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Optimizing the Curriculum in an Engineering Statistics Course with Realistic Problems to Enhance Learning

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OPTIMIZING THE CURRICULUM IN AN ENGINEERING STATISTICS COURSE WITH REALISTIC PROBLEMS TO ENHANCE LEARNING

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Abstract

The primary objectives of an engineering statistics course are to provide the fundamental knowledge necessary to understand both descriptive and inferential statistics and their applications to real life engineering situations. This is important in nearly all engineering disciplines, especially in quality control used in most manufacturing processes. Having a thorough understanding of probability, as it pertains to uncertainty, is critical for all engineering students. Nearly all universities require some type of engineering statistics class in order for students to graduate. The effectiveness of these courses in teaching students how to use and apply statistics in a real world engineering setting is unclear. Most schools teach the basic principles such as general probability, probability distributions, confidence intervals, hypothesis testing, regression, analysis of variance, nonparametric statistics, and statistical quality control. However, these topics are usually taught in standard classroom settings and do not include hands-on solutions to engineering projects. At our institution, the students are required to take a Laboratory Analysis and Reports course, instead of a typical engineering statistics class. In addition to this required course, our school also offers an elective course in quality assurance. In this class, among other things, students study and solve several engineering statistics problems, analyze the data, and perform error analysis and data interpretation. Such a method of teaching helps students learn statistics and its applications in engineering. Solving these realistic problems helps students to enhance their conceptual understanding and motivate them to further pursue their learning in the use of statistics. This paper presents in detail several interesting problems related to different uses of statistics, and how they are linked to convey the message of targeted course objectives. Furthermore, this paper explains the details of such a teaching methodology and addresses the educational outcomes obtained in our Laboratory Analysis course. This paper also discusses a series of problems that are currently used at our institution to help the students apply what they learn in the course. Properly integrating such a teaching methodology in the curriculum to optimize students learning will be addressed. In addition, a study will be conducted of several other colleges to find the best possible problems. From this study, implementation recommendations will be given.

Introduction

Shortly after the Bachelors of Science in the Mechanical Engineering program was first launched at our school, the faculty with input from the department's Industrial Advisory Board (a group representing the major local engineering industries and employers) realized that students lagged in the area of laboratory analysis as well as technical writing. A specific course was devised to address these concerns. The course includes a section on technical writing, uncertainty analysis, error propagation, as well as statistical analysis. A typical student entering the Mechanical Engineering (ME) program usually has no prior exposure to the concepts of probability or statistical analysis, because these were not included in any of the required or prerequisite courses for the program. While students might understand the need and the cause of uncertainties and error propagation, technical writing and statistical analysis tend to be more challenging for them. In particular, they fail to see the usefulness and importance of statistical analysis and are under the impression that they will never have to be concerned with it in their professional careers. The course topics include both finite and infinite sets of data in addition to Gaussian and $T_{v,p}$ tables. In order to convey the importance of the topics to students, several laboratory experiments were used to examine the behavior of data and then were applied to the concepts seen in the statistical analysis part of the course. These labs and analytical methods will be discussed along with a review of the methods used by other schools. From this study, the best applications along with implementation recommendations will be given.

Description of our Program

Eastern Washington University offers two courses using statistical analysis: MENG 300 Laboratory Analysis and Reports and METC 468 Quality Assurance. MENG 300 is a required class usually taken at the sophomore level and is a prerequisite for many engineering courses that have labs. METC 468 is an elective typically taken in a student's senior year. Statistical Laboratory experiments from both these courses in the Mechanical engineering curriculum are introduced for this study.

In MENG 300, the experiments and statistical analysis are all performed during the scheduled two hour lab. The lab class consists of 15 students on average and each individual gets to contribute. Data is generated by having each student throw the darts or roll the marbles a number of times but the data analyzed is that of the entire class. The students use Microsoft Excel to compute the averages and standard deviations; this is done individually. Grading is done by quizzing each individual student at the end of the lab. They are asked to discuss the histograms, their relation to the standard deviations, the different equations used for the standard deviation as well as show how these are generated using Excel. Each class gets to perform one lab on statistical analysis, whether it is the dart or the marble.

