Developing a Probability and Statistics Course for Civil and Construction Engineering Students

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Abstract

The Department of Civil & Environmental Engineering, and Construction Engineering at The Citadel developed and implemented a new undergraduate course in statistics. The curriculum revision was motivated by assessment information from a variety of sources including input from industry, alumni and the Department Advisory Council, as well as results from the Fundamentals of Engineering Exam. The consensus of faculty, students, alumni, industry and Advisory Council was that (1) a solid foundation in statistics is crucially important for civil and construction engineering practice, and (2) "solid foundation" means graduates can select and apply appropriate statistical techniques to analyze real data, interpret and report results. Previously the curriculum did not have a course solely dedicated to statistics providing graduates with the solid foundation representatives from professional practice deemed appropriate. In particular, graduates were not prepared to frame a problem in terms of a hypothesis that can be tested statistically, collect and analyze data using standard statistical models, and report analytical results for use in decision making. As part of a strategy to address this curriculum deficiently, a new probability and statistics course for juniors and seniors was developed with input from faculty, graduates, industry and Advisory Council. Construction Engineering students in their third year and Civil Engineering students in their fourth year are required to take CIVL-331 Probability and Statistics for Civil and Construction Engineering. The new course emphasizes Excel software rather than hand calculations and introduces use of statistical models for analyzing data sets and reporting results.

Keywords

Statistics, statistical models, data analysis.

Introduction

Expectations for graduates entering the engineering profession are changing and intensifying to meet the complex needs of society. Global issues, technological innovation, blending of discipline boundaries, and increased professional complexities are transforming how engineers analyze problems and provide effective solutions. Society demands are requiring engineering graduates possess strong technical knowledge and the ability to think creatively and critically, effectively communicate, and work in teams to solve challenging problems. Many contemporary engineering problems are considered multidisciplinary in nature making it clear that academic programs must educate engineering students for a technological era of increased scope, scale and complexity. Continuously changing technology and industry demands are influential factors in education. The engineering profession relies upon distinctive skills to innovate and effectively compete, and towards meeting those needs academic institutions are expected to provide a curriculum that introduces students to appropriate technologies for successful transformation into

productive careers. As a result, academic institutions are challenged to adopt appropriate strategies to meet innovative educational demands from both students and industry.[1]

Because engineers collect and analyze data to solve problems a knowledge of probability and statistics in the engineering domain is of great value. A knowledge of probability helps engineers examine how likely events could happen and how they can be resolved professionally. Knowledge of statistics facilitates the collection, presentation, analysis and use of data to make decisions, solve problems and design products and processes. Statistics enable engineers to monitor the outcomes of processes and provide a means of adjusting the process based on outcomes, which are within the expected range of variability.[2]

A Department degree requirement specifies that each graduating student take the Fundamentals in Engineering (FE) Examination. As part of the process for establishing a new construction engineering degree, faculty undertook a thorough review of curriculum and assessments. This included analyzing FE examination results for the CIVIL Computer Based Testing (CBT) Exam which averaged 4 – 6 questions on Probability and Statistics which covers; measures of central tendencies and dispersions, estimation for a single mean, regression and curve fitting, and expected value in decision making. The review showed that a dedicated course in probability and statistics would better prepare students for success on the FE exam, as well as engineering practice as assessed by the Accreditation Board for Engineering and Technology (ABET). Table one shows representative results for the Probability and Statistics portion of The Citadel's FE exam results. Using either the ratio score or scaled score, results indicate that Citadel students are performing below the national average for comparator institutions.

Table 1. Probability and Statistics portion of The Citadel's FE exam results.

Fundamentals of Engineering (FE) Exam: Probability & Statistics	Institution Average Performance Index	ABET Comparator Avg. Performance Index	ABET Comparator Standard Deviation	Ratio Score	Scaled Score	# students taking	Uncertainty Range for Scaled Score
Jan 01—Jun 30, 2017	8.70	9.70	3.40	0.90	-0.29	58	± 0.13
Jul 01—Dec 31, 2018	8.5	9.6	3.4	0.89	-0.32	20	± 0.22
Jan 01—Jun 30, 2018	7.8	9.7	3.4	0.8	-0.56	42	± 0.15

The remainder of this paper provides a background of The Citadel, description of engineering programs, course goals and outcomes, and discussion of future plans for the statistics course.

