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Work in Progress: Redesigning a Multidisciplinary Engineering Statistics Course

Dr. James Burns, Western Michigan University

Jim Burns, Ph.D. Assistant Professor Industrial and Entrepreneurial Engineering and Engineering Management Department Bio: Jim Burns holds a Ph.D. in Industrial Engineering from Western Michigan University, and has more than 10 years industry experience in the manufacturing sector in a variety of roles including process engineering, operations management, and technical sales. His area of expertise centers on applying OR/MS and Simulation techniques to Supply Chain & Operations Management problems, and has also conducted research in the areas of Human Factors and Work Design for evaluating time and motion efficiencies of operations. Jim also holds an undergraduate IE degree and a Six Sigma Greenbelt. Prior to joining the faculty at Western Michigan, Jim was an Assistant Professor for the Industrial Engineering Technology program at Purdue Polytechnic Institute.

Megan Hammond, Western Michigan University

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Abstract

Over time, the evolution of academic programs can place new constraints on courses that could not be envisioned when a course was originally designed. This may be especially true for multidisciplinary courses where additional constraints due to changing accreditation requirements, new programs adopting a course, and the shifting emphases of academic programs likely occur more frequently than in many program-specific courses. For example, a new program may require a certain topic (e.g., discrete probability distributions) to be emphasized more than the current programs, which may in-turn de-emphasize the instruction of other course topics. A logical result is that, over time, any attempt to change how a course is taught will be met with resistance from the course's stakeholders. In a worst-case scenario, the constraints could become so numerous, interdependent, and complex that more effort is expended maintaining the status quo than is spent on improving and adapting the course's content, instructional methods, and outcomes to a changing world.

In this work-in-process paper, we will outline our initial work for a two to three-year effort to redesign a multidisciplinary, lab-based, engineering statistics course at a large public university. The course was originally designed nearly 20 years ago for the college's Industrial Engineering program and today serves six programs and approximately 25% of the college's undergraduate students. The timing of this effort coincides with an ever-increasing interest in data science and analytics, and a larger effort to restructure the university's longstanding general education requirements. Our work completed to-date consists of initial efforts to understand the course's constraints stemming from topical coverage, understand stakeholder requirements and preferences, understand student views about the course, and establish a general vision for the future. In this paper, we focus on student views and opportunities to enhance instructional methods to improve student engagement and discuss considerations for assessing student learning. We also outline our larger vision for the course as it relates to students' understanding of statistics and the potential for the course to play a role in the university's general education program.

Introduction, Course Background, and Rationale for the Change

Information and data literacy is becoming an increasingly important concern in higher education [1, 2]. For engineers, statistics is probably more aligned with the concept of information literacy than any other course that will be studied. While it may be going too far to say that the entirety of an introductory statistics course is a vital component to every undergraduate engineering program, it is probably safe to say that certain statistics topics are essential. For engineers, working with data and experimentation are just a fact of life. This fundamental realization, coupled with an opportunity stemming from recent changes to the university's general education program, has motivated us to begin a process to redesign an introductory statistics course that resides in the Industrial Engineering (IE) program but in actuality serves many programs (e.g., Civil Engineering, Manufacturing Engineering Technology)

The current version of the course was conceived approximately 20 years ago as the first course in a two-course sequence in statistics and probability for IE students. The 200-level lab-based course replaced an introductory course in the program that was offered through the Statistics department. Since its introduction other engineering programs have adopted the course, and it has also become a popular way for many students to complete a mathematics minor. Over the years, the course has grown from its initial enrollments of 10-20 students, to consistently having annual enrollments of more than 250 students across multiple sections in the fall semester and one section in a summer session. The increasing enrollments come with certain challenges such as the need for additional teaching assistants (TA) for lab instruction and the need for certain topics to be emphasized based on the requests of various programs. These and other factors, including the fact that the "service course" status means it is often taught by junior faculty who are focused on establishing a research program, make updating the course difficult. However, much has changed in the field of statistics over the past twenty years, making an update absolutely essential.

