Incorporating Laboratory Experiments in an Introductory Statistics Course

Rose Martinez-Dawson
Clemson University

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Abstract

Laboratory experiments using spectrophotometers and pH meters were incorporated into an undergraduate introductory statistics course in order to create an interdisciplinary approach of teaching statistics to non-statistics majors. By conducting laboratory experiments commonly associated with science-based curricula, students were exposed to the relationship between science and statistics through experimental design and data analysis. The laboratory experiments used in the course are related to fields such as chemistry, biology, and environmental sciences and are described in this article.

1. Introduction

According to Gal, Ginsburg, and Schau (1997, p. 39), the two main goals of an introductory statistics course are “to prepare students to deal with statistical situations in the world outside the classroom ... and to prepare students to handle, use or interpret research or statistical data in their academic or professional discipline.” It is the latter goal that is the focus of this paper. Gourgey (2000, p. 3) supports this goal: “Statistics is by nature an experimental discipline, and it should be taught that way as much as possible.”

For most undergraduate non-statistics majors at Clemson University, an introductory statistics course is a requirement, and students usually do not understand why they need a statistics course. “What does statistics have to do with my major?” is an often-asked question on the first day of lecture. One proposed goal of a first semester statistics course is to illustrate this need. An interdisciplinary approach to teaching non-statistics majors may help students see the interplay of statistics with their major. Through this approach, students will understand that how an experiment is conducted determines how the resulting data are analyzed.
Students learn statistics by doing statistics (Smith 1998). Incorporating hands-on activities in an introductory statistics course is an approach that has been used to illustrate statistical concepts and improve student understanding (see Jowett and Davies 1960; Mackisack 1994; Steinhorst and Keeler 1995; Gnanadesikan, Scheaffer, Watkins, and Witmer 1997; Smith 1998). Hands-on activities are simple, inexpensive experiments that have been incorporated in introductory statistics courses (see, for example, Spurrier, Edwards, and Thombs 1995; Scheaffer, Gnanadesikan, Watkins, and Witmer 1996).

Gnandesikan et al. (1997) describe several hands-on activities for use in introductory statistics courses. In one such activity, students sample from a sheet containing 100 rectangles of varying sizes, and then estimate the average area for the population of rectangles on the page. To illustrate factorial experiments, the authors propose a paper-folding experiment called “Jumping Frogs” and a catapult experiment called “Gummy Bears in Space.”

Hunter (1977) lists thirty-two experiments performed by students in a statistics course. In one such experiment, popcorn yield was measured for combinations of two brands of popcorn, two batch sizes, and two popcorn to oil ratios. In another experiment, differing amounts of nickel, manganese, and carbon were used to determine the strength of steel alloy. The extent of iron corrosion was the response for an experiment that considered pH, dissolved oxygen content in water, and temperature. Yet another topic was the number of days for mail to reach its destination based on the type of stamp (first class or air mail), zip code (used or not), and the time of day each letter was mailed.

Zetterqvist (1997) determined the copper concentration for samples of impregnated wood. The mean copper concentration was tested against a mean of 100 micrograms per milliliter. In a calibration experiment, absorbance measurements of the copper content in brass were obtained using a spectrophotometer.

The interdisciplinary approach of teaching statistics in non-statistics courses has been used in a variety of fields. Statistical analysis of geographic data was incorporated in a geography course (Lindquist and Mannel 1998). The mean annual temperature and monthly precipitation were calculated for various cities. Variation in temperature and precipitation were investigated, and scatterplots were constructed to observe trends.

Experiments that focused on process improvement in manufacturing have also been developed. Kopas and McAllister (1992) describe one such experiment called the “Molding dough manufacturing” exercise. In the scenario, dried molding dough is to be used to form toys. In order to produce the specified toy, a certain amount of dough is required. Dough was put in a cup, and the weight of dough was determined using a scale. Variation in dough weights were observed and discussed. The “Sponge Absorbability” exercise examines the amount of time that randomly selected sponges absorb a certain amount of water (Kopas and McAllister 1992). Mean absorption times are calculated, and control charts produced.