The labs consist of three versions depending on how the data was generated. In the first case, the data was generated by simply weighing a large number (more than sixty) of glass marbles using a digital scale. The students are then asked to construct a histogram and compute the average and standard deviation of the sample. They are then asked to comment on the results, to see whether the data does indeed follow the Gaussian distribution or not, answer questions on the probability of a certain measurement between a given range, and provide an estimate of the actual mean given the average of the first ten measured. The second version of the lab generates data by having students get a marble as close to a fixed line as possible by simply rolling it. The data consists of the distance from the marble to the line, and is taken to be negative if the marble stops before the line and positive if it crosses the line. The fact that students expect to see the average at zero, while it usually isn't, creates some meaningful conversation and reminds them that not all data follows a normal distribution. The third version of the lab generates data by using a dart game. The data consists of the radial distance between the center of the target and the dart. The students throw the dart a number of times until they have a sufficient number (again over sixty) of data points. In one instance, there was no distinction between positive and negative values, as a result the average was never zero and the data obtained did not follow a normal distribution. In another instance, any dart that fell below the center line (a horizontal line going through the center of the target) received a negative value and positive otherwise. In this case, the results showed more of a normal distribution than in the previous case, with an average closer to zero. For all of the previous cases, the students were asked to comment on the data obtained and answer a series of questions. They were also asked to construct a histogram for the first ten data points obtained as well as the entire set and compute the averages and standard deviations of the results obtained. Figures 1 to 3 show the experimental setup and corresponding histograms. It is clear that the data does not seem to follow a normal distribution but a trend can be seen. In particular, for the third case the values were all positive since the radial distance was always taken as positive. In this case, the average is really not a good representation of the mean and the distribution did not seem to be a Gaussian one. Aside from the fact that students enjoy the lab due to the nature of the data collection, this lab emphasizes the importance of statistical analysis by providing students with a way to create and analyze their own data. Feedback received recently from local employers showed that recent graduates from the program are now more knowledgeable about statistical analysis indicating a very positive outcome.

