Evaluation of an Interactive Tutorial for Teaching the Central Limit Theorem

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In this article, we present an evaluation of a Web-based, interactive tutorial used to present the sampling distribution of the mean. The tutorial allows students to draw samples and explore the shapes of sampling distributions for several sample sizes. To evaluate the effectiveness of the tutorial, 111 students enrolled in statistics or research methods courses used either the interactive tutorial or attended a lecture and a demonstration on the sampling distribution of the mean. Students in both groups improved from pretest to posttest and no statistically significant differences between improvement scores were found between groups. Additionally, students rated the tutorial as easy to use and understand. In this study, we provide evidence that an Internet tutorial can be comparable in effectiveness to standard lecture or demonstration techniques.

The central limit theorem states that the sampling distribution of the mean for any population, given an adequate sample size, will approximate a standard normal distribution. Understanding sampling distributions is essential to comprehending many core statistical techniques. Unfortunately, students often fail to grasp sampling distribution concepts as presented in statistics textbooks (Dyck & Gee, 1998; Zerbolio, 1989). Consequently, students become confused with advanced topics (Howell, 1997). The sampling distribution of the mean allows one to calculate the probability of obtaining a sample mean given the sample size, population variance, and population mean. Researchers use this probability to assess the validity of null hypotheses and construct confidence intervals. Unfortunately, the teaching of statistical procedures often emphasizes working through problems in a "cookbook" fashion, focusing on mechanics instead of the logic of applications (Garfield, 1995). As a result, students may learn how to reject hypotheses based on a comparison of calculated values to tabled values with little understanding of the reasoning behind the test.

The Web Interface for Statistics Education (WISE) project provides instruction that addresses these shortcomings. The WISE project has created several Web-based tutorials that require only a Java-enabled browser. In this article, we present an evaluation of an interactive, Internet-based tutorial to assist students in learning about sampling distributions. The tutorial, found at http://wise.cgu.edu under "tutorials," consists of a paper-based assignment that guides students through the use of an interactive applet. The applet allows students to compare the population distribution with sampling distributions for samples of various sizes drawn from several different population distributions, although this assignment uses only normally distributed populations. The sampling distributions applet simulates the results of drawing many random samples. This tutorial assumes an audience that has basic knowledge of sampling, means, and normal distributions. For those students who have completed instruction on these topics, the tutorial can serve to replace some in-class instruction on sampling distributions.

The assignment begins with a problem statement. Students read that they will investigate life satisfaction as measured by a scale with a reported mean of 0.50 and standard deviation of 0.20. Using the applet, the student simulates drawing a sample of 100 scores. The applet shows the distribution of the sample cases and the sample mean. The student records the sample mean and notes whether it falls within 0.05 points of the population mean. The student draws 9 more samples of 100 scores and records each sample mean. Then, the student examines the actual sampling distribution of means for samples of 100 scores and estimates the proportion of sample means falling within 0.05 of the population mean. Next, the student uses standard z-score formulas to calculate, by hand, the proportion of sample means expected to fall within the same range around the population mean. The student then relates the observed distribution of sample means to the calculations and estimates by comparing the calculated percentage of sample means expected to fall within a certain range to the observed proportion of sample means actually falling within that range.

The assignment continues this process for samples of 25 scores and then for samples of 5 scores. After drawing samples of 5 scores and comparing results, the student evaluates the following statement: "For any population, the best estimate of the mean is the sample mean—therefore, it shouldn't matter what size sample I use. I'll use a sample of $n = 5$ as this will save a good deal of time and money." The tutorial instructs students to respond to the statement, using information from the exercises that they have just completed.

Method

Participants

One hundred and eleven students, 34 men and 77 women, enrolled in introductory statistics (three sections), intermediate statistics (one section), and research methodology (one section) courses participated in the study as part of regular instruction on sampling distributions. Participants in the study were students from two colleges, a large state university ($n = 73$) and a large community college ($n = 38$). The study included 12 freshmen, 28 sophomores, 29 juniors, 33 seniors, and 9 graduate students. The majority of the students participating in the evaluations were of traditional college age. The course instructor randomly assigned students to the lecture and demonstration or the tutorial within constraints imposed by scheduling restrictions (e.g., limits in the number of available computers).

Procedures

Students attended either a lecture and demonstration on sampling distributions or used the tutorial assignment. The tutorial group ($n = 55$) received a packet with a z table, a review of calculations of z, an overview of the applet, and an exercise guiding use of the applet. These students went to a computer lab and worked independently on the tutorial. Students received assistance navigating the tutorial but did not receive assistance with statistical concepts.

The lecture group ($n = 56$) attended a lecture and demonstration of the sampling distribution of the mean. The demonstration presented a population of 20 to 35 exam scores from which students drew samples of varying sizes. Exam scores were written on slips of paper and drawn from a paper bag. For each set of samples, the class examined how closely the sample means approximated the population mean and the proportion of sample means falling within a certain distance of the population mean compared to the proportion that would be expected to fall within that range. The lead author wrote the lecture and demonstration used for all lecture conditions.