Statistical applications and analyses have been incorporated in chemistry classes. To illustrate variability encountered when making chemical measurements, agate pestles are measured using a meter stick, steel ruler, and a caliper (O’Reilly 1986). Statistical tests such as F- and t-tests are performed on the data to compare measurement techniques.

Spencer (1984) used an experiment to compare polymer chain length and chain orientation of strips of polyethylene bags and Parafilm, a plastic-like material used in laboratories. Strips of both materials are cold-drawn, and the extent to which the materials stretched is recorded and analyzed.

Another application of statistics in a chemistry class involves comparing absorbances obtained from a
spectrophotometer for two food color dyes, FD&C Red #40 and FD&C Blue #1, found in powdered drink mixes (Thomasson, Lofthus-Merschman, Humbert, and Kulevsky 1998). In an extension of this experiment, solutions of different concentrations of food dye are made, and the absorbance recorded. A least-squares regression line is fit to the resulting data.

In Fiorini, Miller, and Acusta (1998), varying number of balloons (from 1 to 6) were attached to a can in which weights were added. Students recorded the maximum number of weights for each set of balloons that could be added to the can and still have the balloons rise. The data are described mathematically, and students are asked to predict the number of balloons needed to pick up their instructor.

At the Internet site, www.statease.com, simple experiments have been compiled that can be used to illustrate statistical concepts. These experiments range from looking at factors such as bounciness for play putty to measuring the strength of two types of paper clips to measuring the diameter of a crater formed in sand by dropping balls of different sizes.

The present study focuses on implementing laboratory experiments in an introductory statistics course. Activities and experiments are needed that not only illustrate statistical concepts but also have relevance to non-statistics majors. In most science-based laboratories, students concentrate only on performing the experiment; the statistical analysis of the results is not emphasized. Laboratory experiments using equipment that is commonly found in a laboratory setting were implemented into an introductory statistics course with the objective of merging science-based laboratory experiences with statistical analysis.

2. Implementation of experiments

The Department of Experimental Statistics at Clemson University offers a junior-level, three-hour introductory statistics course that is attended by students throughout the University. The course consists of two fifty-minute lectures and a one hour and fifty minute laboratory each week. Graduate students who are based primarily in the Department of Agricultural and Applied Economics supervise the laboratories. The lab instructor oversees the experimental process.

Two approaches have been used for performing each experiment. The students in the labs are either divided into groups that then perform the entire experiment and collect the group’s data, or the entire lab conducts the experiment with students being assigned responsibility for performing different parts of the experiment.

3. Experiments

A laboratory manual similar to those in chemistry and biology labs was developed for the course. The manual is composed of several laboratory exercises, and each lab illustrates a different statistical concept. In each laboratory exercise, the purpose of the experiment is explained and the experimental protocol is detailed. Data are recorded in tables provided in the laboratory manual. When appropriate, Web sites for further information on the laboratory topic are also included.

SAS programs are included in the laboratory exercise along with information that explains the syntax. An emphasis is placed on understanding SAS syntax. The data are analyzed using both hand calculations and the SAS program provided in the laboratory exercise, and students are required to compare the results of the two methods for calculation. By performing analyses both by hand and by using SAS, students develop a better understanding of what the information on the SAS output represents and how the results were obtained. Questions concerning the experiment, interpretation of results, and SAS
programming are asked at the end of each laboratory exercise.

Several experiments and versions of these experiments have been implemented in the laboratory section. Each of the experiments will be discussed based on the statistical concept addressed by it. An example of the laboratory exercises from each design can be found in the Appendix. Small sample sizes were used due to the time constraint of the lab session.

3.1 Single mean

Ecologists are concerned about the effect of pollution on the environment, and an experiment was conducted concerning acid rain. To illustrate hypothesis testing for a single mean, rainwater samples were obtained, and the pH of the rainwater was determined using a pH meter. A hypothesis test was conducted to determine if the mean rainwater pH was less than 5.6, an indication of “acid” rain.

3.2 Independent samples

A spectrophotometer, which measures the transmittance of light through a solution, is used to obtain absorbance readings for two types of solutions. Based on Beer's Law, a higher absorbance reading is associated with a darker, more concentrated solution.

