Elements of an Activity-Based Statistics Course for Engineers

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Abstract

Common criticisms of undergraduate engineering statistics courses are that they are too academic in focus, excessively theoretical, and divorced from real problems that appear in industry. This paper describes our effort to make statistics "come alive" through an activity-based engineering statistics course at Western Michigan University. This three-semester hour course is structured to include laboratory sessions, workshop sessions, and problem-based lecture sessions. The laboratory activities are intended to provide the student with an opportunity to become proficient in designing basic experiments, collecting data, and analyzing problems using PC-based statistical software. The workshop sessions involve short lecture segments mixed with team-based problem-solving activities and software tutorials. With the exception of lecture periods, course sessions do not take place in a classroom, but rather are held in a computer-teaching laboratory or in one of the laboratories managed by the Industrial & Manufacturing Engineering Department.

In this paper we discuss our experiences following two offerings of this course to students in industrial, chemical, construction, civil, manufacturing, and paper engineering programs. In particular, we focus on the laboratory and workshop activities. In developing this new course structure two challenging objectives were set: (i) to provide undergraduate students with a positive introduction to engineering statistics; and (ii) to give students hands-on experience with experimental design, data collection and analysis through laboratories and workshops. A comparison is made to our former traditional lecture course.

Introduction

There have been numerous discussions in the statistics community on how statistics should be taught to engineering undergraduate students and to undergraduate students in general. Drastic reform of introductory statistics courses has been advocated due to observations that "students frequently view statistics as the worst course taken in college"[1]. It seems reasonable that to acquire a conceptual understanding of basic statistical concepts, the orientation of an undergraduate statistics course must change from a traditional lecture format to one that engages students in active learning through "hands-on" activities. Bradstreet[2] writes that, "Learning is situated in activity. Students who use the tools of their education actively rather than just acquire them build an increasingly rich implicit understanding of the world in which they use the tools and of the tools themselves."

Cobb[3] presents a summary of 12 NSF grants concerned with the topic of the improvement of the teaching of undergraduate statistics. A majority of these projects include components of active learning that allow students to supplement what they have heard and read. Other projects which focus on statistics education and which include activity-based learning are found in Barton and Nowack[4], Smith[5], Gnanadesikan, et al.[6], Romero, et al.[7], Petruccelli[8], Alloway[9], and Bisgaard[10]. Recommendations for reforming statistics education also include the use of cooperative-learning activities, as a form of active learning, to supplement or replace traditional lectures. Garfield[11] discusses the details for implementing cooperative-learning strategies, and reports that researchers have had success in using cooperative practices in introductory statistics courses (see also: Dietz[12]; Keeler and Steinhorst[13]).

Course Objectives

This paper describes an ongoing project at Western Michigan University (WMU) which has the overriding goal of making statistics "come alive" in an undergraduate engineering statistics course. Based upon the success stories reported in the literature, several faculty members from the Department of Industrial and Manufacturing Engineering (IME) felt that there was a need and opportunity to change the traditional lecture approach of the department's undergraduate engineering statistics course to a more dynamic style that includes relevant and interesting material. At the same time, however, the course content needed to comply with the guidelines set forth in the Accreditation Board for Engineering and Technology (ABET) general accreditation criteria for engineering programs[14] and the additional engineering discipline requirements of the WMU programs which use this course to meet core probability and statistics requirements.

From the introduction of the industrial engineering program at WMU in the 1970's, the structure of the undergraduate engineering statistics course had consisted of three one-hour lectures per week. In its new form, the course now includes two one-hour lectures and one three-hour laboratory (or workshop activity) per week. This engineering statistics course (IME 261) is offered with the primary focus on industrial engineering; however, students from other engineering programs do take this course to fulfill their respective program requirements for probability and statistics. IME 261 is currently utilized by the following programs at WMU: industrial engineering, construction engineering, civil engineering, manufacturing engineering, paper engineering, and chemical engineering. Typically, the depth and breadth of the probability and statistics requirement for accredited industrial engineering programs are greater than what can be covered in a one-semester course. Most undergraduate industrial engineering programs include two to four semester courses covering topics in probability, statistics, design of experiments, and quality control. WMU's Industrial Engineering Program follows a three-course sequence. Therefore, IME 261 must contain the appropriate content to meet the requirements for engineering disciplines other than industrial engineering, and also serve as the first of three courses in the core of the industrial engineering program. In addition to these requirements, IME 261 must prepare students for topics covered in operations research, work measurement, ergonomics, simulation, operations control, and engineering design courses to which IME 261 is a co-requisite or a prerequisite.