Evaluation Materials

Comprehension. Quizzes measured knowledge of sampling distributions before and after instruction. The pretest and posttest both contained questions assessing knowledge of calculation procedures (e.g., probability of obtaining a specific mean value), theory (e.g., relation between sample size and standard error), definition (e.g., identify sample and population means), and application (e.g., decisions involving sample sizes for a research problem). Students completed the pretest measures at the end of the class meeting immediately prior to the lecture or tutorial session. Students completed the posttest measure immediately following the lecture or tutorial.

Student ratings. Students responded to questions regarding the amount that they believed they learned about the topic; how useful they viewed the lecture or tutorial; how clear they found the explanation of statistical concepts; how easy the lecture or tutorial was to understand; the quality of the explanation of statistical concepts; comfort with computers; and demographic information such as sex, class level, and grade point average.

Results

Equivalence of Groups

Those students completing both the quiz and student ratings sections proved to be similar with regard to several variables. No statistical difference between groups existed for grade point average, $t(99) < 1$; sex, $\chi^2(1, N = 111) = 1.69, p = .12$, class level, $\gamma = -.20, p = .15$; or comfort with computers, $t(108) = 1.56, p = .15, \eta^2 = .02$.

Quiz Results

Scores on pretest and posttest quizzes indicated that students using the tutorial and students attending the lecture and demonstration learned comparable amounts. Overall, average performance improved by 2.3 points on the 9-point quiz, $F(1, 109) = 148.5, p < .001, \eta^2 = .58$. Scores on pretest quizzes showed that the tutorial group ($M = 4.66$) performed slightly, although not significantly, better than the lecture group ($M = 4.21$), $F(1, 109) = 1.30, p = .26, \eta^2 = .01$. Scores on the posttest were similar for tutorial ($M = 6.73$) and lecture ($M = 6.79$), $F(1, 109) < 1$. No interaction between pretest and posttest quiz score and learning condition was present, indicating that there were no significant differences in the amount each group improved (Tutorial $M = 2.07$, Lecture $M = 2.58$), $F(1, 109) = 1.72, p = .19, \eta^2 = .02$. Although the tutorial group showed slightly (but not significantly) less improvement, the appearance of this difference may result from the fact that the tutorial group's pretest was slightly higher than the pretest of the lecture group. Confidence intervals around improvement scores for each group indicated that the tutorial group (95% CI = 1.48 to 2.67) and the lecture group (95% CI = 2.09 to 3.06) both improved significantly.

Student Ratings

Students' ratings provided additional evidence for the similarity of the two learning conditions. Forty-three additional students provided ratings of the tutorial or lecture, raising the overall sample size to 154 (tutorial, $n = 83$; lecture, $n = 71$). Students' ratings did not differ between learning condition for ratings of the usefulness of the presentation of topic, $\gamma = -0.04$, $p = .80$; the amount they had learned, $\gamma = 0.01$, $p = .96$; ease of understanding, $\gamma = 0.13$, $p = .32$; or clarity of explanation of statistical concepts, $\gamma = -0.03$, $p = .85$. The majority of students in both learning conditions rated the presentation as being useful, believed that they had learned "a lot," found the instruction easy to understand, and rated statistical explanations as "clear."

Discussion

Pretests and posttests of knowledge demonstrated that the Web-based tutorial was comparable in effectiveness to a good lecture or demonstration in fostering learning about a core statistical concept. An implication is that this tutorial could replace some in-class presentations, freeing class time for discussion or other activities that cannot be incorporated easily into a computerized module. The tutorial provides some important advantages over the lecture format. Perhaps most important, the interactive tutorial gives students substantial control over the learning process. The student can access the tutorial at any time, proceed at any desired pace, stop at any time, redo portions of the module, and so on. It is also important to note that most students rated the tutorial as easy to use and understand, and they perceived the tutorial to be effective in teaching the topic. As students gain experience with computer-based tutorials, we may see even greater acceptance of this medium.

The sampling distribution tutorial incorporated several techniques for enhancing student learning. These techniques include providing authentic challenges to student understanding, presenting multiple perspectives, encouraging reflective thinking, and addressing misconceptions. Authentic challenges (e.g., Park & Hannafin, 1993) are provided through materials that go beyond calculation of statistical values. Multiple perspectives (e.g., Mayer & Anderson, 1992) are presented through problems that require interactive manipulation, sampling, estimation, and interpretation in addition to calculation. Reflective thinking (e.g., Hoffman & Ritchie, 1997) is encouraged through questions that force students to stop at various points in the tutorial and respond to questions about results. Student responses to questions that represent common misinterpretations of concepts allow for active confrontation of misconceptions (e.g., Garfield, 1995). As demonstrated by the sampling distribution tutorial, many important principles of good instruction can be incorporated into Web-based tutorials. Given the encouraging results of this assessment, it is clear that interactive computer-based tutorials can provide an effective supplement, or even replacement, for traditional classroom lectures. However, it is important to test the effectiveness of educational software, as neither users nor instructors can be expected to make valid subjective judgments regarding effectiveness (cf. Jolicoeur & Berger, 1986).

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Notes

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