ME EN 5035/6035 – Design of Experiments
University of Utah
Department of Mechanical Engineering
Lecture: T/TH 10:45am-12:05pm
Lecture Location: MEK

COURSE INSTRUCTOR:
Mark Fehlberg, PhD
Phone: 801.581.8118
Email: **m.fehlberg@utah.edu**
Office: MEK 1674

CREDITS: 3 semester credit hours

TEXT: After careful review, I have determined that no single text can adequately serve as a resource for all of the topics we will review in this course. One textbook which will provide most of the background material for this course is **Design and Analysis of Experiments, by Douglas C. Montgomery** (any edition). I have also selected two online resources that I will reference frequently (links below). Together, these resources will serve to enhance your understanding of the concepts we review in class. I also encourage you to take advantage of the many online resources available through OpenCourseware, Khan Academy, Udemy, Datacamp, YouTube, and others to supplement lecture topics.

OpenIntro Statistics – 4th Edition, David M Diez, Christopher D. Barr, and Mine Cetinkaya-Rundel – 2019
Free download here: OpenIntro Statistics
A First Course in Design and Analysis of Experiments, Gary W. Oehlert (University of Minnesota) – 2010
(http://users.stat.umn.edu/~gary/book/fcdae.pdf)

SOFTWARE: R, download from http://www.r-project.org/. This is free software. I prefer to use R in conjunction with R-Studio (https://www.rstudio.com/) because of its tremendous flexibility and utility for DoE. With over 2 million users worldwide, R is rapidly becoming the leading programming language in statistics and data science. Every year, the number of R users grows by 40% and an increasing number of organizations are using it in their day-to-day activities. Matlab, Minitab, SPSS, SAS, JMP and STATA are also acceptable, but R will be the software used primarily in lecture and with examples.

I strongly encourage all students to review and complete the courses provided by DataCamp (https://www.datacamp.com/courses/free-introduction-to-r). These exercises introduce you to the R language and equip you with the basics to become proficient in R for data manipulation and management. Many of the functions are identical across software platforms, so I don't expect this to be a problem with learning a "new language" if you choose to use R.

OFFICE HOURS: T/TH 4-5pm and by Appointment (Zoom Link on Canvas)

COURSE DESCRIPTION: The purpose of this course is to introduce mathematical concepts and statistical methods used in modern engineering problem solving and analysis. The goal is to introduce students to analytical and numerical tools to design experiments to effectively and efficiently solve real-world engineering problems. Lectures will be supplemented by several programming exercises using R, and a large number of practical examples on relevant engineering topics related to design of experiments

and data analysis. The use of experimental designs is a prescription for successful application of the scientific method. The scientific method consists of iterative application of the following steps: (1) observing a selected state, (2) hypothesizing the mechanism for what has been observed, then (3) collecting data, and (4) analyzing data to draw valid conclusions. Statistical experimental designs provide a plan for collecting data in a way that they can be analyzed statistically to corroborate the hypothesis in question. This is an organized approach which helps to avoid false starts and incomplete or invalid answers to research questions.

COURSE OBJECTIVES: After successfully completing the course, students should be able to do the following:

1. Use statistical methodology and tools in the engineering problem-solving process.
2. Compute and interpret descriptive statistics using numerical and graphical techniques.
3. Understand the basic concepts of probability, random variables, probability distribution, and joint probability distribution.
4. Compute point estimation of parameters, explain sampling distributions, and understand the central limit theorem.
5. Develop problem-solving approaches to learning and acquiring information through sampling.
6. Understand how redundancy of functional components of a system and the general system architecture affect system reliability.
7. Design and analyze single-factor and multiple factor experiments: Analysis of Variance
8. Perform tests of hypotheses for single and multiple variables.
9. Communicate results by summarizing and interpreting data, working as a team, and through a written project report.

Students are expected to gain an appreciation of the important role that statistical methods play in making technological and scientific decisions. Students are expected to learn principles, methods, and tools that will prove useful in later course work and be relevant to the design of experiments, and data analysis situations that may be encountered on the job.

