# CH EN 6400 - Foundations of Engineering Analysis
# Fall 2025

**Lectures**: TuTh 10:45 AM-12:05 PM in WEB L122
**Instructor**: Prof. Tony Saad
**Office**: MEB 2286
**E-mail**: Via Canvas
**Phone**: 801-585-0344
**Office Hours**: Tuesdays from 2:00 - 3:30 PM. Also Announced weekly or by appointment. Please come prepared with clear questions. Time limits are set for students seeking help so as to make sure everyone can get a chance to discuss their questions.

**Teaching assistant**: Michael Barkdull
**E-mail**: Via Canvas
**TA Office Hours**: TBA - (**MEB 4th Floor Conference Room**). Please come prepared with clear questions. Time limits are set for students seeking help so as to make sure everyone can get a chance to discuss their questions.

IMPORTANT NOTICE: To abide by FERPA regulations and for everyone's privacy and security, **ALL course-related communication MUST be done through canvas email**. Any other form of communication such as instant messaging or texting is not allowed.

Questions about homework assignments could either be asked in person (during office hours or help sessions) or via canvas messaging/mail (please copy both the TA and Prof. Saad).

**Prerequisites**: Basic background in mathematics, linear algebra, calculus, and differential equations.
**Catalog description**: This course is designed for students transitioning from the sciences to chemical engineering or seeking a refresher in engineering fundamentals. It provides essential mathematical and computational tools for success in advanced chemical engineering coursework. Topics include differential equations, numerical methods, vector calculus, multivariate vector fields, and foundational transport concepts. Emphasis is placed on solving and interpreting chemical engineering problems such as continuous stirred-tank reactors (CSTRs), unit operations, reaction kinetics, and transport phenomena involving advection, diffusion, and reaction systems, using both analytical and numerical techniques.

## COVID-19 and other illnesses

This is an in-person class. If you are feeling ill for any reason **you are strongly advised to stay home and watch the recorded lectures**. Because some colleagues and students might have special situations (such as immunocompromised, caring for elderly, etc…), please report any COVID-19 exposure as needed.

# Lectures

Because of the nature of how this class is taught, it is very difficult to live-stream the lectures over zoom or youtube. Therefore, ***it is preferred to attend class in person***. For those who registered for this class for remote study, please make sure that you watch the lectures as soon as they are uploaded. All lectures will be recorded and posted on Prof. Saad's YouTube Channel.
You can access those on Prof. Saad's youtube channel:
ProfessorSaadExplains
**Subscribe to Professor Saad's YouTube Channel**
(www.youtube.com/ProfessorSaadExplains)

# Grading

Assignments: 35%
Projects: 35%
Exam(s): 30%

Grades will be assigned on the following scale, normalized to the highest student in the class (who, by definition, is 100%):
92< A ≤ 100, 89 < A- ≤ 92
86 < B+ ≤ 89, 81 < B ≤ 86, 78 < B- ≤ 81
75 < C+ ≤ 78, 70 < C ≤ 75, 67 < C- ≤ 70
64 < D+ ≤ 67, 59 < D ≤ 64, 56 < D- ≤ 59
E ≤ 56
I reserve the right to adjust this scale downward if I deem it necessary. Note: I do not curve grades in this course. It is theoretically possible for everyone in the class to get an A (or an F). Your performance depends only on how you do, not on how everyone else in the class does. It is therefore in your best interests to (1) do well on your own, and (2) help your classmates within the limits of the academic integrity policy. I also reserve the right to adjust (boost) your final grade in a way that reflects your participation in class, progress throughout the course, creativity in answering questions, etc...

# Textbooks

NO TEXTBOOK is required. Material is adopted from various resources and from Prof. Saad's other courses.

### *Reading Assignments*

Suggested reading will be provided as needed.

### *Other Resources*

I highly recommend watching the following videos available on YouTube

1. Prof. Saad's Numerical Methods course

# Projects (tentative)

We will have two to three projects and you have one to two weeks to complete a project depending on its complexity. Projects will be assigned in conjunction with homework assignments.