In preparation to redesign IME 261, we set the following two challenging objectives:

1) Provide undergraduate students with a positive introduction to engineering statistics.

2) Give students hands-on experience with experimental design, data collection, and statistical analysis.

Course Content and Structure

Course topics have been chosen predominantly based on the topic list suggested in "*A Core in Statistics for Engineering Students*" proposed by Hogg[15]. The content of Hogg's course was developed for 45 lecture hours (3 hours a week for 15 weeks), including periods for tests and review. The syllabus for this course resulted from the collaboration of a subgroup of attendees at the Quality Engineering Workshop held in 1993, directed by John S. Ramberg and sponsored by NSF and the University of Arizona. The course structure has been adapted from a course that is taught at Penn State University, *Process Quality Management*, as described in the paper by Barton and Nowack[4].

Workshops occur in a computer-teaching laboratory during the same three-hour time block as the laboratories (on the weeks when laboratory sessions are not held) and are limited to approximately 24 students. The workshop topics are presented in very short lecture segments mixed with problem-solving activities. Student teams are required to complete and hand-in a worksheet for each workshop that is in turn assessed and returned with comments. An example of a workshop session is described below:

<u>Hypothesis Testing I</u>: *The initial hypothesis testing workshop demonstrates the meaning of Type I and Type II errors through the simulation and evaluation of a scenario in which shipments are sampled and tested to see if they will be accepted or returned to the vendor. True population parameters are revealed following testing at which time students evaluate the appropriateness of their test findings. The remainder of this workshop is used to practice implementing and interpreting the results of various single population hypothesis testing procedures, both manually and via software.*

The laboratory sessions are limited to approximately 24 students and last a maximum of three hours. They are intended to provide the opportunity for students to become proficient in solving real-world problems using PC-based statistical analysis. All activities take place in teams. During the labs, students must choose a data collection procedure, collect and analyze data, and make appropriate recommendations. During each laboratory session, each team is required to submit a one-page report on the tasks completed and recommendations made based on their experimentation and analysis. The location of the laboratories is dependent upon the laboratory activity. An example of a laboratory session is discussed on the next page:

Work Methods Design: *The work methods laboratory demonstrates that the method of assembly can significantly influence the time required to assemble a product. Participants are required to collect time data on 6 different "employees" assembling identical products via three different methods. Upon completion of the data collection phase, student teams are to complete the appropriate analysis in order to answer one question: Which method should the company be using? The experiment is set up in such a manner that if the teams do not use the appropriate design of experiment an erroneous conclusion will be obtained.*

At present, we have developed 6 workshop sessions and 6 laboratory sessions for this one-semester course. The laboratory (workshop) time period is also used to administer course tests during the semester. Workshop and laboratory titles and descriptions are as follows.

Workshop 1: Introduction to Minitab and Graphical Displays of Data.
For this workshop, data sets from sources such as the Space Shuttle Challenger are given to the students and others are randomly generated in Minitab. Since this workshop occurs during the first week of the semester the students are walked through many of the basic commands available in Minitab. This is followed by exercises in developing appropriate graphical summaries of data for continuous and categorical data sets.

Workshop 2: Probability Rules and Discrete Probability Distributions.
In this workshop, probability topics such as conditional probabilities and Bayes Theorem are motivated and illustrated through manual and computer simulations. Simulation is also used to illustrate the probability mass functions and cumulative probabilities distributions of the Binomial, Poisson, and Hypergeometric distributions.

Workshop 3: Normal Distribution and SPC (variable data).
Normal probability distribution calculations, the construction of Normal Probability Plots, the transformation of Log-Normal Data, and the illustration of percentile data are illustrated. Simulated data and data from a local industry are used to illustrate the concepts of variables data control charts, and their link to the Central Limit Theorem and Sampling Distributions.

