Session 2464

Materials Science Experiments and Engineering Statistics

Surendra K. Gupta and Carol E. Marchetti
Rochester Institute of Technology

Abstract

This paper describes three of the five engineering modules being developed for use in three statistics courses: *314 – Engineering Statistics*, *351 – Probability & Statistics I*, and *352 – Probability & Statistics II*. *314* is a mandatory course for all mechanical engineering (BSME) students; *351* & *352* are mandatory for all industrial & systems (BSIE) engineering students. To answer a student's (often unasked) question "why should I learn this?" in these courses, we sought to develop several engineering application modules. The intent of these modules is to provide the student with context for statistics concepts and the motivation to learn them.

The only engineering courses with hands-on lab experience that all BSME & BSIE students take before or concurrently with these statistics courses are *343 – Materials Processing* and *344 – Materials Science*. Consequently, we chose experiments or experimental data from these two materials courses for designing the modules. Funding from a Provost's Learning Innovations Grant is providing support for a materials science and a statistics professor in development of these five modules.

Statistics textbooks have data from engineering applications, but the problems tend to be simplistic in nature. From the one or two sentences of background information that are usually provided with textbook problems, it is difficult to understand why someone would want to collect and analyze this data. We have created modules consisting of more complete problems, including why someone would want to examine this type of data and how the statistical method used will provide a solution. Each stand-alone module contains a background and description of an engineering problem. In some cases data is provided, in others the mechanism for data collection is provided. Statistical processing of data, presentation of reduced results, and interpretation are a part of each module. The modules can be assigned to students individually or in teams.

The first module is a hands-on kit to collect mass, diameter and thickness data of a set of 100 new pennies and 100 old pennies. Statistical analysis of data is then combined with interpretation to explain the differences between the new and old pennies. The second module involves a collection of Rockwell hardness data on several samples of hardened tool steel, and statistical methodology is used to predict probable range of hardness values of the next sample. The third module involves collecting load versus indentation size data in micro-hardness testing of a polished steel specimen, and statistical method is used to determine the uncertainty in the resulting hardness values.

We anticipate that by actively engaging students in applying statistical methods to engineering problems, they will be more motivated to learn the material, will see the connections between their courses in science and engineering, and will be better prepared for subsequent courses. These modules will provide faculty with an additional resource aside from the textbook. We also anticipate that, given materials and appropriate support (e.g. training), faculty will be more inclined to adopt changes in their courses. Feedback from students and faculty members will be collected to formally evaluate the effectiveness of each module.

Introduction

In order to teach well, every instructor should be ready to answer a student's (often unasked) question: "Why should I learn this?" In fact, an instructor should have several different and persuasive answers to this question that help provide students a context where they might use the course material as well as motivate them to learn it better.

This project resulted from bi-weekly lunch conversation series that the two authors had about their teaching styles and their impact on the learning outcomes of students. Carol expressed the concern that even though the current statistics textbooks did have engineering problems, often the problems were simplistic in nature and did not provide sufficient engineering background to build a student's motivation. She also confided that she was not fully conversant in the engineering concepts to help students appreciate how statistics was being meaningfully applied to the textbook's engineering problem. Vinnie, on the other hand, was frustrated that students having taken the *Engineering Statistics* course still struggled with statistical analyses of experimental data in later engineering courses.

The two authors concluded that by developing and delivering a series of engineering modules in several different formats (e.g. engineering kits, videos, and case studies) they could help educate the statistics instructors about engineering applications; provide high-quality resources to statistics instructors for easy integration into their statistics courses for engineers; begin a collaboration among statistics and engineering faculty that teach the same sets of students; and provide engineering students the motivation to learn statistics well, and be able to apply their statistical skills to engineering data in a meaningful and productive way.

The engineering modules proposed are based on concepts and laboratory experiments from two courses: *Materials Processing* (a 1st year course) and *Materials Science* (a 2nd year course). Both are mandatory courses for mechanical as well as industrial engineering students. Having seen the concepts and experiments already, the modules will actively engage students in applying statistical methods to known engineering problems.