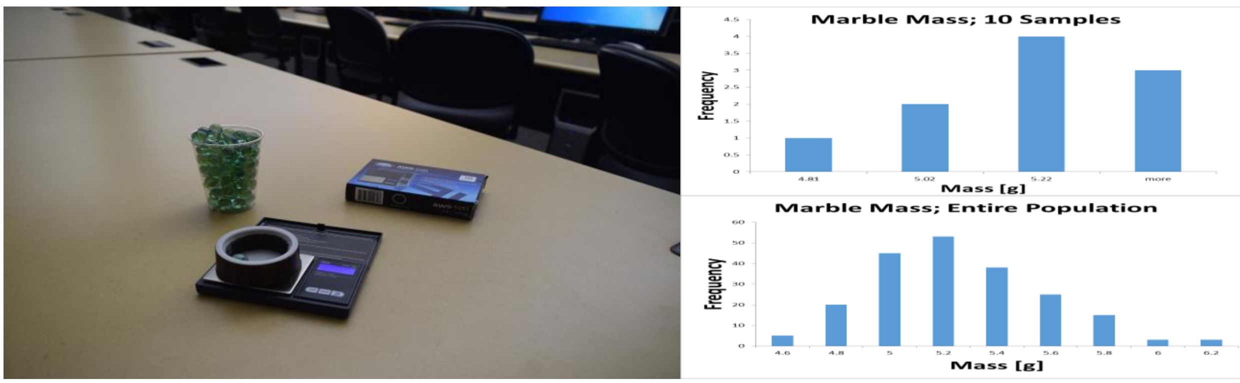

Figure 1 Experimental Setup for Marble Mass Measurements and Histograms

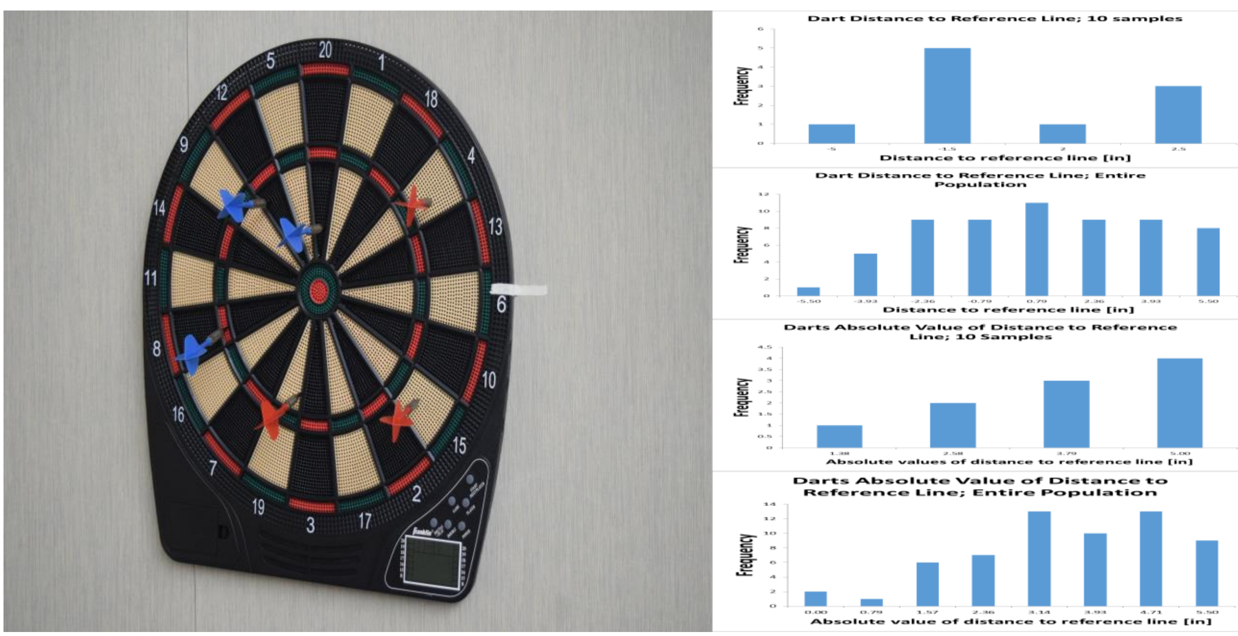

Figure 2 Experimental Setup for Dart Experiment and Histograms

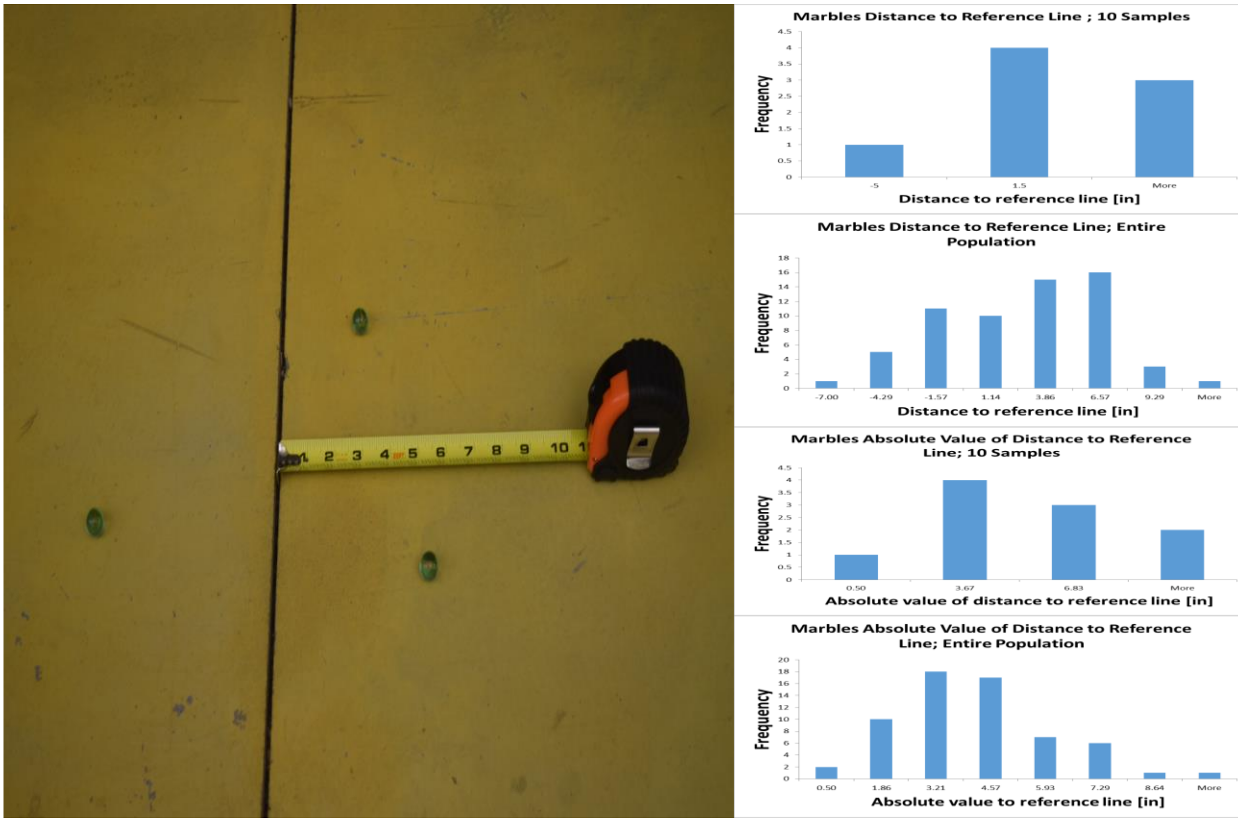

Figure 3 Experimental Setup Marble Distance Experiment and Histograms

In METC 468, the experiments and statistical analysis are all performed during the scheduled two hour lab. The lab class consists of 15 students on average and each individual gets to contribute. In METC 468, control charts are used in statistical control to indicate when special-cause variation is present in a manufacturing process. Typical special-causes are poor employee training, worn tool, machine needing repair, etc. Charts indicate when a source of variation occurs, the chart patterns provide hints to the cause of the variation and the workers can use the hints along with their experience to identify the source of the variation problem and eliminate it. Figure 4 is a typical example of control charts. Upper Control Limit (UCL) and Low Control Limit (LCL) indicate the 3 standard deviations from the mean value. If the data point is located out of UCL or LCL, there is a special-cause variation in a manufacturing process. METC 468 Quality Assurance class implements several laboratory experiments to use various types of control charts. Among the labs, the Chex Mix lab utilizes the *p* control chart. The *p* control chart is used to monitor the proportion of nonconforming units in a sample such as % of defective and number of flaws. The value *p* is the fraction or percentage of the number of items checked that are defective or unacceptable.