- Project 1 will be assigned at the end of Part 1 (week of 9/8).
- Project 2 will be assigned by the end of part 2 (week of 9/29).

- A final project might substitute for the final exam.

# Exams

We will hold one or two exams (including the final), depending on how much material is covered. A final project might substitute a final exam.

### *Midterm Examinations*

A midterm exam will likely cover part 3 of the course

### *Final Examination*

**If there is a final exam, it will be on <u>Thursday, December 11, 2025 10:30 am – 12:30 pm</u>** in the regularly scheduled classroom. The final will be a comprehensive closed-book, closed-notes examination. During the final, you are allowed to have 2 letter-size, double-sided, hand-written summary sheets prepared by you. I will also give you equations copied from Wilkes with the exam.

# Homework

Up to ten assignments. Homework assignments can be either typeset using LaTeX, Word, or any other software of your choice or handwritten. If your typeset reports include graphical illustrations, they may be created using appropriate software or drawn by hand, scanned, and included in the report. All reports (typeset or not) must be turned in electronically, through Canvas. If your assignment is handwritten, the writing must be readable and clear. Homework is **assigned on Thursdays** and is **due Thursday a week later** at **midnight**. Submissions after the deadline will cause a 25% daily penalty. NO EXCEPTIONS. Those with formal CDS forms are provided extensions as needed and no more than three days. If you need to request an extension due to extenuating circumstances, you must discuss this with Prof. Saad immediately and no later than 3 days after the homework is assigned. You are allowed up to two courtesy extensions in total.
Assignments will receive **some partial credit** (see below). Homework will be graded if you get the answer correct. Questions will rarely depend on the result from a previous question or they will be framed in such a way that you can assume that you have the result.

### *Late policy*

- 25% penalty, up to 1 d late
- 50% penalty, 1-2 d late
- 75 % penalty, 2-3 d late
- 100% penalty (no credit), 3+ d late

# Contesting your grade

You have **three days** from the date that your homework or exam grade is released to contest your grade. You must open a case by sending an email to me and the TA via canvas and provide sufficient and adequate documentation as to why you are contesting your grade.

### *Partial Credit*

Homework assignments will **receive some partial credit** according to the following policy:

- Method correct, no errors: 100%
- Method correct, but contains arithmetic or minor errors: -20% per error. For example, you had a typo in one of the factors although your formula is correct.
- Solution contains a minor theoretical error: -40% per error. For example: in calculating the sample-based standard deviation you used n instead of n -1 in the denominator. This is a minor theory error.
- All other errors will result in no credit for the question.

For exams, **<u>adequate partial credit will be given</u>**.

# Learning Objectives
After completing this course (CH EN 6400 - Foundations of Engineering Analysis), students should be able to:

1. Utilize Python to develop computational models for solving a range of engineering problems, including systems of algebraic equations and differential equations.
2. Analyze and solve linear and nonlinear systems of algebraic equations commonly encountered in engineering.
3. Formulate and solve ordinary differential equations (ODEs) and partial differential equations (PDEs) representing temporal and spatial phenomena in engineering systems.
4. Apply vector calculus concepts, such as gradients, divergences, and curls, to model and interpret vector fields in engineering contexts.
5. Demonstrate proficiency in employing numerical methods, such as finite difference techniques, to solve transport equations involving advection, diffusion, and reaction processes.
6. Demonstrate conceptual and computational understanding of conservation laws and their role in deriving mathematical models of physical systems.
7. Build a strong foundation for advanced chemical engineering coursework by mastering essential mathematical and computational tools relevant to transport phenomena and reaction engineering.