The modules are for use in three statistics courses: *314, 351* and *352. 314 – Engineering Statistics* is a mandatory course for all mechanical engineering students whereas *351* and *352 – Probability & Statistics I & II* are mandatory for all industrial engineering students. *351* is also among the list of recommended science electives for mechanical engineering students. The table below summarizes the enrollment statistics:

Enrolled in	Matriculated in	Type of Course	#/year
314: Statistics	Mechanical Engineering	Mandatory	140
351: Probability & Statistics I	Mechanical Engineering	Science Elective	30
351: Probability & Statistics I	Industrial Engineering	Mandatory	30
352: Probability & Statistics II	Industrial Engineering	Mandatory	30

We anticipate that by actively engaging the engineering students in applying statistical methods to engineering problems, they will be more motivated to learn the material, will see the connections between their courses in Statistics and Engineering, and will be better prepared for subsequent engineering courses. The modules will also provide statistics faculty with an additional resource (besides the textbook) that is customized to RIT engineering students they teach. We also anticipate that given instructional materials and appropriate training support, statistics faculty will be more inclined to adopt/adapt the modules to their courses.

The Modules

The modules are being developed in *three* different formats: engineering kits, videos, and case studies. Statistics instructors can then choose one or more formats for inclusion in their courses depending on their course structure, teaching style, and their students' learning styles. Each module includes guided data analysis with appropriate contextual questions, instructions for a formal write-up, and an evaluation form.

Pennies Module. The motivation for this module comes from the number of examples and problems related to dimensional and mass data on coins in the statistics textbook[1] as well as a similar laboratory exercise on large metal washers described by Standridge and Marvel[2]. We chose pennies because they are cheap and easily available. Furthermore, the website of United States Mint provides specifications and interesting facts about pennies. In 1982, the composition of penny was changed to 97.5% zinc and 2.5% copper (copper-plated zinc). The standard mass, diameter and thickness are 2.5 g, 19.05 mm and 1.55 mm respectively.

The kit contains 100 old pennies and 100 new pennies, and tools for measuring diameter, height, and mass. In collecting their own data, students can see first-hand the difficulties that researchers encounter – e.g. some observations don't fit the "standard" that we expected (the penny may be deformed) and it's not always obvious how to make the measurement (the penny may not have a uniform height). The intent of this module is for students to explore relationships between two quantitative variables or between one quantitative and one qualitative variable.

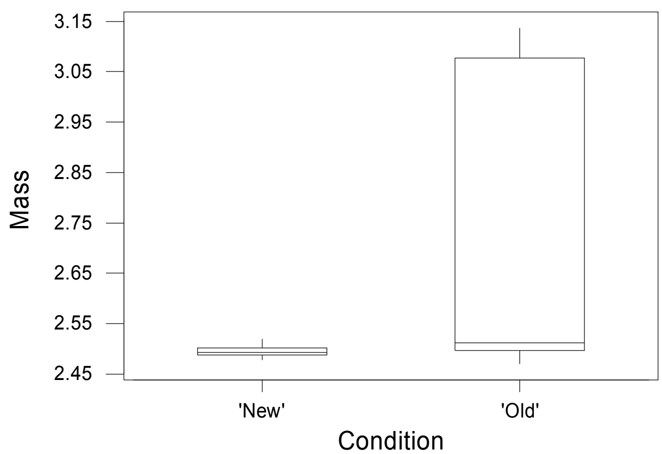
Several options are available with this module. Simple linear regression analysis (including scatterplots, correlation, least squares regression, etc.) is one option. Students can investigate the relationships between mass and height, mass and diameter, and mass and volume. Obtaining regression equations, interpreting parameters, predicting response values, and verifying assumptions are included here. Alternatively, an instructor can 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.

In samples obtained by the authors, side-by-side boxplots of mass for old and new pennies, as well as descriptive statistics, seem to indicate that older pennies have somewhat larger "typical" mass than new pennies and significantly greater variability among individual mass values.