EVALUATION OF STUDENT PERFORMANCE:

Evaluation:	
HOMEWORK (10x25)	250
DISCUSSIONS (10x10)	100
PROJECT PROPOSAL	50
PROJECT INFOGRAPHIC	100
PROJECT REPORT	200
EXAM 1 (Quiz)	100
EXAM 1 (Project)	200
EXAM 2 (Quiz)	100
EXAM 2 (Project)	200
EXAM 3 (Quiz)	100
EXAM 3 (Project)	200
TOTAL	1600

HOMEWORK (15%): The homework assignments will emphasize material covered in lecture. You are encouraged to work in groups to complete the homework, but must prepare individual assignments to be handed in. These will require some programming using software to complete the analyses. I encourage students who are using R to consider a Markdown or Notebook format for your homework submissions.

DISCUSSIONS/PARTICIPATION (15%): Throughout the semester we will utilize breakout rooms on Zoom to hold small group discussions. Each of these discussions will provide opportunities to virtually interact with other students and discuss topics relevant to lecture material. A submission is required on Canvas using the discussion board for credit. 3 discussion topics will be "dropped" from scoring in case there are circumstances that require you to miss a lecture or online discussion.

PROJECT (20%): Projects will represent a group effort of 3-4 students (this will differ between Undergrad and Graduate students). Projects from individuals will not be accepted without prior permission from the instructor. The purpose of the semester project is to design an experiment and conduct an in-depth investigation and analysis of data related to an engineering topic. The project proposal is designed to encourage students to write a formal experimental plan. The written report is designed to help students evaluate data to develop technical writing and research skills. The infographic for the project is designed to encourage sharing and effective presentation of ideas with others. Each student is encouraged to think about a project that requires data collection and analysis. Example projects will be provided on the course website as reference.

EXAMS (50%): Exams will be administered in two parts. The "Quiz" portion will be administered on Canvas as a quiz and will consist of multiple choice, short answer and problems. This portion of the exam will be closed to outside resources other than Canvas. Timing for the exam will be such that you will be able to take the exam at anytime on the date of the scheduled "Quiz". The project portion of each exam is open to course notes, homework, reference texts, and the internet, but only individual work is permitted. No collaborations with others are allowed. The exams will cover all text/handout material and all material/information discussed in class, including assignments. The take home exam project is designed to encourage higher level thinking and data processing.

LATE WORK POLICY: I will not accept late work. Any exceptions to this policy should be prearranged with the course instructor. If you are having trouble making a deadline, communicate this with the instructor ahead of time so we can work with you. Assignment extensions and various forms of reasonable accommodation will be made on a case by case basis.

Approximate Grade Ranges

93-100%	A
89-92%	A-
87-89%	B+
84-86%	B
79-82%	B-
77-78%	C+
74-76%	C
69-73%	C-
<69%	E – D+

Credit/No Credit: There is not an option to elect CR/NCR for this course according to the department of Mechanical Engineering Guidelines and ABET. For more information about CR/NCR please contact your academic advisor.

Class Recording: All lectures will be recorded via Zoom and these recordings will be made available on Canvas to comply with FERPA.

Academic Honesty: All students are responsible for their own work. Please review the University of Utah's "Rights & Responsibilities of Students (Student Code/Misconduct)" policies for details about the consequences of misconduct. Students must also complete the Canvas Module for Academic Integrity before accessing other materials on the course Canvas site.

Violations include, but are not limited to:

Cheating on an examination, such as copying from another's paper, using unauthorized notes, calculators, etc., or giving or receiving unauthorized aid, such as trading examinations, whispering answers, passing notes, or using electronic devices to transmit or receive information.

