Using Interactive Simulations in Assessment: The Use Of Computer-Based Interactive Simulations In The Assessment Of Statistical Concepts

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Interactive computer-based simulations have been applied in several contexts to teach statistical concepts in university level courses. In this report, the use of interactive simulations as part of summative assessment in a statistics course is described. Students accessed the simulations via the web and completed questions relating to the simulations. Importantly, the questions could only be answered by combining declarative knowledge of statistics with the experiences resulting from actively engaging with the simulation. In this way, the assessment approach was able to assess functional knowledge related to procedural concepts and skills in application. The answers were submitted online and students received immediate feedback on the grade obtained. The interactive assessment tool was used by a large proportion of the students in the course. Feedback given by the students is discussed to give an indication of the benefits and limitations to its use.

1 INTRODUCTION

Statistics courses at university seem to be well suited to the use of computer-based technology. Statistical software packages facilitate the calculation of statistics and are in common use, particularly in advanced courses (Bartz and Sabolik, 2001). Furthermore, web-based tutorials and computerized multimedia have been used to supplement teaching (Lane, 1999; González and Birch, 2000; Blilwse, 2005) and computer software has been developed so that students can conduct virtual studies and analyse the resulting data (Malloy and Jensen, 2001). A number of authors have developed individual computer-based simulations that focus on a particular statistical concept. The Rice Virtual Lab in Statistics (Lane, 1999) is a compilation of such simulations. The Regression by Eye simulation, for instance, will plot data on a scatterplot and encourage the user to draw a regression line that best fits the data. The users regression line is compared to the actual regression line calculated from the data and the two can be compared visually or through statistics (e.g., mean squared error). The user can also estimate the correlation from the data in the scatterplot and compare that to the real calculated correlation coefficient.

The interactive nature of computer-based simulations has the potential to engage students in a meaningful way and allow them to explore the relationship between data, the use of statistics, and interpretation. The emphasis on the use of such simulations has been overwhelmingly on the teaching of statistical concepts. For instance, researchers have examined the effects of using simulations on the learning of inferential statistics (Meletiou-Mavrotheris, 2003), correlation and regression (Morris, Joiner, and Scanlon, 2002; Dunn, 2004), central tendency (Morris et al., 2002), and generalised liner models (Dunn, 2004). By comparison, less attention has been paid to how computer-based simulations could be used in assessing student understanding in statistics. Crisp (2002) described how JAVA applets can be used to make on-line assessment interactive in a wide range of disciplines at university (see also, Baker and Mayer, 1999; Crisp, 2006; Boyle, 2007). The present report illustrates one means by which computer-based simulations can be used in the assessment for a statistics course.

2 RATIONALE FOR USING COMPUTER-BASED SIMULATIONS IN ASSESSMENT

Biggs and Tang (2007) distinguish between two types of knowledge. Declarative knowledge refers to content knowledge or knowing about things. Functional knowledge, in contrast, is based on the experiences of the student. In functional knowledge, the student applies their declarative knowledge to solve problems, apply their knowledge in new contexts, and perform tasks. Due to the fact that statistics is not a subject that can be mastered by memorising facts, it is important that statistics teachers use methods that promote the learning of functional knowledge. Computer-based simulations are consistent with this viewpoint in that they use an active learning approach and promote the learning of problem-solving skills and critical thinking (Bowker, 1988). However, Biggs and Tang (2007) also emphasise that there should be a constructive alignment between the intended learning outcomes and the methods of assessment. By consequence, if the instructor intends to teach functional knowledge, they should use assessment tools that can assess this knowledge. The use of computer-based simulations in assessment may offer a means to fulfil this need.

The use of computer-based simulations in assessment may also confer advantages over the use of traditional assessment approaches (e.g., paper and pencil tests). Because this assessment approach can potentially be made
available on-line via the World Wide Web, it provides flexibility in terms of the delivery (e.g., time, place) of the assessment. This flexibility can be important given that large classes can limit the ability to assess functional knowledge (Biggs and Tang, 2007). Another advantage is that computer-based applications can allow the instructor to confidentially track the activity of the students and to collect, store, and grade performance on the assessment item (Bower, 1988; Bostow, Kritch and Tompkins, 1995). Feedback to the student can be immediate. Moreover, it can relieve the instructor of time spent in doing these tasks manually thereby increasing efficiency in course administration.

