional small fee ($10), which is required for some homework problems and can be useful for projects. **(https://answers.uillinois.edu/illinois.engineering/81693)**

Course Objectives:

The primary objective of this course is for students to gain the knowledge and creative skill required to translate practical engineering design problems into mathematical optimization problems that can be

- Demonstrate an understanding of how design optimization fits into the overall engineering design process.
- Learn how to formulate practical engineering design problems as well-posed optimization problems.
- Understand continuous optimization theory and its implications for algorithm development, problem formulation, and system modeling.
- Develop a detailed understanding of numerical methods for optimization through both theoretical development and implementation in MATLAB.

The final course grade for each student is based on how well these learning objectives have been met as assessed through quizzes, homework, exams, the semester project, and other class assignments and activities.

Textbook:

- **Required:** Engineering Design Optimization (SE 413 Course Notes, **EDO Allison, pdf available (https://canvas.illinois.edu/courses/45087/files/11184035?wrap=1) (https://canvas.illinois.edu/courses/45087/files/11184035/download?download_frd=1)** to SE 413 students)
- **Optional Additional Reference: Engineering Design Optimization (https://www.researchgate.net/publication/352413464_Engineering_Design_Optimization)** [**free pdf download (https://canvas.illinois.edu/courses/45087/files/11183981?wrap=1) (https://canvas.illinois.edu/courses/45087/files/11183981/download?download_frd=1)**] (Martins and Ning, 2021)
- **Optional Additional Reference: Principles of Optimal Design: Modeling and Computation (http://www.optimaldesign.org/)** (Third Edition, Papalambros and Wilde, 2017)
- **Optional Additional Reference: Numerical Methods for Unconstrained Optimization and Nonlinear Equations (http://epubs.siam.org/doi/book/10.1137/1.9781611971200)** (Dennis and Schnabel, 1996)
- **Optional Additional Reference: Nonlinear Programming (http://www.athenasc.com/nonlinbook.html)** (Bertsekas, 1999)

All reading assignments for each week are specified in the **Lecture Schedule Page (https://canvas.illinois.edu/courses/45087/pages/lecture-schedule-topics-links-reading-assignments)**. The assigned reading is fair game for exam questions, although exams will focus on content covered in lecture.

Lecture slides, MATLAB code, and other materials are made available either through Canvas (see the Files section) or the shared Box folder for this course (See **Lecture Schedule Page (https://canvas.illinois.edu/courses/45087/pages/lecture-schedule-topics-links-reading-assignments)** for details). Synchronous lectures will be in person. In-person lectures will be recorded and made available years are made available to students as optional supplemental resources. Recorded synchronous lectures are made available to SE 413 students through MediaSpace or Box. Some asynchronously recorded lectures are made available publicly through **YouTube (https://www.youtube.com/@designimpact2178)** . Please see the **Lecture Schedule Page (https://canvas.illinois.edu/courses/45087/pages/lecture-schedule-topics-links-reading-assignments)** for a convenient single location to find all required lecture videos and other materials.

Comment on information found within Canvas: After teaching this course for several years, student questions and other factors have led to the creation of a significant amount of insightful information within **supplementary Canvas Pages (https://canvas.illinois.edu/courses/45087/pages/useful-information-pages)** , as well as detailed discussions within homework and project deliverable assignment descriptions. Please be sure to pay attention to this content.

Grading:

The final course grade is based on how well students have met the stated course objectives. Course assessments (e.g., homework assignments and exams) aid the instructor in determining how well each students has met the course objectives.

Grade breakdown:

- Homework: 30%
- Exams: 30%
- Course Project: 25%
- Class Participation: 10%
- Quizzes: 5%

The general grading scale for an overall weighted score X is:

- 94% $\leq X \leq$ 100%: A
- 90% $\leq X <$ 94%: A-
- 87% $\leq X <$ 90%: B+
- 83% $\leq X <$ 87%: B
- 80% $\leq X <$ 83%: B-
- 77% $\leq X <$ 80%: C+
- 73% $\leq X <$ 77%: C
- 70% $\leq X <$ 73%: C-
- 67% $\leq X <$ 70%: D+
- 63% $\leq X <$ 67%: D
- 60% $\leq X <$ 63%: D-
- $X <$ 60%: F

reflect how well students met course objectives. Specifically, if implemented, a curve would only improve final student grades.

The two lowest **homework** grades will be dropped (use this opportunity wisely). Homework is due at 11:59 pm on the Friday following the week the material was covered. Please submit homework **electronically** through Canvas by the due date/time. The following policy will be applied to late homework submissions:

$<$24 hours late: 80% of unpenalized score

$\geq$24 hours, $<$48 hours late: 60% of unpenalized score

$\geq$48 hours, $<$72 hours late: 40% of unpenalized score

$\geq$72 hours late: no credit

As an example, if an assignment would have earned a score of 18 points if submitted on time, but it was submitted 30 hours late, the score awarded would be: $18 \times 0.60 = 10.8$ pts. Homework that is not submitted before the first asynchronous lecture after the due date will not be accepted. During some asynchronous lectures we will review recent homework solutions.