Descriptive Statistics: Mass by Condition

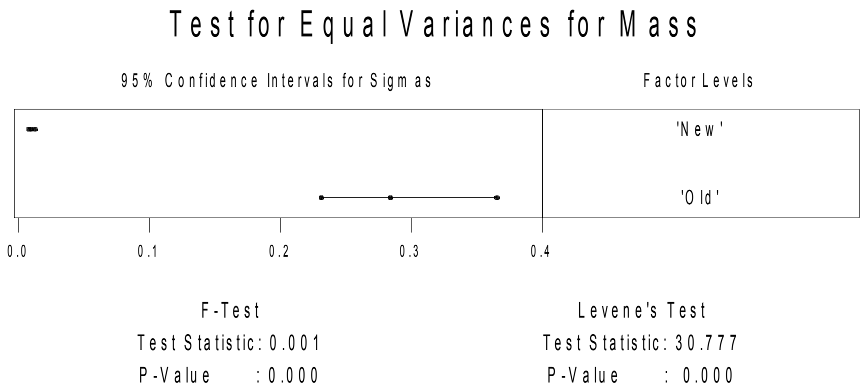
Variable	Conditio	N	Mean	Median	TrMean	StDev
Mass	'New'	50	2.4953	2.4929	2.4948	0.0097
	'Old'	50	2.7168	2.5114	2.7053	0.2838

Variable	Conditio	SE Mean	Minimum	Maximum	Q1	Q3
Mass	'New'	0.0014	2.4771	2.5183	2.4879	2.5021
	'Old'	0.0401	2.4698	3.1360	2.4972	3.0759



Minitab provides the mean, median, 5% trimmed mean, standard deviation, standard error (SE) of the mean, minimum, maximum, and also the first quartile (Q1, or the 25th percentile) and the third quartile (Q3, or the 75th percentile). Before making the measurements, we had naively expected the old pennies to have a lower average mass due to wear and chipping. However, the average mass is larger because of corrosion products, oil, grease or dirt.

Additionally, a formal test for equal variances (shown below) finds sufficient evidence that the populations of old and new pennies do, indeed, have different variances.



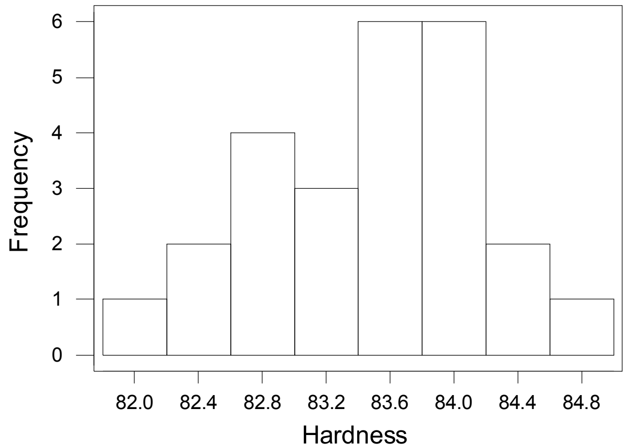
A variety of techniques are available to test the equality of two population variances. Recall that the variance is approximately the average of the squared deviations from the mean. To test the null hypothesis that two population variances are equal, Minitab provides the F-test and Levene's test. The F-test examines the ratio of the sample variances. If the value of F is close to 1, then there is no evidence to reject the hypothesis that the two population variances are equal in value. Levene's test considers deviations from the median, rather than the mean (this test is considered to be more robust for smaller samples).

Rockwell Hardness Module. Rockwell hardness test[3] is the most valuable and most widely used mechanical test for evaluating the properties of metals. The Rockwell test is simple to perform and does not require a highly skilled operator. A single hardness measurement can be made in less than a minute making it an excellent choice for process and quality control applications. In a C scale Rockwell hardness (R_C) testing, a 10 kg minor load is applied first on the diamond indenter to establish the reference position. A subsequent major load of 150 kg is then applied, and the additional indentation depth is automatically converted into the R_C number displayed digitally.

The data set includes 25 hardness measurements for each of five hardened tool steel specimens. The instructor may choose to use a single specimen or to compare several specimens. Guided data analysis with appropriate contextual questions is provided for exploring graphs, descriptive statistics, population models, and statistical inference. The instructor may use any parts of the module individually or together.