Plagiarism. This is using someone else's work without giving credit. It is, for example, using ideas, phrases, papers, laboratory reports, computer programs, data - copied directly or paraphrased - that you did not arrive at on your own. Sources include published works such as book, movies, Websites, and unpublished works such as other students' papers or material from a research service. In brief, representing someone else's work as your own is academically dishonest. *The risk of plagiarism can be avoided in written work by clearly indicating, either in footnotes or in the paper itself, the source of any major or unique idea or wording that you did not arrive at on your own. Sources must be given regardless of whether the material is quoted directly or paraphrased.*

Unauthorized collaboration. This is working with or receiving help from others on graded assignments without the specific approval of the instructor. *If in doubt, seek permission from the instructor before working with others.* Students are encouraged to learn from one another: Form study groups, discuss assignments, BUT each assignment must be individual work unless specifically stated and turned in as a group assignment.

- Copying another student's assignment and putting your name on it is plagiarism.
- You are encouraged to talk to one another about your assignments; however, all assignments must be done by the student whose name is on it!

Academic Integrity: Engineering is a profession demanding a high level of personal honesty, integrity and responsibility. Therefore, it is essential that engineering students, in fulfillment of their academic requirements and in preparation to enter the profession, adhere to the Department of Mechanical Engineering Policy for Academic Misconduct. This policy is based upon the University of Utah's Policy 6-400: Code of Student Rights and Responsibilities. As part of the ME policy, students must review and acknowledge the "ME EN Academic Misconduct Policy" Both documents can be downloaded from the course Canvas page. **Students must provide acknowledgment of the MEEN Academic Misconduct policy via the Canvas Academic Integrity Module for this course before the end of the second week of class or they will be unable to access course content through the Canvas modules.**

COLLEGE OF ENGINEERING GUIDELINES - https://www.coe.utah.edu/students/academic-affairs/academics/semester-guidelines/

University Policies

ADA Statement

The University of Utah seeks to provide equal access to its programs, services, and activities for people with disabilities. If you will need accommodations in this class, reasonable prior notice needs to be given to the Center for Disability Services, 162 Olpin Union Building, (801) 581-5020. 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.

University Safety Statement. The University of Utah values the safety of all campus

community members. To report suspicious activity or to request a courtesy escort, call campus police at 801-585-COPS (801-585-2677). You will receive important emergency alerts and safety messages regarding campus safety via text message. For more information regarding safety and to view available training resources, including helpful videos, visit https://safeu.utah.edu/

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).

Wellness Statement. Personal concerns such as stress, anxiety, relationship difficulties, depression, cross-cultural difference, etc. can interfere with a student's ability to succeed and thrive at the University of Utah. For helpful resources contact the Center for Student Wellness at www.wellness.utah.edu or 801-581-7776.

For Drop/Withdrawal dates and any other helpful University related information, please contact your Academic Advisor.

SUGGESTED REFERENCE MATERIAL

- Software for Data Analysis: Programming with R, ISBN 978-0-387-75936-4
- Design and Analysis of Experiments with R, John Lawson, ISBN 9781439868133

COURSE OUTLINE

For the most current information about due dates and course materials, please refer to the Canvas Course Website. A schedule of topics by date can be found on the next page.

