Engineering Statistics as a Laboratory Course

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Abstract

Highly influenced by the reform movement in general introductory statistics courses, we have developed and are continuing to improve 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 course is required of all engineering students and is nominally scheduled for the second semester of the freshman year.

I. Introduction

Recently, many statisticians have become involved in a movement to reform general introductory statistics courses[2]. This reform has focused on changes in content (more data analysis, less probability), pedagogy (fewer lectures, more active learning), and technology (for data analysis and simulations)[3]. A principal objective of the reform movement is to help students learn and apply statistical thinking. Statistical thinking has been defined as thought processes that recognize that variation is all around us and present in everything we do[4].

A fundamental challenge is to apply what has been learned from the reform movement for general introductory statistics courses to introductory engineering statistics courses. Meeting this objective involves helping students see how variation effects engineering in all disciplines. Doing so requires addressing product, process and operations issues via data collection, statistical analysis, and statistical inference. Thus, a laboratory component must be a significant part of an introductory statistics course. The lecture component of the course must be designed to support the laboratory component. The content of the lecture should emphasize data analysis. Teaching methods such as active learning and co-operative learning groups are necessary.

This paper describes our current efforts and future vision for achieving a reformed introductory engineering statistics course. A course overview is given as well as detailed information about the laboratory and lecture components of the course.

II. Course Overview

An introductory engineering statistics course is required of all students in the Padnos School of Engineering at Grand Valley State University. The course is nominally scheduled during the second semester of the freshman year with prerequisites of Calculus I and English composition and Calculus II as a co-requisite. The course meets twice per week, once for a two-hour lecture and once for a three-hour laboratory. There are typically 25-35 students per lecture and 15-20 students per laboratory.

The course provides prerequisite material for two subsequent courses: quality control and design of experiments for manufacturing and mechanical engineering students as well as probability and stochastic processes for students in computer and electrical engineering.

III. The Laboratory Component

The laboratory component of the course instructs students in dealing with various product, process, 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.

The first laboratory exercise involves a descriptive study of large metal washers. A sample of washers is selected. Both weight and thickness are measured, the former using a mass balance and the latter using a caliper. Students compute descriptive statistics about both quantities as well as developing histograms and plots. As a follow on, the last laboratory exercise involves using simple linear regression to fit a line to predict thickness from weight. Students are asked why not all of the variation in the thickness is due to the variation of the weight and what other sources of variation might exist.

The second measurement exercise involves establishing a time standard and a loss percentage for the assembly of circuit cards. Students work in pairs to measure the assembly time using a watch. Each student must perform the soldering necessary to make the circuit card work. Any card that requires rework is included in the loss percentage. A standard time to assemble 1000 cards must be determine. This requires the application of the Central Limit Theorem.

The third exercise involves confirming that a set of resistors conforms to the nominal resistance specified by the manufacture. Each pair of students is given resistors with a different nominal resistance. Resistances are measured with a digital multi-meter (DMM). Confidence intervals are estimated for two cases: 1) the standard deviation of the resistance is estimated from the data and 2) the standard deviation of the resistance is assumed to be a function of the stated manufacturing tolerance. If the confidence intervals contain the nominal resistance, the resistors are considered to be conforming.

The fourth measurement laboratory addresses conducting a gage repeatability and reproducibility analysis using micrometers and Vernier calipers. The gage R&R study is used to determine the amount of measurement variation due to the operator, the gage, and the combination of both as a percentage of allowable tolerance and as absolute values.

The fifth laboratory addresses sizing an array of panels for a solar powered building at a particular site. A small solar panel is attached to a fluorescent light. Using DMM's, the voltage and current characteristics of the solar panel can be measured for various resistances. From this information the power capacity of the solar panel can be determined.

Information concerning the solar radiation available at the building location can be found in the national solar radiation database (http://rredc.nrel.gov/solar/pubs/). Thus, the number of solar panels needed to meet the power requirements of the building can be computed.

In addition, operational questions concerning the solar panels can be addressed using hypothesis testing:

1. Can a solar panel absorb the minimum minimum amount of radiation each day?
2. Is the amount of radiation a solar panel can absorb each day different from the annual average?
3. Show that the maximum maximum is more radiation than the solar panel can absorb each day.

Laboratory reports provided students with their first technical writing experience. This experience lays a foundation for technical writing throughout the engineering curriculum.

The laboratory report has the following major sections: abstract, introduction, apparatus, procedures, results and discussion, and conclusions. Writing instructions are given for one or two sections per week. For the descriptive statistics laboratory, only the apparatus, procedures, and results and discussion sections are required. The next laboratory requires these sections plus the conclusions section. This practice is followed until students are writing a complete laboratory report.