Another factor in the decision to redesign the course now stems from the current efforts by the university to redesign its general education program. Rather than having specific areas of study (e.g., Fine Arts, Social and Behavioral Sciences, Natural Sciences, Communication), the new program will focus on assessment of essential skills (e.g., scientific literacy, effective written communication, effective oral and digital communication). Under the new model, any course may apply to be a part of the new general education program, and we have applied for this course to become a general education course in the area of *oral and digital communication*. While the terminology is broad, there are specific goals assessing student learning. Appendix A lists the two university-required student learning outcomes (SLO) along with the course-specific objectives (CO). In short, competence in the area of oral and digital communication means a student will be able to locate and analyze information, draw meaning from the analysis, and then communicate the meaning using modern (digital) methods. This makes engineering statistics a natural choice for a general education course.

Given our intention to redesign this course, we have two motivations for writing this paper. The first is to outline some of the challenges we are sure to face during the redesign process. We assume there are others who are in similar situations and will benefit from the perspective. The second motivation is to outline the basic elements of our vision for the course to those outside the immediate IE statistics education communities. Since analysis of data and experiments will be a reality for most engineers in the workplace, hearing from a wider audience of engineering professionals will certainly help refine our vision and improve the goals we have set. In the following sections, we present a description of the course in its current form, highlight important student views and student engagement issues, discuss constraints and opportunities, and present our vision for the course's future as well as our roadmap for completing the transformation.

Current Course Structure and Topical Coverage

The course is currently structured in a lecture-lab format, with the lecture portion (2, one-hour meetings per week, ~100 students) taking place in a large lecture hall and the lab sections (1, three-hour meeting per week, ~25 students) taking place in a computer lab. The pedagogical philosophy is traditional. Topics are introduced by the lead instructor, usually a professor, during lecture periods using theory and examples. Shortly after a topic is introduced it is featured in a lab session where a TA reviews the topic, provides additional examples, and in some cases demonstrates how to use statistical software (Minitab) to solve problems. A lab assignment is given at the end of each lab session that students complete in teams of two. The rationale for this approach is that after the lecture and lab sessions, students should be well-prepared for working through homework problems from the textbook on their own.

The topical coverage of the course is more broad than deep, and the sequence of topics follows that of most introductory statistics textbooks. Most chapters of the course textbook [3] are covered, but some sections are not covered at all and others are covered superficially. Table 1 provides a summarized listing of the course topics, their sequence, and the instructional emphasis

Table 1 – Current Topic Coverage & Instruction Emphasis

Topic Area	Weeks	Topic Coverage	H	S	C
Obtaining Data		**Sampling methods**: Random, systematic, stratified. **Types of studies**: Experiment, observational, survey.	0%	0%	100%
Basic Statistics, Graphical Displays of Data	1	***Descriptive statistics**: Mean, median, variance, skewness, etc.. ***Graphical displays**: Time-ordered, scatter plot, stem and leaf, histograms, bar chart, pie chart, Pareto charts ***Concepts**: Selection & interpretation of graphical displays, identifying misleading graphical displays.	25%	50%	25%
Probability	1.5	**Concepts**: Sample space, events, relationships, conditional probability, independence. **Counting rules**: Permutations, combinations, partitioning. **Rules**: Bayes' rule, complement, additive, multiplicative.	60%	10%	30%
Discrete Distributions	.5	**Discrete distributions**: PMF, CDF, Expectation, variance. **Random Variables**: Bernoulli, binomial, *hypergeometric.	60%	10%	30%
Continuous Distributions	.5	**Continuous distributions**: PDF, CDF, Expectation, variance. **Normal distribution**: Standard normal	60%	10%	30%
Sampling Distributions	1	Sampling distribution of the mean, central limit theorem. Other sampling distributions: t, Chi-Square.	80%	0%	20%
Statistical Intervals		**Intervals**: Mean, variance, proportion, prediction, tolerance.	80%	0%	20%
Hypothesis Testing	2	**Concepts**: Null & alternative hypothesis, significance, test statistic, rejection region, critical values, p-values, Type I & II errors. **1-Sample tests**: Mean, variance, proportion. **2-Sample tests**: Means, variances, paired tests.	60%	20%	20%
Analysis of Variance	2	**Concepts**: Designed experiments, ANOVA, residuals, factor plots. **Techniques**: CRD, RBD, 2-factor factorial	5%	75%	20%
Correlation, Regression	1.5	**Concepts**: Correlation, coefficients, prediction, transformations. **Techniques**: Simple linear regression.	5%	75%	20%