Design of Experiments Schedule/Topics* - Schedule subject to adjustments throughout the semester						
Week		Content	Reading	Tuesday	Reading	Thursday
1	1/18/2021	Intro to DoE Why do we need DoE? What is the outcome/result of an experiment? How do we control for uncertainty in an experiment? Definitions and terminology.	Montgomery: Ch1 OpenStats: Ch1	Intro to DoE "you can't pull good information from a poorly designed experiment" Demming, controlling uncertainty to determine results	Spurious correlations: http://www.tylervigen.com/spurious-correlations OpenStats 1.2-1.5	Overview of design types and analysis types, dependent vs independent variable correlation vs. causation confounding factors Observational Study vs Experiment Hypothesis testing true-positives, false positives, etc. research ethics Intro to R
2	1/25/2021	probability, expected values, binomial distribution, standard error, distributions, and point estimates review basic statistical concepts, t-test, paired comparison design, assumptions	OpenStats 3.1-3.3 On the Origins of the .05 Level of Statistical Significance (Link in Canvas)	Conditional Probability, probability, point estimates, distributions, sampling, standard error, Law of Large Numbers	OpenStats: 3.4-3.5	Connect probability to hypothesis testing, continuous distributions Coin/Weighted Coin Examples dice examples R examples
3	2/1/2021	Simple Comparative Experiments, Concepts of the Statistical model, hypotheses to be tested, conclusions, Type I and Type II error, power of a Statistical test	Montgomery: Ch2.5	Inferences about the differences in Means, randomized designs	OpenStats: 4,5 - Foundations for inference	central Limit Theorem confidence Intervals continuous distributions, z-scores, normality
4	2/8/2021	Finish discussion of hypothesis testing and confidence intervals Exam 1	Montgomery: Ch3 Power, Power analysis for means comparison. Single Factor Experiments - ANOVA	hypothesis testing, sample size, determining power t-distribution	Handouts and Class Notes, Practice Exam Problems	
5	2/15/2021	Experiments with a Single Factor - the One-way ANOVA, Non-parametric methods	OpenStats 5.1-5.1.5, Oehlert 7.1, Montgomery Ch3	Experiments with one factor and multiple levels, Sample Size, Dunnett Test, One-way random effects models, the general linear test, Exam 1 Review	OpenStats 5.1-5.1.5, Oehlert 7.1, Montgomery Ch3	Exam 1
6	2/22/2021	Exam 1 (Take Home Project Due) correlation coefficients, other tools, little linear regression(R^2)	Montgomery Ch4, Oehlert 13, 14	Introduction to Blocking, Latin Squares and Related Designs	Montgomery: Ch4, Oehlert 13,14	Corssover Designs, incomplete block designs

7	3/1/2021	correlation coefficients, other tools, linear regression(R^2), Fitting Regression Models, Hypothesis Testing in Multiple Regression	Montgomery Ch5.1-5.3	Introduction to Factorial Designs two-factor factorial design	Montgomery Ch5.4-5.6	General Factorial Design, fitting response surface models, blocking in a factorial design
8	3/8/2021	2k factorial designs	Montgomery Ch6	2^2 design 2^3 design general 2^k design	Montgomery Ch6.7-6.9	Optimal designs, center points, coded design variables
9	3/15/2021	Finish discussion of coded variables and material for exam 2	Handouts and Class Notes, Practice Exam Problems	Exam 2 Review	Exam 2 Practice problems and review notes	Exam 2
10	3/22/2021	Exam 2 (Take Home Project Due) statistical process control (SPC) taguchi 6 sigma	Allen 1.3.1-1.4.4, 2-2.2, 4-4.2	SPC, Quality Control "in control" Specifications- upper & lower ARL - average run length (between special case) Gauge R and R	Allen 4.3-4.7	Charting: p-charting, u-charting, xbar, and R charting Process Capability Index, Pareto Chart cause- effect diagram check sheet survey sampling acceptance sampling continuance sampling
11	3/29/2021	Blocking and Confounding in the 2^k factorial design	Montgomery: Ch7	Blocking in unreplicated designs the 2^3 design	Montgomery: Ch7.4	Split Plot Design, Confounding a main effect with blocks
12	4/5/2021	2-level fractional factorial designs	Montgomery: Ch8	More fractional factorial designs (8.1) Foldover Designs Plackett-Burman Designs	Montgomery: Ch9	3-level and mixed level factorials and fractional factorials
13	4/12/2021	Linear Regression Introduce multivariate experiments (multiple factors) Factors/levels Overview of design types case study	Montgomery Ch10 Oehlert 13.3-13.3.3, 18-18.3	MANOVA factorial multcompare, power sample size, Blocking	Oehlert 13.3-13.3.3, 18-18.3	Introduce two-way ANOVA through continuation of factorial examples
14	4/19/2021	Optimal Design Methods	Montgomery: Ch11-13	Response Surface Methods and Designs, Robust Parameter Designs	Montgomery: Ch14	nested and split plot designs
15	4/26/2021	Info Graphic/Final Report Due	Review Materials, Notes, Assignments, Exam 3 Review	Exam 3 Written	Reading Day (4/28)	
Final Exam	4/30/2021	Exam 3 Take Home Project Due 12:30pm				