Two midterm **exams** will be given during class time. No final exam will be given; the semester project fills the role of an integrative assessment. Exams are open-book taken remotely without proctoring, but require students to sign an academic integrity statement before submission. While the exams are open-book, it is recommended that you compile your own set of summary notes to improve your time efficiency when working through the exams. Exam questions will focus on topics covered in class, although students are expected to know all material from the assigned reading.

Homework Submission: Submit homework **electronically through Canvas**. Please submit 1) a main answer document (pdf), and 2) supporting files (e.g., code). Please use the following instructions:

- The main answer document should be a single pdf file that contains, in order, the answers to all homework problems. You may need to form this document by concatenating multiple pdf files. Please name this file so that it is easy to identify (e.g., HWK1_Answers_NETID.pdf). The purpose of creating this file is to make it possible to grade all homework problems by viewing this single file within Canvas. Having this as a separate file (not inside a zip file) will make it possible to view using the Canvas grading utility.
- All supporting files, such as MATLAB code, should be submitted as a single zip file. Please name this file appropriately (e.g., HWK1_supporting_NETID.zip). These should be provided in a way such that, if needed, the instructor/TA/grader can replicate your results and award partial credit when appropriate. MATLAB files should be .m (or other appropriate file types, such as .mat or .p), not pdfs, so that they can be used to check your work by the grader.

- When homework assignments include programming problems, please include in the main answer document a pdf generated using the **publish** command that displays 1) appropriate headings and comments, 2) MATLAB code organized into sections to improve readability and interpretation of outputs, and 3) command line and figure output. Using Live Scripts can also be a good option for submitting MATLAB code. (See also **this page on sharing MATLAB code (https://www.mathworks.com/help/matlab/matlab_prog/publishing-matlab-code.html)**).
- Please ensure that all code is **well-commented** so that we can understand the logic of your code. Please organize these files (in subfolders if it makes sense) and name them appropriately so that it is easy to make sense of them. Within the files please make very clear what problem solutions you are presenting, especially if multiple problem solutions are contained in a single file. The instructor/grader should be able to replicate your results based on the files submitted.
- If a student persistently submits homework assignments in a format other than that described above, the homework score **may be penalized**.

Notes regarding Canvas homework submissions:

- When submitting assignments electronically through Canvas, click on the assignment in Canvas. You will then see a button to click for making your submission. You can resubmit if needed before the assignment deadline.
- Canvas allows resubmission of homework up to the homework deadline (if you need to update your submission). If your latest submission is submitted after the deadline, your assignment will be marked late by Canvas, and the late penalty described above will be applied.

Asynchronous Quizzes: Most weeks of lecture will be followed by an asynchronous quiz early the next week. These quizzes will be based on the reading assigned during the previous week and the in-person lectures delivered during the previous week. These quizzes will be taken over Canvas, will be timed, and will largely be multiple choice. These short quizzes will be due just before lecture at the beginning of the week following material coverage. The first lecture of each week will be an opportunity for students to ask questions about the quiz. Quizzes and topics are specified on the **Lecture Schedule Page (https://canvas.illinois.edu/courses/45087/pages/lecture-schedule-topics-links-reading-assignments)** .

Spring 2023 Quiz Exception Policy: In rare cases an alternative to an asynchronous quiz can be arranged for students in the in-person sections. This is intended to accommodate excused absences (see **this part of the Student Code (https://studentcode.illinois.edu/article1/part5/1-501/)** for details). The alternative assignment is to submit a 1-page typewritten summary of what you learned from the lectures during the previous week and the assigned reading. Students must make arrangements with the instructor for this alternative assignment before the synchronous lecture that will be missed, and the report must be submitted to the instructor before the corresponding quiz due date/time.

Class participation is a significant portion of the final grade. Please be sure to attend class and be

2. Instructor evaluation
3. Class activities

Some class activities (assignments) are to be completed on your own time, and some will be completed during lecture time. If any class activities during lecture time are graded (either required or extra credit), an appropriate remote activity will be provided for students in the online section. All required graded in-class activities will be announced beforehand. Some impromptu in-class activities may be held, but will be extra credit instead of required. Attending regularly and participating in unannounced activities will help your grade, but there is not a penalty for missing unannounced activities.