To achieve the aim of using computer-based simulations in the assessment of functional knowledge in statistics requires that certain elements of design are present. The simulation must be designed so that the student can be active in the task - it must be interactive. The simulation should allow the student to change values, simulate events in different ways, and observe what effects these have. There are ample examples of such interactive simulations in the literature, such as the compilation in the Rice Virtual Laboratory in Statistics (Lane, 1999), the simulations embedded in the Computer-Assisted Statistics Textbook (CAST; see: http://cast.massey.ac.nz), and those described by other authors (e.g., Lane, 1999; Morris et al., 2002; Meletiou-Mavrotheris, 2003; Dunn, 2004). A further important design element is that there should be opportunity for the integration of declarative and functional knowledge. The aim should be that the questions relate to new information that is generated by the student, their interpretation of that information, and a reflection of their experiences. These elements require a constructive alignment between the design of the interactive simulation, the instructions that accompany their use, and the content of the questions.

3 DESCRIPTION OF THE ASSESSMENT APPROACH

The interactive assessment approach was developed as part of the assessment for a first year research methods and statistics course in the psychology undergraduate program at Griffith University (Gold Coast Campus, Australia). The course has enrolments of approximately 200 to 250 students per semester and is taken mainly by students who are studying psychology and have a limited scientific or mathematical background. The topics covered include descriptive statistics, correlation, probability, sampling distributions, and simple experimental design and hypothesis testing (e.g., t-tests). It has four assessment items: a mid-semester exam, assignment, end-of-semester exam, and the interactive assessment. The interactive assessment contributed 10% towards the final grade.

The assessment associated with the interactive simulations was structured in the following way. A set of seven simulations were developed. The topics covered descriptive statistics, correlation, taking samples, sampling distribution of the mean, confidence interval of the mean when σ is known, confidence interval of the mean when σ is not known, and errors in hypothesis testing. Students could obtain 2% towards their grade if they completed a topic, up to a maximum of 10%. To obtain the 2%, they had to complete 10 questions associated with each exercise. If the student obtained 8 out of 10 or better, it was deemed a pass and 2% was awarded. However, if the student obtained 7 or lower, it was deemed a fail and the student was allowed to repeat the simulation. Students could attempt an exercise a maximum of three times (one initial attempt and two repeats) before being barred from any further attempts.

The students accessed and completed the interactive assessment according to the flow chart shown in Figure 1. The assessment was accessed on-line via a web browser. A link for each assessment topic was provided on the course web site. The student would log on to access the assessment using their university student number and password. Once gaining access, the student followed the instructions and answered the questions associated with the interactive assessment topic. The questions were answered on-line using a multiple-choice response format. After completing all questions, the students could submit their answers to a database for marking. The database recorded that the answers were submitted and calculated the number of correct answers. Feedback was provided to the students by displaying a feedback page. The students were told how many questions were answered correctly, but were not told of which specific questions (if any) were answered incorrectly.

Each interactive assessment was structured using a common interface layout. Figure 1 gives a schematic diagram of the main features. The screen was divided into four panels, as shown in Figure 2. The panel in the middle left was the largest as this was where the simulation was positioned. The simulations were written in either the JAVA or Flash programming language with each covering a particular topic, as noted previously. The simulations could potentially function as independent learning tools and were sometimes used in the lectures presented in the course. Like similar simulations developed by others (e.g., Lane, 1999; Morris et al., 2002; Meletiou-Mavrotheris, 2003; Dunn, 2004), the main aim of the simulation was to provide a means to conduct data analysis, to simulate a principle, or to illustrate a statistical concept. The crucial aspect of each simulation was that it was interactive. Students were able to change data values, simulate events, and see what effects their changes had. It was this interactive nature that was exploited in the assessment approach.
To provide structure for students, the right side of the screen presented instructions (see Figure 2). The initial part of the instructions gave an overview of the main features of the simulation. Subsequent instructions asked students to interact with the simulation in particular ways. For a simulation on constructing histograms, the student may have been asked to change the class (bin) width of a histogram and observe what effect it had on their interpretation of the distribution, such as the number of peaks, skewness, and kurtosis. Other instructions may have focused on a different issue, such as examining the relationship between a histogram and a stemplot as a means to represent data. The right side of the screen also contained a link to the questions to be answered for the assessment. Links to each question were also provided by buttons along the bottom of the screen. Clicking on a link to a question would move the screen down to the list of questions. After each question was a further link of “Return to simulation” to allow for easy return to the simulation and to show the instructions related to the next question.
The screen layouts shown in Figure 3 highlight the diversity of the assessment topics and how the interactive assessment combined a statistical simulation with instructions and questions relevant to the simulations. The simulations were diverse and allowed students to either calculate statistics (e.g., construct a histogram and stemplot see middle left panel in Figure 3), simulate a statistical principle (e.g., sampling distribution of the mean, sampling error, confidence intervals), or showed what factors influence statistics or statistical decisions (e.g., errors in hypothesis testing). In most cases, a simulation had multiple functions. Some of the simulations used were custom-developed and others were based on those that have been previously published on the Internet. Moreover, the simulations were based on real data sets to show the practical application of statistics. The data sets were the same for all students. While the nature of the simulations themselves is important, the main focus in the current application was how they were used when embedded within an interactive assessment task that was designed to test functional knowledge related to procedural concepts and skills in the application of statistics.