Background

The Citadel is a military teaching college in Charleston, SC, with a day program student body numbering about 2,200 students, and an evening program of graduate and professional studies with a student body of about 1,600. The mission of the Civil & Environmental Engineering, and Construction Engineering program is to provide a nationally recognized student-centered learning environment for the development of principled leaders in the civil engineering and construction engineering communities through a broad-based, rigorous curriculum, emphasizing theoretical and practical engineering concepts, strong professional values, and a disciplined work ethic. The Department of Civil and Environmental Engineering and Construction Engineering recognizes that civil engineers and construction engineers are people-serving professionals who manage resources as well as technology. Civil engineers and construction engineers plan, design,

construct, and maintain facilities essential to modern life in both the public and private sectors. Accordingly, the Department strives to develop the skills of its engineering students in the management of resources, time, materials, money, and people through effective combination of effective academic curriculum and military discipline.[3]

Prior to Spring 2019 a three-credit hour course, CIVL 330 Measurements, Analysis and Modeling for CEE Systems, was offered to the students. This course introduced concepts of 1.) uncertainty and variability of physical systems; 2.) analysis of measurement systems; 3.) physical modeling and scaling techniques; 4.) mathematical and numerical modeling; and 5.) impact of uncertainty on project economics. Based on faculty input, industry feedback, and curriculum reviews it was determined to sunset this course and establish a new dedicated course focusing solely on probability and statistics to the curriculum. Through the process of establishing a new construction engineering major, and review/comparison of curriculums from a number of civil and construction engineering programs at comparable schools, a list of core concepts and topics was identified for inclusion in a new probability and statistics course. The following learning goals were recognized for inclusion: 1.) to introduce civil and construction engineering students to concepts and techniques necessary to organize and analyze technical data, and 2.) combine descriptive statistical measures and probability theory to provide the basis for statistical decision-making techniques applicable to the practice of civil and construction engineering. Specific topics include data collection and presentation, measures of central tendency; measures of variability; basic probability laws and distributions; sampling theory, confidence intervals, hypothesis testing, analysis of variance, regression analysis, process control, and forecasting.[2]

Spring 2019 Offering

To introduce civil and construction engineering students to the application of probability and statistics, a pilot three-credit hour course, CIVL 453 Special Topics in Civil Engineering, was developed and offered as a technical elective to junior and senior civil and construction engineering students, as an initial offering in the transition to the new three-credit hour course CIVL 331 Probability and Statistics for Civil and Construction Engineering. Following the pilot offering of CIVL 453 in Spring 2019, the course was approved by appropriate undergraduate curriculum committees and established as CIVL 331. After which, three sections were offered in Fall 2019, two sections to day students and one section to evening 2+2 civilian students.

The major challenge in preparing a course of this type is in deciding how to condense abundant subject matter into allocated time constraints, while still providing significant technical content. In the first offering of CIVL 453 the planned range of topics to be cover in a one semester course was ambitious and it was a challenge to cover all of the desired material. Following the pilot course offering several lectures were condensed to allow for more class time to be allocated for solving of example problems using excel software. For CIVL 331 the two-day sections met three days a week for 50 minutes. To accommodate the evening section, which met two days a week for 75 minutes, course developers (aka paper authors) combined several lectures allowing differing versions of the course to maintain the same content. Table 1 provides a list of the course objectives, while Table 2 depicts how classroom hours are apportioned.

Table 1. CIVL 331Course Learning Objectives

CIVL-331, Probability and Statistics for Civil and Construction Engineering List of Course Objectives
1. **Analysis:** Access, manipulate and analyze data using excel. Produce appropriate graphs and descriptive statistics for one and two variables, for both categorical and continuous data. Calculate measures of dispersion and variation.
2. **Comprehension:** Distinguish between Population and Sample data, and categorical and numerical data. Distinguish between random and non- random sampling and create such samples. Interpret graphs and descriptive statistics for one and two variables. Know and apply the basic probability rules, the concepts of expected value and variance for discrete and continuous variables. Know and apply the Central Limit Theorem, which is crucial for inference.
3. **Synthesis:** Understand confidence intervals and hypothesis tests. Carry out and interpret one-sample and two-sample analysis for means and proportions. Carry out and interpret statistical modeling using regression and analysis of variance. Know and apply basic quality control procedures. Develop and interpret forecasting models.

Table 2. Course Schedule showing topic hours scheduled.