# Python
This class will make exclusive use of Python – a modern programming language that is suitable for scientific computing. Python is easy to use and – most importantly – free! We will also focus on using Python within Jupyter Notebooks: a great way to combine text, math, and programming into one document that is edited and executed in a web browser (See this example). You will learn about that in the class.
There are two ways that we will access Python. The first is via your web browser and the Center for High Performance Computing (CHPC) at the University of Utah.
You must first, however, apply for a CHPC account. You can do so here:
Link: https://www.chpc.utah.edu/role/user/student.php?class=CHEN6400
Class: CHEN6400
Token: 372c075381a3352c
Semester: Fall2025
Expiration Date: 2025-12-21

Once your account is setup, you will be able to access python via:
https://ondemand-class.chpc.utah.edu/

The second way to access Python is to download your own Python + Jupyter Notebook. I suggest the Anaconda distribution here. Please go here for an easy tutorial on Python by Prof. Saad. **It is your responsibility to get up-to-date with the basics of Python programming**.

### *Python programming*
Python is very ubiquitous and a google search can usually turn up answers to many of your questions. But here are a few ideas of places to look if you want to learn python:

- General Python programming resources:
  - CodeAcademy Python class and the youtube version
  - Google's Python class

    - Python for data science
    - Trinket is an online programming platform that provides some pretty good python documentation/tutorials.
    - Professor Saad has prepared a set of introductory material for python available here.
- A brief tutorial on arrays in python that includes discussion of python lists as well as numpy arrays.
- Python has a vast number of libraries to simplify many tasks. Among those that you will probably use regularly:
    - matplotlib provides very powerful plotting capabilities. A quick way to get started on a plot is to look at the matplotlib gallery. Here is another great resource on matplotlib.
    - NumPy provides really powerful array handling capabilities like those in Matlab to allow you to create and manipulate arrays of data. It also has some algorithms that operate on the data. We will use numpy extensively in this class.
    - SciPy has a large number of algorithms such as interpolation, quadrature (numerical integration), optimization, ODE solvers, linear algebra tools, etc. There is some duplication between NumPy and SciPy.
    - pandas provides a lot of data analysis tools. This includes tools to read/write data, analyze and manipulate data, etc.
- If you are a Matlab user, here are a few resources:
    - Numpy for Matlab users (I find this quite useful as a general summary of common Python operations)
    - Python primer for Matlab users

### *Jupyter Notebooks*

Jupyter notebooks allow you to run Python code fragments interspersed with markup text including equations, plots, etc. This is really useful for communicating results, and will be the format required for homework submission. You will need to familiarize yourself with Jupyter notebooks since you will be submitting homework as a notebook. Here is a link to a Jupyter notebook that provides a crash course on some of the key features of a notebook.

All your homework assignments must be completed using Jupyter Notebooks and must include discussions, plots (if applicable), and your code. Discussions must be typeset in the Jupyter notebook using markdown and equations/formulas must be typeset using LaTeX. The "homework" directory on canvas includes several cheat-sheets to help you with markdown and LaTeX so please check those out.

## AI-Use Policy

### *Purpose of AI Usage*

- AI tools are to be used primarily as a supplement to traditional learning methods. They should serve to enhance understanding, facilitate research, and assist in coding tasks related to numerical methods.
- The goal is to use AI as a tool for deepening knowledge, not as a replacement for fundamental learning.

### *Research and Learning*

- Students are encouraged to use AI to explore concepts, gather information, and gain different perspectives on numerical methods.
- However, students should critically evaluate the information provided by AI, cross-referencing it with course materials and other credible sources.

### *Coding and Problem Solving*

- AI can be used to suggest code snippets, algorithms, or approaches to problems.
- Students must understand and be able to explain any code generated by AI. Simply copying and pasting AI-generated code is not acceptable.
- Modifications and improvements to AI-generated code are encouraged to demonstrate understanding and mastery.

### *Critical Evaluation*

- Students should critically assess the output provided by AI, especially in complex or nuanced problems.
- Any limitations or inaccuracies in AI-generated solutions must be acknowledged and corrected.

### *Academic Integrity*

- All work submitted must be the student's own. If AI tools are used, this must be clearly acknowledged.
- Plagiarism rules apply to AI-generated content in the same way they apply to any other source.