The analysis begins with an examination of the data. Students create histograms and/or boxplots and use these for an initial assessment of typical value, variability, unusual observations, and distributional shape. Next, descriptive statistics (mean, median, standard deviation, etc.) are obtained. Students must choose the "best" measure of center and spread among those obtained.

A histogram of the hardness measurements for one specimen (**S#4**), and descriptive statistics for this sample, are shown below:



Descriptive Statistics: Hardness

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Variable              N       Mean     Median     TrMean      StDev    SE Mean
Hardness             25     83.444     83.500     83.443      0.689      0.138

Variable        Minimum    Maximum         Q1         Q3
Hardness         82.000     84.900     82.900     83.950
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The histogram is unimodal and fairly symmetric. Thus, the mean and standard deviation are the preferable measures of center and spread for this sample.

After the sample(s) have been examined, students may continue the analysis by using the samples to investigate the population of interest. This starts with creating probability plots to determine a reasonable population type for the measurements. Based on this population type, the students may choose an appropriate method for statistical inference (e.g. normal theory method, non-parametric method, or bootstrap method). Several topics in statistical inference are applicable here – constructing a confidence interval for a single population mean, comparing two population means with two-sample methods, or comparing several population means via one-way analysis of variance.

Additionally, one may use a sample to estimate the mean hardness measurement or to predict a future value for a hardness measurement. The table below summarizes statistics from specimen **S#4**, specimens **S#4** and **S#3**, and specimens (**S#2** through **S#4**):

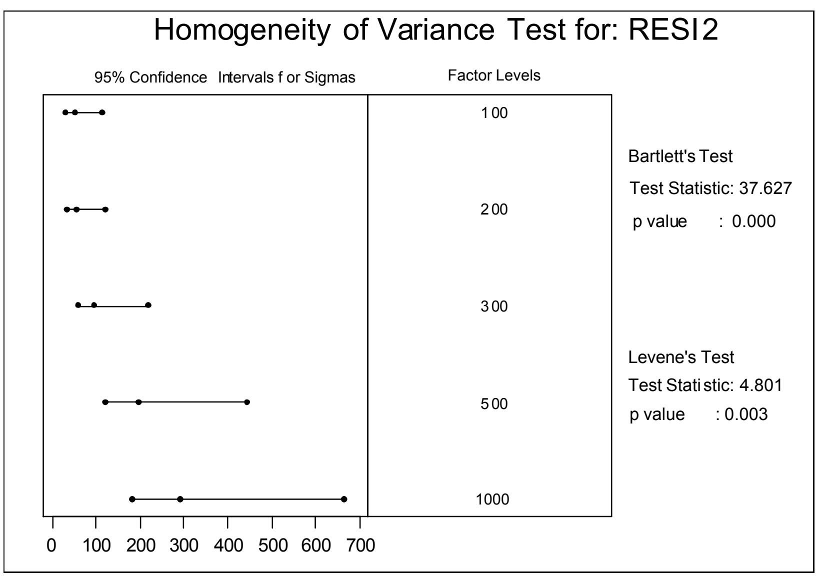
Variable	**S#4**	**S#4 + S#3**	**S#2+S#3+S#4**
N	25	50	75
Mean	83.444	82.668	83.138
Median	83.5	82.9	83.7
Standard Deviation	0.689	1.652	1.523
Minimum	82	76.5	76.5
Maximum	84.9	84.9	84.9
95% Confidence Interval	(83.16, 83.73)	(82.21, 83.13)	(82.79, 83.48)

One expects that with more data, the confidence interval would be narrower. However, this is not what we see with the data in the table above. In this case, the samples from specimens 2 and 3 have much more variability than the sample from specimen 4. This is a good demonstration of the sampling variability that occurs with real world data.

Knoop Indentation versus Load Module. In Knoop microhardness testing[3], a precisely shaped rhombic-base pyramidal diamond indenter is used with loads of 100 to 1000 g. The ratio of long to short diagonal of the indentation is approximately 7, and therefore the length of the long diagonal is measured with aid of a microscope. The Knoop hardness number (KHN) is the ratio of the applied load (in kg) to the unrecovered projected area (in mm^2) of the indentation. KHN testing is a valuable method for controlling numerous production operations, and is also widely used in materials research. A single measurement takes less than two minutes making it an excellent choice to collect data for statistical studies.