Topic	Hours
Introduction to Descriptive and Inferential Statistics	1
Data collection and sampling; Variables and Types of Data Observational and Experimental Studies	1
Measures of Central Tendency, Variation, Position	1
Frequency Distributions and Graphs	1
Probability and Counting Rules	3
Numerical Descriptive Measures; Probability	2
Discrete Probability Distributions; Continuous Probability Distributions	1
The Central Limit Theorem and the Normal Distribution	3
Confidence Intervals and Sample Size Estimation	3
Hypothesis Testing	3
Comparison of Two Populations	3
Testing the Difference Between Two Means, Two Variances, and Two Proportions	3
Midterm Exam	1
Correlation and Simple Linear Regression Analysis	4
Multiple Regression Analysis	4
Process Improvement Using Control Charts	3
Forecasting	4
Comprehensive Final Exam	3
Total	44

Course Goal

Students enrolled in CIVL 331 should develop a practical background in statistics that will allow them to apply statistical techniques to problems of data analysis, process control and experimental design in both research and process engineering environments. This course presents core learning concepts and uses engineering related problem sets in the homework assignments and exams for each concept to increase comprehension. In the first course module, students are introduced to basic concepts of descriptive statistics and are introduced to techniques for visualizing relationships in data, probability concepts and estimation. In the second course module, students are introduced to inference using confidence intervals and hypothesis testing as well as continuous and discrete distributions. In the third module, students draw on previously learned concepts to develop statistical modelling skills using regression, process control, forecasting and systematic techniques for understanding the relationships between data variables. Each homework problems sets required students to analyze, comprehend, and synthesis the lecture topics. The intention was to expose students to an assortment of related probability and statistics topics which build a foundation from which to conduct data collection and analysis.

Course Design

Use and availability of computers is changing how statistics is taught. Computers allow an emphasis on interpretation of data and de-emphasize hand calculations. Computers allow automation of two important aspects, calculations and graphics which in turn allows more student attention on the fit between statistical models and reality.[4] There are four principal aspects receiving primary emphasis within the course design: 1.) Calculations, hand methods are demonstrated and exercised in practice problems prior to demonstrating how to use excel for the calculations; 2.) Problem Solving, time is built into each class to discuss problem solving approaches using Excel; 3.) Higher-level practice, the homework assignments include problems requiring analysis, evaluation, and reporting; and 4.) Assessment, assessment of student learning focuses on higher-level assignments.

The course focuses on developing a deeper understanding through solving practical application problems. As expected in engineering practice, students are taught to use software for statistical calculations and graphics. Applicable equations are introduced, and calculations are explained and then demonstrated using Excel. Students are not expected to memorize or interpret the formulas. Rather, students are expected to choose the correct statistical technique to appropriately analyze data and to arrive at a solution, and then report results of the analysis.

Department faculty decided to adopt Excel as the official course software for the following: 1.) most students already have and are comfortable with Excel for solving problems; and 2.) Excel is a standard software package that is available to practicing engineers making the statistical problem-solving skills learned in this course transportable. Students are expected to learn more about using Excel for analysis on their own as the term progresses and seek individual help from faculty when necessary.

Course Assessment

Course assessment of student performance is based on the practical application problem sets solved for homework along with a midterm and comprehensive final exam. The course incorporates eleven homework assignments of increasing complexity requiring students to

collect data; develop an approach for analyzing the data using appropriate statistical techniques; solve the problem; and report results and conclusions. Simply performing calculations and providing a numerical outcome will not lead to a passing grade on these problem assignments. Students must demonstrate the ability to develop a problem-solving approach using appropriate statistical techniques and to interpret and report results. Table 3 presents a summary of the assessment outcome for CIVL 453. Further analysis is intended to assess course objectives for CIVL 331 in a similar manner at the end of the Fall 2019 term, and for subsequent offerings.

Table 3. Assessment of student performance on a key course objectives.

1. Analysis: Access, manipulate and analyze data using excel. Produce appropriate graphs and descriptive statistics for one and two variables, for both categorical and continuous data. Calculate measures of dispersion and variation.					
	LO1	LO1	LO1	LO1	LO1
Student	Hwk1	Hwk2	Q6 Mid	Q5 Final	Hwk7
Average	94.6%	95.4%	87.2%	93.8%	93.1%
Performance to Standard	92.8%				

2. Comprehension: Distinguish between Population and Sample data, and categorical and numerical data. Distinguish between random and non- random sampling and create such samples. Interpret graphs and descriptive statistics for one and two variables. Know and apply the basic probability rules, the concepts of expected value and variance for discrete and continuous variables. Know and apply the Central Limit Theorem, which is crucial for inference.							
	LO2	LO2	LO2	LO2	LO2	LO2	LO2
Student	Hwk3	Hwk4	Hwk5	Q9 Midterm	Q10 Midterm	Q 11 Midterm	Q 13 Final
Average	86.2%	89.2%	96.2%	82.3%	81.5%	90.8%	91.5%
Performance to Standard	88.2%						