* Indicates a topic that is introduced and covered exclusively by a lab instructor.

that is given to each topic. We classify the instructional emphasis along the lines of its focus on calculations done by hand (H), using software to solve problems (S), and developing a conceptual understanding of the material (C). The table also indicates the amount of time spent on each topic (given in weeks, where 1 week is equivalent to 2 lectures and 1 lab period). It is noteworthy that of the 15 weeks available during a semester, several lecture periods are essentially lost due to examinations, holidays, special university events, and the need to synchronize the two lecture sections to the lab sections. Effectively, there are only 10 weeks available for lecture instruction and 12 for lab instruction.

Statistical software plays an interesting role in the course. The current structure of the course has examinations taking place during lecture periods, which precludes the use of software in assessments (output from software is sometimes used). Additionally, software is used nearly exclusively for some topics but it may not be used at all for others. For example, software is the primary tool for learning regression analysis, but practically all probability calculations are done by hand. The rationale for how software is used seems to be based on an effort to prevent cheating and to simplify the grading of exams by administering them during lecture periods.

Student Views & Engagement

This section discusses student views as understood by a review of the end-of-semester course evaluations. The data below was collected from the Fall 2018 semester class consisting of 211 students, divided among 2 lecture sessions (~100 students each) and 9 lab sessions (~25 students each). In total, 138 students submitted evaluations (~ 65% response rate) that included both open-ended questions and traditional numerical response questions. Although only 1 semester of evaluations is reviewed here, the response rate is quite high and the results seem to be consistent with previous evaluations. We summarize key findings from the evaluations here.

Figure 1 displays a sampling of responses from certain numerical-response questions on course relevance and quality. Response scales ranged from 1 to 5, and we consider any response of 4 or greater to display positive sentiments. The questions are abbreviated on the graphic below but are shown with the exact wording in Appendix B. Overall, students expressed satisfaction with the course and the degree to which the course improved their understanding of the material (Questions 1, 2, 3 & 5), but they communicated a slightly less positive sentiment regarding the value and relevance of the course as a whole (Questions 8 & 9). Still, given our experience with the subject of engineering statistics and the fact that the course serves many programs, these responses were higher than we expected. Responses to the question of prerequisites (Question 4) suggest students felt prepared for the work and did not find the material difficult. However, questions regarding personal interest of the course material (Questions 6 & 7) suggest students are not positively engaged with the subject matter.

In addition to closed question responses, each student had the opportunity to express their opinions of the course through open-response question prompts. The 4 open-ended questions (see exact wording in Appendix B) asked of the students were:

- What do you suggest to improve the course?
- What is your opinion regarding using an online tool for practice/homework problems?
- Describe your IDEAL lecture session.

- Describe your IDEAL lab session.

A wide array of sentiments were expressed in the responses to these questions, but some general conclusions were able to be drawn. Some common thoughts for improving the course and characteristics of an *ideal* lecture were to present and review more practical examples during lectures, to take the time to work out more problems by hand (i.e., more interactive lectures), and to design questions to be more relevant to their specific fields of study.

Responses for an *ideal* lab structure were more evenly divided between keeping the lab sessions the same (i.e., walking through examples together) versus calls to have more time to work problems independently. A common rationale for less walk-through instruction was that the software component, covered in the labs, was not tested during exams or homework, therefore some students suggested limiting/removing the software element.

There was not a favorable opinion of an online platform for homework and practice problems. Several comments referenced issues with submission and access when similar platforms were used in past courses.