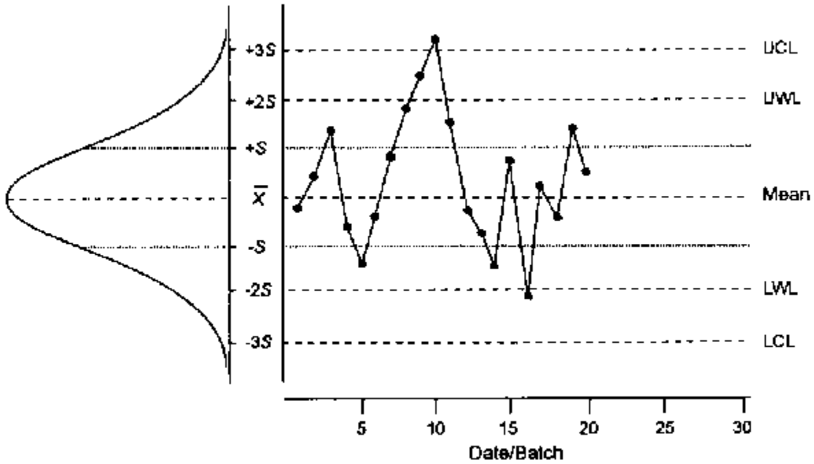

Figure 4 A Typical Example of Control Charts

The purpose of the lab is to practice generating *p* control charts from data collected by analyzing the quality of the contents of a Chex Mix bag. Students analyze the data by setting base criteria for defective chips and non-defective chips in the mix. Figure 5 shows the good and bad standard for each category of the Chex Mix. Once a baseline is determined, they sort and measure the weight of the good and bad chips. These results are then analyzed by creating the *p* control chart. Figure 6 shows the results of the analysis using the *p* control chart. From the *p* control chart shown in this figure, students are able to analyze the result that the round pretzel was below its lower limits, which means that it had low defect. The brown chip, on the other hand was out of the upper control limit which means that it had high defect. Students are also able to analyze that there is a special cause variation for the brown chip.