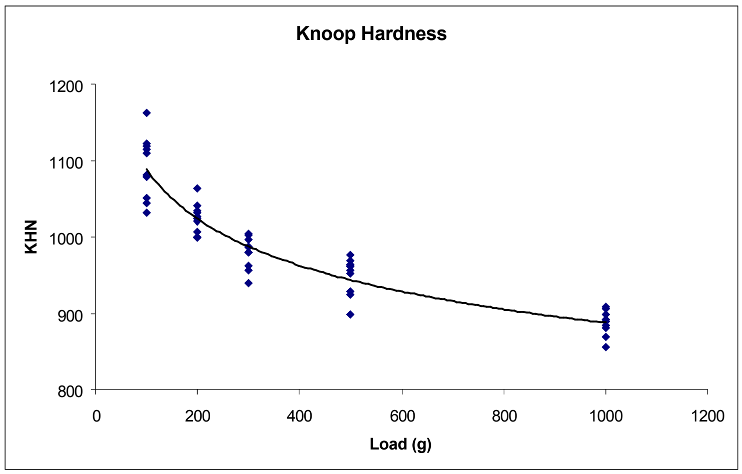
This data set contains ten indentation size measurements at each load setting (100, 200, 300, 500 and 1000g). The module is designed to assist students in an investigation of least squares regression. The analysis starts with a scatterplot of indentation size versus load. Students examine the graph for evidence of a relationship between load and indentation size. Next they compute the coefficient of correlation and evaluate whether a linear relationship would be appropriate.

In examining the variances, a student may note as shown below that the scatter in indentation size for 1000g load is the largest in the absolute terms, and come to an incorrect conclusion that the resulting hardness values are least precise.



When testing the equality of three of more population variances, one may Bartlett's test or use the generalized version of Levene's test. Bartlett's test is constructed using deviations of each observation from the mean, while Levene's test considers deviations from the median. Bartlett's test requires normally distributed populations, while Levene's requires only continuous populations.

Even though it is often assumed that KHN is independent of the applied load, it is observed[4] that KHN values decrease with increasing loads when loads are less than 500 g. The apparent increase in KHN with decrease in load is attributed to errors in the determination of the indentation size and aberrations in the elastic recovery of the indentation. As shown below, as the load increases, the hardness values stabilize and the scatter decreases.



The Feedback Process

Each module that is used by an instructor will be evaluated by *two* separate surveys: one of the statistics instructor, and the other of engineering students. Evaluation forms will be provided as part of each module. These brief forms will assist in determining the motivation of the students and their perception of how much they learned from the modules, as well as the instructor's perception of these items. At the end of the term, the information that is collected through the evaluation process will be processed and used to evaluate the effectiveness of the modules.

Status of the Project

Currently, the three modules described above are ready for use in the spring quarter. Additional information about these modules can be found in another paper[5] in the proceedings of this conference. Modules using particles size analysis and surface roughness are in the development stage. We plan to have five (or possibly six) modules in total. At the end of the spring quarter, an overall evaluation of the project will take place.

Conclusions

This project aspires to achieve several important outcomes – to improve student learning outcomes and to increase collaboration among colleagues – through the development of engineering modules for statistics courses. Each self-contained module provides data (or the tools to collect data) and guided data analysis with appropriate contextual questions to lead students through an investigation of an engineering concept. Options within each module allow the course instructor to choose statistical topics that are applicable at a variety of points throughout the introductory engineering statistics course.

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SURENDRA K. GUPTA
"Vinnie" Gupta is a Professor of Mechanical Engineering and Materials Science & Engineering, and the winner of the 2000 Eisenhart Award for Excellence in Teaching. At RIT, he teaches undergraduate and graduate courses in Applied Mechanics, Computational Techniques, and Materials Science.

CAROL E. MARCHETTI
Carol E. Marchetti is an Assistant Professor of Mathematics and Statistics, and the winner of the 1998 Provost's Award for Excellence in Teaching. She teaches introductory and upper-division statistics courses, and is a member of the Institute Effective Teaching Committee.