### *Continuous Learning*

- Students are encouraged to stay informed about the capabilities and limitations of current AI technologies as they evolve.
- Sharing experiences and insights about using AI tools in numerical methods can enhance collective learning.

### *Feedback and Revision*

- Students are encouraged to provide feedback on the effectiveness and accuracy of AI tools in their learning process.
- Continual revision of this policy may be necessary as technology and its use in education evolve.

### *Declaration of AI Usage:*

- Students must explicitly declare the use of AI assistance in their homework, projects, or any other assignments. This declaration should be made wherever AI-generated code, graphs, tables, or other materials are used.
- Alongside declaring the use of AI, students are required to provide the exact prompts or queries they used to generate the content with the AI tool. This includes, but is not limited to, code snippets, data analysis, graph generation, and table creation.
- A brief explanation or rationale for using AI assistance should accompany the provided prompts. This could include why the AI was used, what specific assistance was sought (e.g., optimization of code, data visualization, complex calculations), and how it contributed to the overall task.

(*This AI Policy was generated with the assistance of ChatGPT 4.0* )

## Addressing Sexual Misconduct

Title IX makes it clear that violence and harassment based on sex and gender (which includes sexual orientation and gender identity/expression) is a Civil Rights offense subject to the same kinds of accountability and the same kinds of support applied to offenses against other protected categories such as race, national origin, color, religion, age, status as a person with a disability, veteran's status or genetic information. If you or someone you know has been harassed or assaulted, you are encouraged to report it to the Title IX Coordinator in the Office of Equal Opportunity and Affirmative Action, 135 Park Building, 801-581-8365, or the Office of the Dean of Students, 270 Union Building, 801-581-7066. For support and confidential consultation, contact the Center for Student Wellness, 426 SSB, 801-581-7776. To report to the police, contact the Department of Public Safety, 801-585-2677(COPS).

## Academic Misconduct

All instances of academic misconduct will be handled in accordance with the Student Code (http://regulations.utah.edu/academics/6-400.php). Consequences include failing the class, getting zero on the assignment(s) or exam(s) in question, and possibly dismissal from the graduate program. All instances of academic misconduct will be reported to the department, graduate committee, and the primary advisor of the student.

## Academic Ethics

Refer to the University's Code of Student Rights and Responsibilities ("Student Code").

## Accommodations, Students with Disabilities (ADA)

The University of Utah seeks to provide equal access to its programs, services, and activities for people with disabilities. If you need accommodations for this class, reasonable prior notice needs to be given to the Center for Disability Services, 162 Olpin Union Building, 801-581-5020 (V/TDD). The CDS will work with you and the instructor to make arrangements for accommodations. All written information in this course can be made available in an alternative format with prior notification to the Center for Disability Services. Additional information is found in the College Guidelines.

## Tentative Schedule

| W | Tuesday | Thursday | Events |
|---|---|---|---|
| 1 (8/18) | Introduction, Syllabus, Python, etc… | Errors (true, absolute and relative)<br>Vector/Array norms<br>Introduction to verification | |
| **Part 1: Solving Algebraic Equations**<br>This part of the courses focuses on methods and techniques to solve algebraic equations, both linear and nonlinear. | | | |
| 2 (8/25) | Systems of linear equations, conversion to matrix form, matrix vector multiplication<br><br>Types of matrices: (dense, sparse, diagonal, etc…) | Python: how to program matrices and vectors, matrix vector multiplications, etc…<br><br>Overview of Direct and Iterative Methods<br><br>Python built-in linear solvers<br>Simple examples with Python | HW 1 assigned on Thursday. |
| 3 (9/1) | Heat Transfer Example, Direct solution with built-in solvers | Nonlinear equations, fsolve/root<br>Examples | HW 1 due on Thursday.<br><br>HW 2 assigned on |

| | | | |
|---|---|---|---|
| | | Systems of nonlinear equations (fsolve/root) | Thursday. |
| 4<br>(9/8) | Interpolation, polyfit, basic regression | nonlinear and general regression, curve_fit, general regression models<br>Numerical integration | HW 2 due on Thursday<br>HW 3 assigned on Thursday |