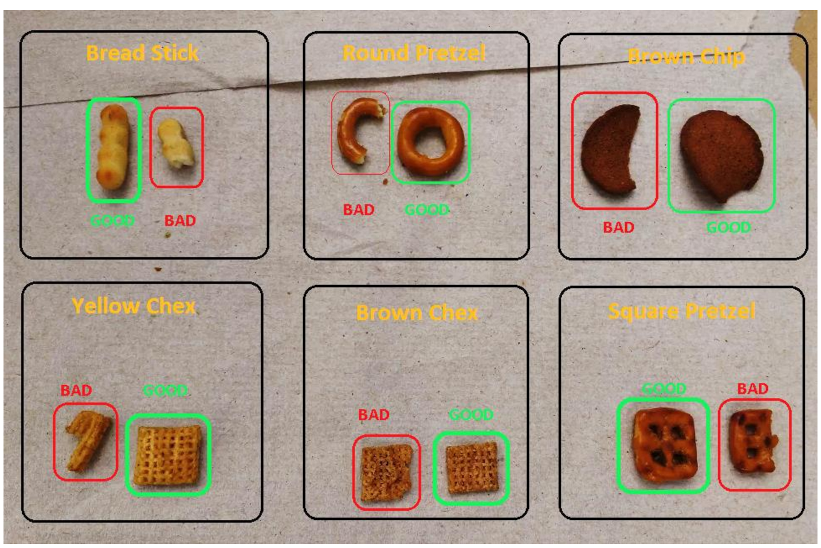

Figure 5 Good and Bad Standard for each Category of the Chex Mix

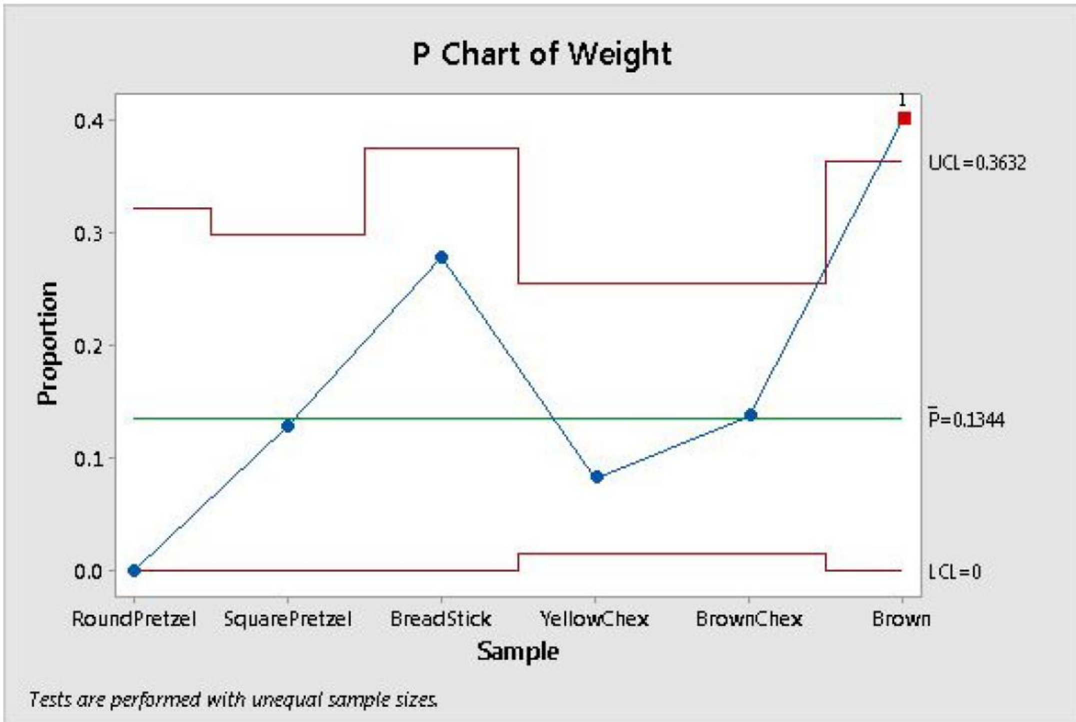

Figure 6 *P* Control Chart for the Weight of Defective Pieces using Minitab

Methods Used by Other Schools

Most schools require that their engineering students take at least one statistics class. This class is usually taught by either the mathematics or the engineering department and the curriculum can vary greatly from university to university. However, most universities realize that practical application is necessary to be taught in statistic classes in order for engineering students to learn how to apply statistical methods to real life engineering problems.

At the University of Wisconsin Madison[1] (UWM) attempts have been made to teach statistics as part of the scientific method. This includes teaching engineers' inductive reasoning, experimentation, and problem solving using statistics. In particular, this involves working on real engineering problems, performing detective work, drawing conclusions, and taking action.
To make it real, Soren Bisgaard a professor from UWM describes an example he has used in his statistics class building and testing paper helicopters. He tells his students that they are in the process of developing a better helicopter and, therefore, they need to test this prototype. Specifically, he tells them that an important characteristic of the helicopter is flight time. Then he has students climb up on a ladder and drop the helicopter four times from the ceiling, measuring the time it takes to hit the floor, and, of course getting different numbers. Next, he has them plot the data as a dot diagram showing that the first step in any analysis is to plot the data. From the plot, they develop the ideas of location and dispersion and learn how to quantify these notions in terms of the average and the standard deviation. His students are also given simple diagrams that explain the central limit effect and the fact that an average has the same mean with a smaller

variance than the original observations. Everything is introduced heuristically, inductively, and intuitively, so that students develop a feel for what it means in the engineering context of the problem. The helicopter experiment immediately raises questions by students about how to measure flight time, operational definitions of when the flight time begins, etc. According to Dr. Bisgaard, conducting the experiment for the class brings realism to statistics and stimulates valuable discussions. He also indicates that such experiments emphasize the point that statistics is a natural part of engineering. It should be important for a good engineer to test the prototype before manufacturing and production of the real product.

In another study [2] entitled "The Effect of Active Learning Methods on Student Retention in Engineering Statistics" an experiment was carried out to investigate the long-term effects of active learning methods on student retention in an introductory engineering statistics class. Two classes of students participated in the study; one class was taught using traditional lecture-based learning, and the other class worked on group projects and cooperative learning-based methods. Retention was measured by monitoring students immediately after completion of the course, and then again eight months later. The findings suggest that active learning can help increase retention of students with average or below average grades. Graphical displays of the data, along with standard statistical analyses, help explain the observed difference in retention between students in the two different learning environments.

Other techniques used to teach statistics involve using computer simulation. In a study entitled[3] "Teaching engineering statistics with simulation: a classroom experience", the course content alternated between a (simple) textbook example and one of five experiments. The main objective was to increase interest in and to develop appreciation for statistical methods in engineering students. This was achieved by giving practical interpretations to the experiments. The first two experiments were illustrated through the example of a lathe operator. The third experiment exemplified the operation of an assembly plant with the first part representing the complete assembly process and the second part representing the quality control stage. In the fourth experiment, the assembly plant was more complicated since it included two different production lines similar to assembly lines in automotive industry. Finally, the fifth example represented the operation of the checkout counter of a supermarket. At the beginning of each homework assignment, the experiment was explained, so that students would understand the statistical nature of the problem. Then the engineering applications of the methods were applied through computer simulations.