As stated previously, there appears to be an overall positive opinion regarding current course structure and quality, but enrolled students are not excited by the course material. From the open-response questions, students generally seem to think they would benefit from a more interactive learning lecture (i.e. more examples), while overall they are content with the current lab structure. There appears to be a disconnect with the course assessments (i.e. tests and homework) and the use of software. Overwhelmingly students would rather perform calculations by hand,

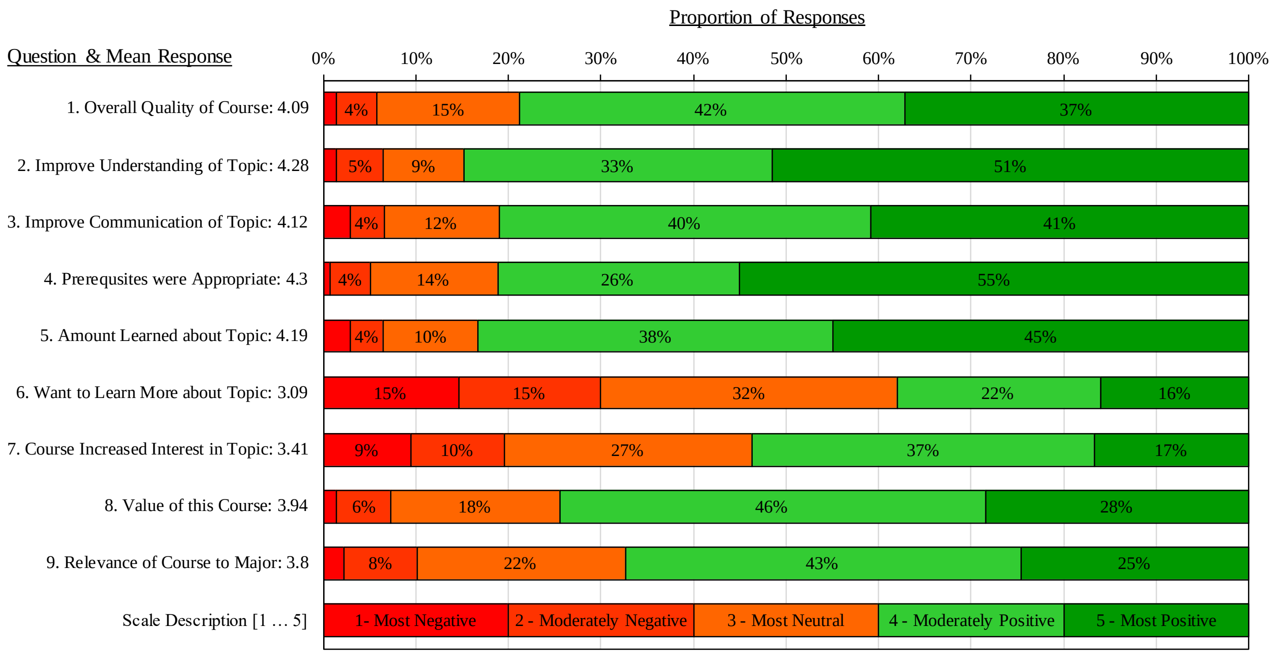

Figure 1 - Student Views: End-of-Semester Evaluation Numerical Question Responses

referencing its aid in their comprehension of the material, and do not see the benefit of learning the current statistical software (i.e. they are not allowed to use the software on exams). General comments about the lecture also reflected that too much material is being covered, the lecture periods feel rushed, and therefore the exam periods seem too short.

Constraints, Challenges, Opportunities

Some comments from the above section reflect some expected frustrations given the nature of teaching statistics in a multidisciplinary environment [4]. The breadth of topics covered makes it necessary to move quickly during lectures and the diversity of the student population makes it difficult to design examples that will be relevant to all engineering disciplines. There also appears to be a lack of engagement with the topic of statistics itself that may stem simply from the growth of the lecture sections over the years (from 20 to 100 students). Personal engagement with students must now come through labs. With 5-7 TA's needed to cover up to 9 lab sections, the skill, experience, and teaching styles reach the ends of a large spectrum, making it difficult for students to have a consistent experience with the subject matter.

Another issue with engagement likely stems from the emphasis on examinations during lecture periods, which precludes using software. We believe reducing the subject to hand calculations and conceptual understanding (albeit without fully understanding the central role software in applying statistics) is very tedious for many students because they see the calculations and concepts as trivial. As mentioned before, most students seem to feel prepared to study statistics, but too many do not want to learn more about it after taking the course.