Workshop 4: Confidence Interval Estimation, Prediction Intervals, and Tolerance Intervals.
Students begin by collecting a sample and constructing a confidence interval and then the confidence intervals are collected and compared against the known population mean. This is done to illustrate the meaning of the confidence level. The lab then proceeds with students simulating data samples from known distributions to illustrate the effects of sample size, standard deviation, and confidence level on the width of the confidence interval. This includes looking at both symmetrical and skewed populations. Similar exercises on simulated data are used to illustrate the differences between confidence intervals, prediction intervals, and tolerance intervals.

Workshop 5: Hypothesis Testing: Single Population Tests and Investigation of Type I/Type II errors.

This is the shipment evaluation activity previously described. In this workshop, the simulated shipments are generated in Microsoft Excel. In other laboratories and workshops simulation takes place directly within Minitab.

Workshop 6: Nonparametric Tests.

Exercises illustrating the implementation of the Sign Test, Wilcoxon Rank Sum Test, and the Kruskall-Wallis Test are completed. Comparisons of test results are made to parametric tests using data sets which are and are not appropriate for the implementation of the parametric tests.

Laboratory 1: Descriptive Statistics and Their Use in the Comparison of Data from Different Populations.

This session introduces the use of descriptive statistics in conjunction with graphical summaries such as box plots, stem-and-leaf plots, and quantile plots, as initial tools for describing and comparing data sets. Sample data from various populations are collected and analyzed. Data collection includes items such as anthropometric measurements (which can be compared by gender or against published population data) and the identification of various types of defects in a sample of machined parts (which allows students to consider categorical data). After collecting and summarizing data, students are asked to make inferences about the populations from which the data was collected.

Laboratory 2: Sampling Distributions, the Central Limit Theorem and the Law of Large Numbers.

Sampling distributions for the *sample mean* and *sample proportion* are illustrated through samples collected by the students. The laboratory starts with an exercise in which a population consisting of four numbers is used to illustrate that the expected value of the sample mean is equal to the population mean through the collection of all feasible samples from this population of size n = 1, 2, 3, and 4. Two other experiments take place during this lab, one illustrating the sampling distributions of the sample mean and one illustrating the sampling distribution of the sample proportion. In both cases, the effect of sample size on the sampling distribution is illustrated and the implications of the Central Limit Theorem and the Law or Large Numbers are discussed.

Laboratory 3: Hypothesis Testing: Two Independent Samples and Paired Sample Test.

In this laboratory each student team is given a unique situation to evaluate. Because the situation for each team is unique, each team must determine an appropriate hypothesis to test, devise an appropriate data collection scheme, collect an appropriate sized sample, analyze the collected data, and finally, make appropriate inferences based on their findings. Examples of proposed situations include comparing air pressure gauges (analog and digital) to determine if they yield the same average psi readings and determining if two manufacturing processes yield the same proportion of defective parts.

Laboratory 4: Single-Factor Analysis of Variance: Randomized Design and Blocking Designs.
Recall, this activity is based on the previously described assembly task. The experiment is setup in such a manner that if the student does not block in the analysis an erroneous conclusion is obtained.

Laboratory 5: Design of Experiments: Factorial Experiments.
Similar to Laboratory 3, various 2 and 3 factor problems are assigned to teams. Because the situation for each team is unique, each team must determine an appropriate hypothesis to test, devise an appropriate data collection scheme, collect appropriate sized samples, analyze the collected data, and finally, make appropriate inferences based on their findings.

Laboratory 6: Simple Linear Regression and an Introduction to Multiple Linear Regression.
To introduce the use of Minitab to construct regression equations and the corresponding statistical analysis, students devise and implement a data collection protocol to collect travel distance of rubber bands of different widths (same launch device used for all experimentation). A prediction equation and subsequent validation runs are performed. The second part of the lab involves a multiple regression experiment. In this experiment various anthropometrical and physiological factors collected by the students are considered in the prediction of an optimal product design, which can be adapted to individual characteristics.

Experiences with New Course Structure

In teaching statistics, it has been the authors' experience that students often get caught up in the tools and techniques of the course and never see how the topics relate to one another. Therefore, in developing the laboratory and workshop materials the goal was to show how the different elements of statistics fit together within the course, throughout the curriculum, and in the practice of engineering. By developing practical and realistic activities for the laboratories and workshops it was assumed that the students will gain the confidence to apply the statistical techniques learned in new and different situations.