In a paper[4] called "Development of a Freshman Engineering Measurements and Analysis Course Integrated with Calculus-based Statistics" a redesigned statistics course was developed with seven cases along with their corresponding lectures. These seven cases were as follows: Case 1: Process Variability and Direct Measurement, Case 2: Linear Regression and Indirect Measurement, Case 3: Probability Concepts, Case 4: Power Measurement and Ohm's Law, Case 5: Convection Heat Transfer, Case 6: Stress and Strain Measurements from a Cantilever Beam in Bending, and Case 7: Gage Repeatability and Reproducibility. After the initial offering of this redesigned course, students were asked to provide feedback on the course structure. Students feedback were positive and indicated that the significant amount of hands-on data collection and use of laboratory equipment were important elements in understanding statistical analysis methodology.

Another paper[5] entitled "Elements of an Activity-Based Statistics Course for Engineers," describes an ongoing project at Western Michigan University (WMU) which has the over-riding 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 included relevant and interesting material. Evidence gathered from students regarding this new course structure was positive. Six workshops along with six labs were developed for a semester long statistics course. The six workshops, included the following: (1) Introduction to Minitab and Graphical Displays of Data, (2) Probability Rules and Discrete Probability Distributions, (3) Normal Distribution and SPC (variable data), (4) Confidence Interval Estimation, Prediction Intervals, and Tolerance Intervals, (5) Hypothesis Testing: Single Population Tests and Investigation of Type I/Type II errors, and (6) Nonparametric Tests. The six labs included the following: (1) Descriptive Statistics and their use in the Comparison of Data from Different Populations using deflects in a sample of parts, (2) Sampling Distributions, the Central Limit Theorem and the Law of Large Numbers using a sampling of numbers picked by the students, (3) Hypothesis Testing: Two Independent Samples and Paired Sample Test using examples such as comparing air pressure gauges (analog and digital) to determine if they yield the same average psi readings, (4) Single-Factor Analysis of Variance: Randomized Design and Blocking Designs using some of the data from the past labs, (5) Design of Experiments: Factorial Experiments using data chosen by the students, (6) Simple Linear Regression and an Introduction to Multiple Linear Regression collecting the data of the travel distance of rubber bands of different widths.

At Rochester Institute of Technology[6], the engineering department developed statistic modules in order for their students to know how to apply and use statistics in engineering. The modules were developed in three different formats: engineering kits, videos, and case studies. Some of the examples of these modules were: (1) the Rockwell Hardness, (2) the Knoop Indentation versus Load, (3) the Penny module. For the Rockwell Hardness module, the data set includes twenty five hardness measurements for each of five hardened tool steel specimens. The instructor chooses to use a single specimen or to compare several specimens. Guided data analyses with appropriate contextual questions were provided for exploring graphs, descriptive statistics, population models, and statistical inference. Similarly for the Knoop Indentation module a number of indentation measurements were made with a rhombic-base pyramidal diamond indenter. This data set contained ten indentation size measurements at each load setting (100, 200, 300, 500 and 1000g). The module was designed to assist students in an investigation of least squares regression. The analysis would start with a scatterplot of indentation size versus load. Students would examine the graph for evidence of a relationship between load and indentation size. Then, they would compute the coefficient of correlation and evaluate whether a linear relationship would be appropriate.

The third module used 100 new and 100 old pennies in measuring diameter, height, and mass. Washers could replace pennies in this module; however, in this study pennies were used. Several options were available with this module. Simple linear regression analysis (including scatterplots, correlation, least squares regression, etc.) was one option. Students could investigate the relationships between mass and height, mass and diameter, and mass and volume. Obtaining regression equations, interpreting parameters, predicting response values, and verifying assumptions were included. Alternatively, an instructor could have students examine the relationship between condition of the pennies (old or new) and mass (or volume) using two sample inferential methods for comparing means and/or variances.