An important challenge in redesigning the course will be to ensure consistency of instruction and assessment across lecture and lab sections for both the statistics topics and the general education components (oral and digital communication). For this, new assessment strategies must be developed. To illustrate the challenge, Figure 2 presents a summary of aggregate scores for exams (3 total), labs (12 total), and homework assignments (6 total) during the Fall 2018 semester, organized by lab section. These three score categories represent varying levels of difficulty for students, with labs usually being the easiest due to direct TA support, homework being more difficult due to the independent nature of the work, and exams being the most difficult.

As expected, there is variation across the lab, homework, and exam scores. Some of the variation is undoubtedly due to differences in the teaching experience/ability of individual TAs, even though all TAs follow a well-established lab manual and use rubrics for grading. We might expect less variation in exam scores since special procedures are in place to ensure consistency across all labs and lecture sections, but as the graphic illustrates there is significant variation here as well. We are certainly interested in reducing variability introduced by the TAs, but there is little we can do to address other factors that may be particular to engineering programs (e.g., perhaps IEs tend to cluster in certain lab sections), class ranking (e.g., those with higher class rank can register earlier, and they possibly prefer certain labs), or individual students (e.g., perhaps students with internships prefer evening labs). Based on the inconsistent variance across the three categories of scores, we believe there are likely several factors involved. It is worth

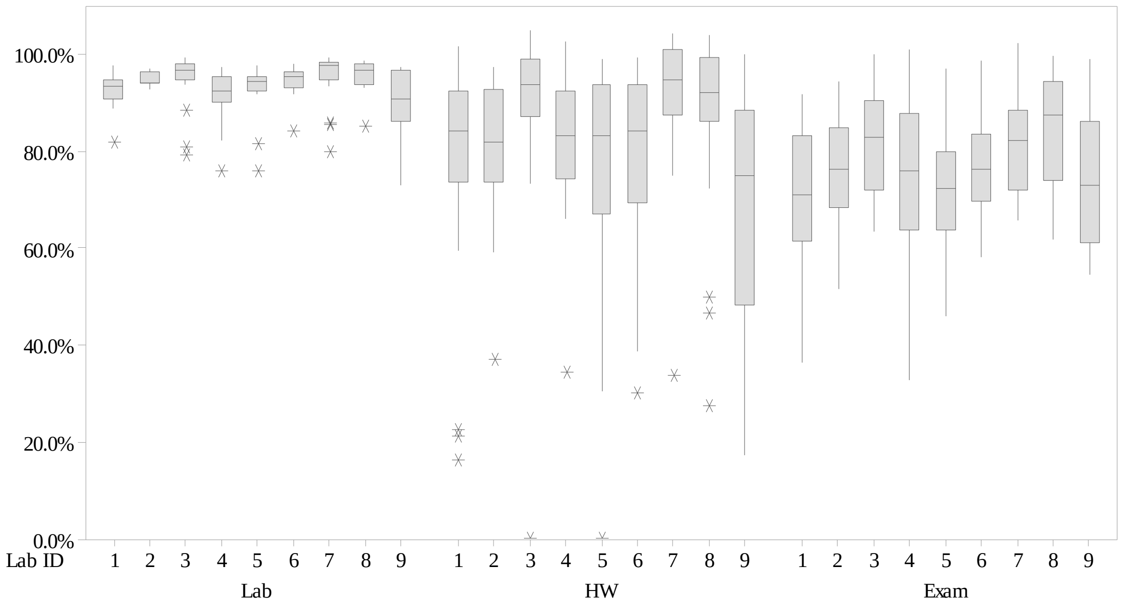

Figure 2 – Average Lab, Homework, and Exam Scores (%) by Lab Section

noting that when the same comparisons are made between lecture sections instead of lab sections, there is little variation in scores.

These are challenges that must be overcome in order to transform the course into one that is uniquely valuable to students. We summarize some of the most fundamental items to address as questions that must be answered in order to move forward.