Software:

Course examples and assignments will make use of MATLAB, particularly the Optimization and Global Optimization toolboxes. Information on how to use MATLAB is located in Ch. 2 of the SE 413 Course Notes [**EDO Allison (https://canvas.illinois.edu/courses/45087/files/11184035?wrap=1)** **(https://canvas.illinois.edu/courses/45087/files/11184035/download?download_frd=1)**]. Term projects may be done entirely in MATLAB, or students may choose to incorporate other engineering analysis software *that they have prior experience with* into their project work. Students are discouraged from defining term projects that require learning software (other than MATLAB) that they have no prior experience with. Term projects should focus on learning EDO, as opposed to learning new software or modeling tools.

Term Project:

Students will be required to complete an integrative project as a means to tie together topics covered in class. Students must choose ahead of time one of two project options: 1) a **standard project**, or 2) an **intensive project**. Intensive project participants must register for 4 credit hours of SE 413 instead of 3. All projects *must* connect in some way to a design problem that involves a **physical engineering system**. Scheduling, queueing, supply chain, or other operations research (OR) type problems are not appropriate as a term project for this course. Projects must involve non-trivial problem formulations (explained in class in more detail, and on **this page (https://canvas.illinois.edu/courses/45087/pages/project-information)**). All standard projects **must be group projects** (2-3 students, group size should be justified, >3 requires approval). Intensive projects are also encouraged to be group projects, but individual projects are an option with instructor approval for students in the 4-credit section. With each *group* project deliverable submission, a short description of **how each group member contributed** must be included. Project group members will submit peer evaluations at midterm and at the end of the semester. Please see the **project information page (https://canvas.illinois.edu/courses/45087/pages/project-information)** for more details.

Standard projects are projects based on an engineering design application of interest to student groups. Students propose their own projects that must consist of system modeling, design space design beyond what is covered in the original problem. Students should **make this extension clear** in project proposals, as well as in subsequent project deliverables as appropriate. Individual standard projects are not permitted.

Intensive projects are available for students who desire a deeper experience with design optimization. These are primarily intended for graduate students who plan to use design optimization in their research, who are preparing for qualifying exams, or who need to increase total credit for this course to 4 credit hours. The deliverables are on the same schedule as for the standard project, but have higher expectations. Significant modeling and analysis effort outside the normal scope of the class is expected for intensive projects (e.g., finite element analysis, state-space models, or other advanced modeling tools). Students participating in the intensive project will enroll in the 4 credit hour section of SE 413 instead of the 3 credit hour section.

All students, whether participating in a standard or intensive project, should meet with the instructor or TA during office hours to discuss their project proposal before submission. Students should discuss their project progress with the instructor during office hours regularly throughout the semester. It is imperative not to get behind with project milestones, especially **construction of a successful design-appropriate model (https://canvas.illinois.edu/courses/45087/assignments/903405)** (PD3).

The **first class participation assignment (https://canvas.illinois.edu/courses/45087/assignments/903384)** will aid students in identifying potential project group members. Homework sets and exams are designed to help students be successful in term projects. The term project requires submission of several intermediate deliverables to help groups stay on track. Final project deliverables include a final comprehensive report and a recorded video presentation that will be reviewed by peers and the instructor.

Schedule Overview:

Week 1 (L1): Introduction to EDO, Design Automation, and and Algorithmic Thinking

Week 2 (L2): Optimization Solver Introduction and Mathematical Preliminaries

- HWK 1 due (MATLAB)

Week 3 (L3): Numerical Foundations for Optimization

- HWK 2 due (opt intro/mathematical preliminaries)

Week 4 (L4): EDO Problem Formulation and Analysis

- HWK 3 due (optimization numerics)

Week 5 (L5): Putting EDO Into Practice

Week 7: Exam 1

Week 8 (L7): Unconstrained Optimization Part A

Week 9: Spring Break

Week 10 (L8): Unconstrained Optimization Part B

- HWK 5 due (Unconstrained Optimization 1)

Week 11 (L9): Constrained Optimization Part A

Week 12 (L10): Constrained Optimization Part B

- HWK 6 due (Unconstrained Optimization 2)

Week 13 (L11): EDO in Practice

- HWK 7 due (Constrained Optimization 1)

Week 14: Project Work Week

Week 15: Exam Review and Project Work Week

- HWK 8 due (Constrained Optimization 2)

Week 16: Exam 2

Week 17: Final Project Deliverables

Resources for Students With Disabilities

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail **disability@illinois.edu (mailto:disability@uiuc.edu)** or go to the **DRES website (http://disability.illinois.edu/)** . If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available on campus that can help diagnosis a previously undiagnosed disability by visiting the DRES website and selecting "Sign-Up for an Academic Screening" at the bottom of the page.

If you anticipate requiring DRES accommodations at all during the semester, please **notify the instructor immediately** (beginning of the semester, not right before a homework due date or exam), and arrange to meet with him to discuss your needs. Early notification is especially important if you require out of the ordinary accommodations (e.g., something beyond extended-length, reduced