This course was offered for the first time in its modified structure during the Fall 2002 Semester. The traditional lecture-based course was also offered during this time period to the same student population. Of the 68 students enrolled in this course, 25 students took part in the lab-based course stream and 43 students enrolled in the course stream with the traditional structure. The same instructor taught both course streams, including the supervision of laboratory and workshop activities. To assign grades, the evaluation instruments were two 75-minute tests, six short (unannounced) quizzes, and a final exam. The lecture-based stream of students also handed-in homework assignments, which counted for the same percentage of their grade as the laboratory and workshop assignments counted toward the students in the lab-based stream. The tests, quizzes, and final exam were the same for both streams of students. One open-ended question was also placed on the final exam which asked the students to describe how they would carry out an experiment (from data collection to final recommendations) based on a given scenario. The second offering under the new course structure took place during the Fall 2003 semester. The Fall 2003 offering included two distinct lecture streams each with two laboratory sections. The lab-based course was the only structure offered during the Fall 2003 semester. The Fall 2002 final exam was again administered to the Fall 2003 students. For further comparison, two summer lecture-based sections, Summer 2002 and Summer 2003, used the same syllabus, evaluation instruments and final exam as the Fall 2002 lecture-based stream. Again, the same instructor taught both of these course sections. In total, for the four academic sessions, there were 87 students who took the lab-based course and 71 students that completed the lecture-based course. The following table (Table 1) is a brief summary of the two student populations based on student GPA's prior to taking IME 261.

Table 1: GPA Summary of Lecture-based and Lab-based course sections

	Student GPA
Lecture-based Sections (n = 71)	mean = 2.8 median = 2.8 std. dev. = 0.6
Lab-based Sections (n = 85)	mean = 2.9 median = 2.9 std. dev. = 0.6

Evidence gathered from students regarding the new course structure is positive. While not surprising, the most interesting finding to date is that a good student will perform well in almost any learning environment while the average student appears to be most positively affected by a more hands-on learning environment. This can be inferred from the fact that a higher percentage of students in the lab-based sections for certain GPA ranges earned grades higher than their respective GPA than did students in the lecture-based sections. This was most evident in the 2.0 to 2.5 GPA group (71% of lab students versus 55% of lecture students) and the 2.5 to 3.0 GPA group (70% of lab students versus 57% of lecture students). Furthermore, the lab-based students in these two GPA groups scored higher than the lecture-based students on the final examination's open-ended question. There was no significant difference in students with GPA's greater than 3.0 for the two groups. This information is summarized in Table 2 below.

Table 2: Percentage of Students Earning a Course Grade which was above their GPA

GPA Range (4.0 scale)	***Lab Sections*** **% of students earning a grade higher than their GPA**	***Lecture Sections*** **% of students earning a grade higher than their GPA**
3.0 – 3.5	61%	62%
2.5 – 3.0	70%	57%
2.0 – 2.5	71%	55%
1.5 – 2.0	33%	33%

Subjective student ratings regarding the lab-based course structure were also quite positive. In particular, there is a statistical difference in how students responded to the following statement: "*My overall evaluation of this course is that it is in the top 25% of all courses taken at WMU*." Students who were enrolled in the lab-based sections rated this stated more positively than those in the lecture-based sections. Approximately a 0.5 point difference was realized between the two course structures based on a 5 point Likert Scale, where 1 = Strongly Disagree and 5 = Strongly Agree (Lecture-based average score = 3.70 and Lab-based average score = 4.22).

As long-term evaluation of future offerings of this new course structure occur, a more thorough assessment and evaluation of the effectiveness of the changes from the lecture environment to the lab-based environment will be made. While student-based assessment of the course has and will continue to occur, plans are also in place to interview and survey the engineering faculty members that teach the courses to which IME 261 is a prerequisite to help determine if the new course structure has any effect on the statistical maturity of the student and their ability to appropriately apply statistical concepts and techniques. The surveys and interviews will differentiate between students based on the IME 261 course format completed, when possible.

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