- Which topics should be taught, and which of those topics should be emphasized to make the course most relevant for students?
- What should be the role of software in the course? Which software package or packages should be used?
- How can instructional effectiveness be maintained across all lab sections?
- How should student learning be assessed?

In addition to these general challenges, there are specific challenges brought about by certain constraints placed on the course due to its multidisciplinary nature:

- Varying ABET learning outcome requirements for specific engineering programs exist.
- Inclusion of certain topics are necessary to meet the needs of specific engineering programs.
- Because the course serves many programs, changing the format (large lecture & lab) would be very difficult due to scheduling conflicts and classroom capacity in the college.
- Assessment as prescribed by university's general education requirements (if the course is accepted as part of the general education program) must be applied consistently across all sections and labs.

Despite the challenges and constraints, there is still strong motivation to transform the course in light of the great opportunity to better prepare students for a world where data and information are playing an ever-increasing role. Having backgrounds in Industrial Engineering and Applied Mathematics, we tend to believe a strong foundation in statistics would be an advantage for any engineer and might feel justified in redesigning a course to reflect our own preferences. However, we recognize that our preferences may not serve all disciplines equally well and are therefore committed to taking a thoughtful and research-based approach. The next section broadly outlines long-term vision for the course as we understand it today and our timeline for executing the transformation over the next 3 years.

Long-Term Vision for the Course & Roadmap

Our vision is to transform the existing course into one that balances the classical statistics topics that are most relevant to the engineering profession with the realities of today's need for information literacy. Therefore, regardless of whether the course is accepted into the general education program initially, we intend to incorporate the oral and digital communication components into the course. Another element of the vision is to give students the opportunity to interact more with the data they are analyzing. This is of course not a new idea in teaching statistics. We believe there is value in novel techniques for teaching statistics [5], but favor a contextual approach for engineering education [6]. We are exploring the possibility of designing a lab space which will be (mostly) dedicated to teaching statistics and other data-centered topics in the IE program (e.g., Probability, Design of Experiments, Data Mining). Table 2 presents a summary of some of the key design characteristics the redesigned course will have, as we understand them today.

Table 2 – Anticipated Future Design Elements & Rationale

Element	Rationale
By way of a multi-week project, give students the opportunity to analyze and synthesize data/information in the context of a real-world problem and to communicate central findings.	This will allow students to choose a problem that is interesting to them and work with real data. We believe is in-line with current education trends.
Place a greater emphasis on regression analysis, including multiple regression.	Simple linear regression is familiar to many students and is an essential statistical technique. Most (all?) real problems have more than one important variable.
Deemphasize (not eliminate) assessment during lecture periods to allow for greater flexibility and allow for more time to be dedicated to instruction.	Restricting assessment to lecture periods limits how the subject can be taught and reduces the time available for instruction.
Place a greater emphasis on experimentation and analysis of variance (ANOVA) techniques.	ANOVA, Regression, and experimentation go hand-in-hand. Many of our students work in industry where Design of Experiments techniques are common.
Place a greater emphasis on using real/realistic and relevant data and examples in all aspects of the course.	Real data and relevant examples are just more interesting in a multidisciplinary course.
Emphasize graphical visualization of data using software for aspects of the course.	This is in-line with the assessment criteria for digital communication. Graphics techniques should be relevant (e.g., NOT stem and leaf plots).
Deemphasize rudimentary execution of basic statistics concepts that have little chance of being needed in practice (e.g., performing t-tests manually).	Engineers understand the mechanics of t-test calculations easily. The emphasis should be on application.

The transformation of the course is expected to occur over the next 2-3 years. The deadlines associated with the general education aspect of the course dictate the pace of the transformation. If approved as a general education course during the spring or summer 2019 semesters, the course is required to launch during the Fall 2020 semester. The lengthy timeline is also necessary given the size of the course and the significance of the curriculum changes. The roadmap for the redesign efforts includes achieving certain milestones by certain dates. Table 3 presents a chronological summary of the activities, milestones, and deadlines associated with the work.