The key feature of the interactive assessment tool was that the questions were formulated so that they were answered based on the experiences in interacting with the simulation and knowledge of statistics. To illustrate this concept, consider the simulation in which a student can construct a histogram from real data. The student is asked to select a range of class widths and generate a histogram for each. When the student does this, the histogram will change. Due to the nature of creating histograms, each histogram will be slightly different to each other (e.g., more peaks are generally found as the class width is made smaller). The simulation is not only dynamic, but also interactive because the student has control over what class widths to use. The student is asked to examine the distribution in the data set for each resulting histogram. The question related to these instructions was as follows: “Taking all of the histograms together, which of the following provides the best description for the shape and number of peaks in the “Cigarettes” data set?” Following this question was a list of four options that referred to the number of peaks and the symmetry, for example “the distribution is unimodal and skewed to the right”. The student would only answer the question correctly if they had changed the class widths on the histogram appropriately and had correct knowledge regarding describing the characteristics of a distribution. The appendix provides a sample set of instructions and questions that accompanied the interactive assessment based on graphing data.
Figure 3  Examples of six interactive assessments. The examples show how the simulation (left) was embedded within the instructions and assessment task (right). The simulations covered a range of topics including confidence intervals of the mean (top left), sampling distribution of the mean (top right), graphing data (middle left), sampling data (middle right), correlation and regression (bottom left), and hypothesis testing (bottom right).

A similar principle was followed for the interactive assessment that related to the other topics. It was a relatively simple exercise to develop the instructions and set of questions for each. One interactive simulation was based on correlation and it allowed students to select different data sets, to plot the data on a scatterplot, and to calculate the correlation for the data. Similar to all simulations, the display changed dynamically based on the data set selected and the functions selected by the student (e.g., a regression line could be drawn or the correlation value could be changed and this would change the data values in the scatterplot). For this topic, questions were based on the interpretation of the data plotted in the scatterplot, the strength and direction of the association found, the extent to which the association is linear, and the relationship between the scatterplot, correlation, and regression line. Another interactive assessment was based on the sampling distribution of the mean. The exercise allowed the student to take samples from a population and to dynamically construct a sampling distribution of the mean calculated from these samples. Statistics based on the sampling distribution (e.g., mean, standard deviation) were also updated dynamically. The questions related to this simulation were based on the relationship between the distribution shape of the population and that of the sampling distributions, the values obtained for the standard deviation and mean of the sampling distribution of the mean, and the relationship between sample size and these factors. As before, to answer the questions it was necessary to interact with the exercise to observe the processes in action and to calculate the values of the statistics.
4 EVALUATION OF THE ASSESSMENT APPROACH

Completion of the interactive assessment was examined across two semesters using a total enrolment of 452 students. Students could complete between zero and five interactive assessments. The interactive assessment was a component of the total assessment for the course. However, it was not required for students to have attempted the assessment or gain a minimum mark to pass the course (i.e., it was possible for a student to not attempt any interactive assessment but to still pass the course provided that they gained high enough marks in the other assessment items). The percentage of students that passed the assessments were as follows: zero items: 6.9%, 1 item 4.6%, 2 items: 2.7%, 3 items: 4.9%, 4 items: 9.7%, and 5 items: 71.2%. In short, 91.1% of students passed at least one assessment item with 71.2% of students completing and passing the required five items. This data indicates that the interactive assessment enjoyed widespread use across the students. As with any other assessment approach, there is some variability in the extent to which the students successfully completed it.