Detailed writing instructions specific to each laboratory are given. A generic example laboratory report is provided. Laboratory reports are graded for quality of technical content and of writing. Reports are returned quickly. Thus, students may use instructor feedback concerning their writing in developing the next laboratory report.

A term project is the laboratory capstone. Students download data concerning flight volume for one control tower from the Internet and use hypothesis testing to answer assigned questions. Subsequently, each student is paired with another who was assigned a different control tower. The two students work together to compare and contrast their two flight volumes statistically, to write a project report, and to develop and make an oral presentation.

IV. The Lecture Component

The lecture component of the course supports the laboratory component by introducing the statistical concepts required to address product, process, and operations issues. The lecture component is 58% of the course grade.

The lecture component is divided into six instructional modules:

1. Descriptive statistics.
2. Enough probability for confidence interval estimation and hypothesis testing.
3. Confidence interval estimation.
4. Hypothesis testing of one mean.
5. Hypothesis testing of two means.
6. Simple regression.

Materials outlining and summarizing each module have been written[5]. These materials contain all of the technical information needed by a student in summary form. Students obtain more detailed information and examples through selected readings from a standard textbook[1].

In addition, seminars describing industrial applications of the lecture material based on the authors experience are included. These help students better appreciate the industrial relevance of what they are learning.

Each module is covered in the following fashion.

1. A presentation summarizing the technical material is made by the instructor.
2. Students organize themselves into co-operative learning groups. During the lecture period, each group works one problem of each type covered by the module.
3. Homework problems cover each type of problem in the module. Homework is not graded. Students are encouraged to form out of class co-operative learning groups to solve the assigned homework problems. Answers to the homework problems are provided to the students.
4. Each module has a corresponding laboratory for additional reinforcement in learning the problem types in the module.
5. A module examination is given covering all of the problem types. This examination requires about 30 minutes. A solution is presented by the instructor immediately following the end of the examination.

The mid-term examination covers the first three modules and the final examination covers all of the modules.

For example, consider the presentation of the first module on descriptive statistics.

1. The instructor presents basic definitions concerning statistical concepts, terms, and notation.
2. During the lecture, students organize themselves into groups of 3 or 4, preferable with students that they did not previously know. Each student is given a bag of

peanut M&M's and asked to count all of the defects in the M&M's in the bag. From each student's defect count, the group works together to compute summary statistics. Next, all defect values are list on the board. Each group develops a box plot, histogram, and cumulative histogram of the sample values.

3. Outside of the lecture time, the students read written material concerning the first module, including the detailed information from the textbook, and solve assigned homework problems.
4. During the laboratory time, students perform laboratory exercise one as described in the previous section.
5. During the lecture, the first module examination is given.

V. Future Vision

The current version of our introductory engineering statistics course is a work in process. We anticipate significant future improvements in the following areas:

1. *Writing instruction.* Every semester we have made major revisions and improvements to the way we teach technical writing to freshmen. Recent improvements include teaching writing one report section per week and providing a sample laboratory report for students to follow.
2. *Instrumentation and Measurement.* We are in the process of evaluating a strategic change in the course to an introduction to instrumentation, measurement, and statistics. Instrumentation and measurement is an important way in which engineers collect data to aid in resolving product, process, and operations issues. Thus, statistical methods could be introduced in the context of a natural engineering application area.

VI. Summary

We have developed and are continuing to improve an introductory, laboratory-based course in engineering statistics. This development has been greatly influenced by the reform movement of statisticians teaching introductory general statistics courses. Students are required to collect data by making measurements and use statistical methods to resolve product, process, and operations issues. Technical work and writing are essential parts of the student laboratory experience and evaluation. A companion lecture introduces statistical methods and uses both cooperative learning groups and active learning methods.

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Charles R. Standridge is responsible for the development of the lecture and, in partnership with Jon H. Marvel, the laboratory material for the freshman engineering statistics course discussed in this paper. In addition, he develops teaching approaches for systems simulation courses for undergraduate and graduate students in manufacturing engineering as well as simulation-based approaches to industrial problems in supply chain operations.

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Jon H. Marvel is primary responsible for the development of the undergraduate and graduate production operations sequences of course in the manufacturing engineering curriculum. In addition to assisting in the continual development of the freshmen statistics course, other responsibilities include teaching courses in work design and facilities layout in manufacturing engineering curriculum.