In the spectrophotometer experiment, several types of solutions are made. Each of these solutions is made with red food color, but any color could be used. The optimum wavelength to measure absorbance must first be determined. For these solutions, it was determined to be 570 nanometers (nm).

In the current version of this experiment (contained in the Appendix), the mean absorbances of two brands of red food color, one more expensive than the other, are compared. For this experiment, one drop of red food color from each brand is mixed in 20 milliliters (mls) of distilled water, and three solutions of each type are made. The goal is to determine if there was a difference in the mean absorbance for the two solutions at 570 nm.

Several versions of this experiment have been tried. In one version of the experiment, absorbances from solutions made with one drop of red food dye were compared to absorbances from solutions made with two drops of red food color into 20 mls of distilled water. Three solutions of each type were made. In another version, the mean absorbances at 570 nm for old versus new food color were compared. The old food color was at least one year old. For each color, one drop of red food color was put into 20 mls of water. Three solutions of each type were made.

Students are asked about sources that can contribute to variation, such as measurement error. The students are asked questions such as the following: Were drops of food dye that were placed in each beaker of water of uniform size? Were exactly 20 mls of water in each of the beakers? Were possible errors introduced due to reading absorbances from the scale on the spectrophotometer?

3.3 Paired samples

Still another experiment is conducted in the context of acid rain. Water samples from different lakes and streams in Upstate South Carolina are obtained before and after it rains. The pH of each sample is determined using a pH meter. A hypothesis test is conducted to determine if the mean pH of the lake water after it rains is lower than the mean pH of the lake water before it rains. Students are asked to explain why water samples are obtained from the same location both before and after it rains.
4. Issues to consider when incorporating laboratory experiments

A statistics instructor who is interested in implementing laboratory experiments in an introductory course must consider several issues. First is the issue of obtaining laboratory equipment. Several sources for obtaining the equipment that are used in the Clemson course. Equipment was obtained by Departmental purchases, through Innovation Fund grant awards from Clemson University, or from borrowing from other departments at the University.

Another issue to consider is the collection of samples for the single mean and paired experiments. Water samples used in the paired samples experiment had to be obtained from the different sites at about the same time before and after it rains. Advance planning is crucial. This cannot be done at the last minute for fear that the weather may not cooperate.

The instructor should always pilot test the proposed experiments. It is also important to training laboratory instructors on how to properly use the equipment, especially if the equipment is borrowed. Our staff practiced using the equipment during weekly lab meetings. It is important for the laboratory instructors to feel comfortable using the equipment. The results of the practice sessions were analyzed using SAS. In the event of unforeseen equipment problems, these results could be used in the regular lab sessions. In other words, the instructor should always have a "Plan B."

These contextual laboratory exercises provide a perfect opportunity to use the expertise and help of faculty in other disciplines. This will also impress upon students the role of statistics in other fields.

5. Conclusion

The use of experiments to illustrate statistical concepts is not new. In their pioneering work, Jowett and Davies (1960) provide many examples of practical experiments that can be used to illustrate statistical concepts. Student interest and understanding of statistics improved when these experiments were incorporated in the classroom experience. Students involved in the experiments are acting as participants in the process and not merely as bystanders. As an extension of their work, this paper focuses on experiments that may be used in science-based courses using laboratory equipment.

In the future, more diverse laboratory experiments are planned that are relevant to students from a variety of disciplines. With this interdisciplinary approach, non-statistics majors will see how statistics is relevant to their major through the interplay of statistics with science. This approach gives a start-to-finish overview to the experimental process. It is hoped that this will motivate students to have more interest in statistics and to improve their attitude toward using statistics now and in the future.

Appendix

The worksheets are stored as Adobe PDF documents. Click on the title of the worksheet to view it.

- Determining if there is evidence of “acid” rain: An example of hypothesis testing for a single mean
- Determining differences in absorbance readings for two brands of food dye: An example of independent samples
Determining if rain lowers the pH of local lake water: An example of paired samples

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Rose Martinez-Dawson  
Department of Experimental Statistics  
Clemson University  
Clemson, SC 29634  
USA  
Martinr@clemson.edu