3. Synthesis: Understand confidence intervals and hypothesis tests. Carry out and interpret one-sample and two-sample analysis for means and proportions. Carry out and interpret statistical modeling using regression and analysis of variance. Know and apply basic quality control procedures. Develop and interpret forecasting models.								
	LO3	LO3	LO3	LO3	LO3	LO3	LO3	LO3
Student	Hwk7	Hwk8	Hwk9	Hwk10	Hwk11	Q 16 Final	Q 18 Final	Q 19 Final
Average	93.1%	84.6%	82.3%	90.8%	95.4%	86.9%	86.9%	76.9%
Performance to Standard	87.1%							

For Learning Outcome 1 (LO1), students that completed CIVL 453 achieved an average mastery level of 92.8%. This is not surprising as the assessment covered basic concepts of data collection, analysis, plotting and reporting of descriptive statistics. Many of these skills are concepts and served as a refresher for material students had previously been exposed to in introductory classes. Students were easily able to work the homework assignments which gave them a degree of confidence relatively early in the course. The lowest performance was seen in Question 6 on the Midterm Exam which provided a sample data array and asked the student to compute by hand the Mean, Median, Mode, Range, Standard Deviation, and variance. This proved a little challenging to students who had been used to calculating the summary statistics for a data set using Excel. Generally, students utilized the correct steps in the calculations but made basic math errors in their computations.

The mastery levels for LO2 were slightly lower than those of LO1. Students seemed to have a more difficult time understanding the marginal, joint and conditional probability concepts as well as the discrete and continuous probability distributions. The course emphasized a number of basic probability problems in class and introduced the built in Excel functions for discrete and continuous probability functions which the students found to be very easy to use. The greatest student difficulty was encountered when covering the Normal Distribution and Central Limit Theorem. Students were taught to sketch out the Normal curve and to shade the areas of interest when working the Z transform probability problems. Those students who adopted the practice of sketching the curve as part of the problem-solving process scored much higher on that portion of the homework and exams.

The mastery levels for LO3 assessments covered some of the more advanced concepts in the course involving hypothesis testing and analysis and interpretation of statistical models. The average performance measures showed a greater degree of variation than the prior two LOs. Students generally did a good job of organizing raw data sets, and applying appropriate statistical techniques for the Homework assignments; 7 (Hypothesis Testing), 8 (F test), 9 (Simple Linear Regression), 10 (Multiple Regression), 11 (Forecasting). Throughout the course students improved on their ability to interpret results and clearly report them. The relatively low assessment outcome for Q19 of the final exam was surprising. Students were given an excel summary regression output and asked to read the output and;

a. State what the equation for the regression model is.
b. Discuss the r, R square and p values and state what they tell you about the model.
c. Calculate the estimate of Y for an X value of 3.5.

Students had worked a number of similar problems in class and in the homework and performed relatively better than on the exam.

Conclusion

By the end of Homework 11, students were able to demonstrate the ability to gather and organize data, select an appropriate statistical technique to conduct data analysis, and to interpret results and report their conclusions in a clear and concise report format. Initially students showed a tendency to present calculations and numerical results with insufficient interpretation and explanation of what the results mean. Providing students with a report template for homework

helped them to organize their thoughts and by the end of the course few students expressed any resistance to the format. At the end of each course students have the opportunity to fill out a course assessment survey and were asked "What did you like most about this course?" Responses included:

- Very applicable information and skills.
- There were days mixed in where we worked on Microsoft Excel in the computer lab.
- The relation to statistics and engineering.

A number of students stated that by the end of the course they had obtained a much greater appreciation for Excel's built in statistical functions and ease of use. Students felt techniques learned in the course were definitely transportable as they prepared to enter the job market.

In the future, professor's priority is to develop more practical application problems which involve the entire process of collecting, organizing, analyzing and reporting. Continued emphasis of introducing the students to key concepts and equations for problem solving and continued use of software for the calculations will allow the faculty to concentrate on teaching valuable analytic techniques that have direct applicability for real world problem solving.

This paper discussed development of an undergraduate probability and statistics course for civil and construction engineering students. The paper discusses the difficulty in topic selection, and how these difficulties were overcome. Although the new course has only offered twice because of scheduling availability, student response to the course has been universally positive. Improvements to the design of the course will include incorporation of a wider set of engineering related problem sets and presentation of homework results.

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