Discussion

As we mentioned previously, our motivation for this paper is to outline our challenges and goals so that others may benefit and so that we can learn through feedback and the additional perspectives it will bring. A perusal of any engineering statistics textbook will reveal that the approach we are taking is a departure from what seems to be the norm, so it is appropriate to consider if our approach will erode the quality (i.e., rigor) of the course from an engineering perspective. After all, this approach goes against some conventional wisdom and even some feedback we received from students. Several students stated a strong preference for emphasizing hand calculations over the use of software, but we believe this approach to be a disservice to engineering students in an introductory course because it is in stark contrast to what they will encounter during their careers. A well-designed, relevant, and engaging curriculum will provide ample opportunities for rigorous exploration of the concepts.

We believe that aligning the curriculum more closely with modern practices (i.e., emphasis on software, real data sets, etc.) and integrating oral and digital communication principles into this course represents a natural progression for an engineering statistics curriculum. Our goal in this

Table 3 – Redesign Roadmap

Milestone	F18	SP19	SM19	F19	SP20	SM20	F20	SP21	SM21	F21
Initial assessment of student views.	**C**									
Internal application to become a general education course.	**C**									
Approval of general education status of the course (pending).		**IP**								
Construction of dataset and question banks.		**IP**								
Curriculum redesign.		**IP**								
Assessment strategy design.					**D**					
Develop TA Training materials & train TAs for new curriculum.						**D**				
Launch of the redesigned course (Fall 2020 & Summer 2021)							**D**			
Assessment of redesign.										

C: Completed, IP: In-Process, D: Critical Deadline redesign is to further develop fundamental data analysis and decision-making skills in students, and we recognize that such skills may only be beneficial if students can in-turn convert analysis into action by communicating what they know to others. It is better to emphasize the conceptual aspects and applications of statistics and save mathematical theory of the topic for more advanced classes that students may choose to pursue. By redesigning the course to help ensure conceptual understanding, we simultaneously contribute to the information literacy of a large and diverse population of engineering students.

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Appendix A

University Student Learning Outcome (SLO) for effective oral & digital communication and Associated Course Objectives (CO).

SLO #1: Demonstrate and apply information literacy

CO #1: To locate and evaluate information from a variety of sources regarding a relevant question, topic, or research need. Synthesize and use the information to create new insights that contribute to society.

SLO #2: Demonstrate effective and appropriate oral and digital communication abilities.

CO #2: To construct a meaningful central message from synthesized information and supporting material and to effectively communicate the message using oral and digital communication best-practices.

Appendix B – Student Evaluation Questions, Exact Wording

Numerical Response Questions:

1. Rate the overall quality of this course.
   [(1) Exceptionally Low …(5) Exceptionally High]
2. Did this course improve your understanding of concepts and principles in this field?
   [(1) No, Not Much …(5) Yes, Significantly]
3. Did you improve your ability to communicate clearly about this subject?
   [(1) No, Not Really … (5)Yes, Significantly]
4. I had the appropriate prerequisite and technical skills for this course.
   [(1) Strongly Disagree … (5) Strongly Agree]
5. How much have you learned in this course?
   [(1) Very Little … (5) A Great Deal]
6. As a result of this course, I want to take more courses in this area.
   [(1) No, Definitely Not … (5) Yes, Definitely]
7. Did this course increase your interest in the subject matter?
   [(1) No, Not much … (5) Yes, Greatly]
8. How valuable do you consider this course?
   [(1) Not Valuable … (5) Extremely Valuable]
9. Rate the relevance of course content to your major field.
   [(1) Not Relevant … (5) Highly Relevant]

Open-Ended Questions:

- What do you suggest to improve the course?

- Describe what you believe would be the BEST balance between working practice/homework problems by hand or using an online tool for practice/homework problems. Please be as specific as you can and state why you believe it is best.

- Describe an IDEAL lecture session (e.g. focus on theory & concepts, working examples by hand, using software to solve problems). Please be as specific as you can and state why you believe it is ideal. Assume the size of the lecture session stays the same.

- Describe the IDEAL lab session (e.g. review concepts from lecture, learn software, solve small problems, solve big problems). Please be as specific as you can and state why you believe it is ideal. Assume the size of the lab session stays the same.