It should be noted that the interactive assessment was a compulsory component of the assessment and contributed 10% towards the final grade. The compulsory nature would have enhanced student participation. Future research would be required to determine whether similar high levels of participation would be found if the interactive assessment was made an optional component in the course (e.g., as a review exercise for a topic).

A second means to evaluate the approach is to examine the experiences reported by students. Written feedback from students in the statistics course was obtained from Neumann, Hood and Neumann (2008). The feedback was examined by a qualitative coding approach to examine student experiences relating to a range of initiatives in the course (e.g., use of humour, use of real data sets). Their analysis also included an evaluation of the interactive assessment approach. The analysis resulted in seven themes, which are summarised below:

1. Helps learning: The interactive assessment had a pedagogical effect in providing a means to aid the learning of statistical concepts.
2. Helps confidence: The interactive assessment increased the student’s belief that they were able to master the concepts.
3. Practice concepts: The interactive assessment gave a means to revise the material.
4. Alternative learning tool: The simulations gave a different way to learn and check their understanding of the material.
5. More exercises: Students reported that they would like to see more simulations developed.
6. Make compulsory: Students commented that the interactive simulations should remain as a compulsory part of the assessment.
7. See mistakes: Students reported that they would like to see the answers to the questions that they got wrong.

The themes that emerged in the analysis of the student feedback indicated that the interactive assessment had several positive effects on student experiences. The exercises appeared to engender confidence in the student’s ability to master concepts in statistics. The fact that the students in the course largely come from a non-mathematical background and experience showed that many are anxious about studying statistics, any positive benefit to student motivation is an advantage. The students seemed to appreciate the benefits of the exercises sufficiently that it was commented that the exercises should be made compulsory and that more simulations should be developed.

Given that the main function of the simulations was on assessment, it was somewhat surprising to see some comments reflecting learning themes (Helps learning and Alternative learning tool). These themes seem to pick up on the fact that computer-based simulations can be used as an effective teaching tool (Morris et al., 2002; Meletiou-Mavrotheris, 2003; Dunn, 2004). Moreover, it would appear that while interacting with the simulations, students were exposed to new experiences and applied their knowledge in new ways. The questions that accompanied the exercises may have functioned to check the accuracy of their learning experiences. However, it less clear whether the learning benefits that resulted from the interactive assessment approach used are different to the benefits gained when the simulations are used independently of summative assessment. Future research could answer this question by comparing learning outcomes in two groups of students that use a simulation with or without the interactive assessment approach.

A potential drawback of the interactive assessment was that students were unable to see what question they got wrong. In their feedback, some students noted that it would have been beneficial to see their errors so that they could learn from their mistakes. This limitation reflected both the purpose and design of the assessment. The interactive assessment was designed primarily for assessment, rather than teaching. It was considered that due to the limited number of questions, no feedback should be given as this would help to minimize cheating among students. In addition, because the student could make up to three attempts per topic, providing no feedback also limited guessing as a viable strategy to pass the topic. The potential limitation of providing no feedback to students could be addressed by providing the feedback after the due date of the assessment.

5 CONCLUSIONS

Computer-based simulations and multimedia have the potential to enhance educational outcomes in not only the learning of statistical concepts, but also in the assessment of student learning. The interactive nature of simulations written in the web browser friendly JAVA or Flash programming codes allows for the assessment of functional knowledge. This use is consistent with the call from the American Statistical Association that the teaching of statistics should emphasise using less theory, encourage statistical thinking, and use active learning (Cobb, 1992). To ensure a constructive alignment between teaching methods
and assessment (Biggs and Tang, 2007), it is therefore necessary to employ an assessment approach that is consistent with these teaching goals. The present application of interactive assessment provides one way to achieve this. Although the present application was used in a course taught in the on-campus mode, it may be particularly advantageous for courses that are delivered through distance education and use solely on-line materials. The outcomes of the evaluation of the approach described in this report are encouraging and argue that further work could be done to explore the potential benefits of its use.