At Grand Valley State University[7], they have developed a laboratory-based course introducing engineering statistical methods as well as their applications to product, process, and operations issues. Report writing and technical work are equally emphasized in the laboratory experience. The companion lecture introduces statistical methods via co-operative learning groups and active learning techniques. The laboratory component of the course instructs students in dealing with various products, processes, and operations issues through statistical analysis and inference. A variety of measurement devices are employed including calipers, mass balances, digital multi-meters, and gages as well as watches to estimate work time. Large metal washers, circuit board assembly times, resistors, and solar panels are among the subjects measured. Students work in pairs to perform measurements and collect data. Computational work and report writing are done individually. The laboratory component is 42% (=14 laboratories X 3%) of the course grade. Students are introduced to the Mathcad mathematical worksheet tool as well as office software including a word processor with an equation editor, spreadsheet, and presentation graphics. About three laboratory periods are devoted to software tutorials. These software tools are used in subsequent engineering courses.

An interactive laboratory has been used in a probability and statistics course for undergraduate civil engineering students at the University of Texas in Austin[8]. Homework problems are given to students to practice the computations involved with probability and statistics concepts and the labs are designed to give students an opportunity to experience probability and statistics concepts in real-world civil engineering situations. Two types of computer simulations are used in the laboratory. With the exercises for both programs, students collect data from the simulated civil engineering situation, and then apply probability and statistics concepts to analyze the uncertainty in the situation. Students are assigned to groups of four for the semester. They work in pairs from their groups to perform the computer situation and collect data, and then complete the analysis and the lab report as a group of four.

In a study performed at the University of Memphis[9] entitled, "Three Examples to Relate Theory and Application" three projects were presented to improve students' understanding of the value of statistics, to acquire hands-on experience in statistical analysis, and to develop the capacity to learn new concepts on their own. The three projects were as follows: (1) A Food Court Visit where the students collected data related to people visiting various restaurants, (2) A Work Experience project where the primary outcome of this experiment was that the students learned to statistically analyze situations within their own technical job environments, and (3) A Markov Chains project was used in the analysis of historical reliabilities that could be used to help a mechanical engineer determine the most cost effective strategy for replacing machine components. A survey given after completion of this course in one semester showed that 33 percent of students felt that the course exceeded their expectations and 47 percent felt that the course met their expectations. These results were a great improvement from the previous semesters.

Conclusion and Recommendations

From the results of our study of other universities and our own experience, we have found that engineering students greatly benefit by using statistical applications in the classroom. In a study entitled "Teaching with Visuals in the Science Classroom," it has been shown that students learn best by visuals and examples[10]. These methods include using pictures, and realistic problems to show students how to apply concepts and theories. If a student can visually see how all the pieces fit together, they will be able to master the subject and apply it to real-world applications.

After examining all the information, the following are recommendations that a typical engineering statistics course should contain:

(1) A descriptive statistics example involving data collection and sampling should be used. This should include collecting, organizing, analyzing and graphing of data from an example. Pennies, marbles, washers, nuts or bolts could be used and the weights could be measured and graphed along with calculation of their mean, and standard deviation.

(2) Check for outliers using sample data.

(3) Demonstration of sampling distributions, the Central Limit Theorem and the law of large numbers using a sampling of numbers picked by students.

(4) The learning of uncertainty analysis using examples from a fluids, thermodynamics, heat transfer or other engineering laboratory experiments.

(5) A Rockwell Hardness test and/or tensile test on number of specimens should be measured and used for statistical inference, quality control analysis, etc.

(6) Two Independent Samples and Paired Sample Tests using examples,such as comparing air pressure gauges (analog and digital) to determine if they yield the same average psi readings.

(7) Simple Linear Regression and an Introduction to Multiple Linear Regression collecting the data of the travel distance of rubber bands of different widths.

(8) A final group project chosen by students to demonstrate various applications of statistics in an engineering setting.

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