## Part 2: Solving Ordinary Differential Equations (Time OR Space)

This part focuses on the theory and techniques to solve ordinary differential equations. We cover single initial value (single and systems of) and boundary value problems. We focus on 1D in space. Project goes to 2D/3D in space (Poisson equation).

| | | | |
|---|---|---|---|
| 5<br>(9/15) | Intro to differential equations, classification, boundary conditions<br><br>Examples of ODEs and PDEs<br><br>Initial Value Problems | Example with solve_ivp (Lobster cooking example)<br><br>System of IVPs with odeint (SIR epidemic model, Kinetics) | HW 2 due on Thursday.<br>HW 3 assigned on Thursday.<br>Project 1 Assigned. |
| 6<br>(9/22) | Stiffness in ODE solvers<br><br>Explicit/Implicit methods overview<br><br>Additional options for solve_ivp (methods, events, max_step)<br><br>Example with falling object | Boundary value problems 1 (linear, Nonlinear)<br><br>Finite difference methods | HW 3 due on Thursday.<br>HW 4 assigned on Thursday |
| 8<br>(10/6) | **FALL BREAK (Oct. 4 - 12)** | **FALL BREAK (Oct. 4 - 12)** | |

## Part 3: Partial Differential Equations and Conservation Laws

This part focuses on the theory and techniques to solve partial differential equations and how they tie into the great conservation laws.

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|---|---|---|---|
| 7<br>(9/29) | Scalar fields, vectors, vector fields, vector calculus, grad, div, curl<br>How to create and visualize scalar and vector fields in Python, contour, contourf, quiver etc… | | HW4 Due on Thursday<br>NO HW Assignment<br>Project 2 assigned |
| 8<br>(10/6) | **FALL BREAK (Oct. 4 - 12)** | **FALL BREAK (Oct. 4 - 12)** | |
| 9 | What are PDEs? | Continue Mathematical | |

| | | | |
|---|---|---|---|
| (10/13) | Mathematical foundations for PDEs (partial derivatives, gradient, divergence, curl, dot and cross products) | foundations for PDEs: Elements of vector calculus<br><br>Great conservation laws: integral form, fluxes, control volumes, control surfaces, unit normals, etc…<br><br>Eulerian vs Lagrangian<br><br>Reynolds transport theorem 1<br><br>(we need a model equation here. conservation of mass)<br>We can do this with a control volume | |
| 10 (10/20) | Reynolds transport theorem 2<br><br>Divergence (Gauss') theorem<br><br>Integral to differential forms<br><br>Generic scalar transport<br><br>Vector transport, tensor and dyadic notation | Examples of conservation laws: Advection-diffusion-reaction eqs, Energy equation, Navier Stokes, Species transport, etc…<br><br>Students are expected to become familiar with the terms in these equations and how to expand them and identify their names<br><br>Do examples in vector and tensor forms and go through different expansions<br><br>(Other coordinate systems?Might postpone that discussion to a little later.This is a primary advantage of vector forms.) | |
| 11 (10/27) | We need a win here: let's do a 1D advection-diffusion equation with an analytical solution. We code this up in Python using CDS and odeint.<br><br>Boundary Conditions overview<br><br>Do verification and discussion of what advection and diffusion does | 1D unsteady diffusion: Stokes' second problem - oscillating plate in a fluid<br>Discuss boundary conditions<br><br>1D unsteady diffusion: Transient Diffusion into a Semi-Infinite Solid<br>Discuss boundary conditions | |
| 12 (11/3) | | | |
| 13 | | | |

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|---|---|---|---|
| (11/10) | | | |
| 14 (11/17) | | | |
| 15 (11/24) | | **Thanksgiving - NO CLASS (Nov. 27)** | |
| 16 (12/1) | | LAST CLASS | |