REFERENCES


AUTHOR NOTES

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David Neumann is a senior lecturer in the School of Psychology, Griffith University, Australia. He received a BSc. (Hons) and PhD from The University of Queensland, Australia and a Graduate Certificate in Higher Education from Griffith University. He has taught statistics courses in psychology and business. His research interests include questions on improving the teaching of statistics to non-mathematicians, particularly through novel means such as using technology, humour, and data collected from students.
A sample set of instructions and questions is provided for the interactive assessment illustrated in Figure 3 (middle left panel). The sample is focussed only on the questions related to working with quantitative data with histogram and stemplots. The interactive assessment also included instructions and questions on working with qualitative data via a bar chart and pie chart, but these are not shown here.

Instructions and questions

Click on the tab at the top of the interactive that is labelled “Return”. Next click on the button [work with Quantitative data]. You will see a screen that is set out in a very similar way to that for the qualitative data. You are able to use the drop down list to select one of three different data sets. The raw data for each of the data sets are shown in the table below and the histogram of the data is shown below the table to the left and the stemplot for the data is shown below the table to the right. For the histogram, you can specify the width of each class by selecting a particular width from the drop down list. The histogram and stemplot can be drawn by clicking on the [Generate Charts] button. You can also choose to enter in your own data by clicking on the [Use own Data] button.

Select the data set “Cigarettes” and a class width of “9”. Click on the [Generate charts] button. You will see that the histogram is drawn so that each class has a width of 9. The values for each of the classes is represented by one number that gives the middle value of that class. For instance, the value of 13.5 indicates a class that ranges from 9 and up to but not including 18. The stemplot is drawn so that each stem consists of all but the final digit and each leaf consists of the final digit.

Question 5. What is one of the major differences between a histogram and a stemplot?

(a) You can work out the value of each individual observation only in a histogram.
(b) You can work out the value of each individual observation only in a stemplot.
(c) Only the stemplot can show data that has a sample size greater than 15.
(d) Only the histogram can show data that has a sample size greater than 15.

You can obtain a lot of information about the distribution of scores from a histogram and stemplot. This information includes that of shape, number of peaks, centre, spread and the presence of outliers. In this interactive session we will be mainly concerned with the interpretation of shape and the number of peaks in a distribution.

Question 6. Based on the histogram with a class width of 9, which of the following provides the best description of the cigarettes data with regards to its shape and number of peaks?

(a) The distribution is unimodal and symmetrical.
(b) The distribution is bimodal and symmetrical.
(c) The distribution is unimodal and slightly skewed to the right.
(d) The distribution is bimodal and slightly skewed to the right.

One of the advantages of a histogram is that you can easily change the width of each of the classes. By changing the width of the classes you are able to look at whether the shape and the number of peaks, and thus your interpretation of the distribution, changes. The best situation is when the shape and number of peaks in the distribution is not affected by the class width. This is because you can be more certain that your interpretation of the distribution is not overly influenced by the class width you have used. If, however, the shape and number of peaks of the distribution varies with changes in the class width, the correct interpretation is more complex.

For the Cigarettes data set, use the drop down list to select a class width of “4”. Click on the button [Generate Charts]. You will notice that the distribution is roughly symmetrical. However, it appears that there are three peaks in the distribution - one around the centre, and two either side of that. In some cases, you will get more than one peak in a distribution when you use a small class width. This is because there can be a lot of “random” noise in the data set. You can smooth a distribution by using a larger class width. Use the drop down list to select a class width of “9”. Click on the [Generate Charts] button. You will see that the distribution now has just one peak.

When you use a larger class width you will reduce the influence of random noise in the data set. However, you also lose information. If your class width is too large, you may lose too much information and produce a biased interpretation of the distribution. Select a class width of “20” and click on the [Generate Charts] button.

Question 7. What happened to the shape of the distribution when you used a very large class width of 20 in comparison to the class width of 9?
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(a) The distribution has become more normal in shape, so we have lost information about the shape of the distribution.
(b) The distribution has the same number of peaks, so we have lost no information about the number of peaks in the distribution.
(c) Both of the above.
(d) There is no change in either the shape or the number of peaks in the distribution.

It is often difficult to come up with just one interpretation of a distribution. This is particularly the case when it comes to interpreting the number of peaks in the distribution as this characteristic is often greatly affected by the class width that is used. But don’t despair. Consistent practice of your statistical skills will help you to improve your interpretation of the characteristics of a distribution. The most appropriate interpretation of the shape of a distribution will be one that is most consistent across a reasonable range of class widths - those widths that are not overly influenced by random noise, but are also not too wide that they hide the main features of the distribution.

You can select a whole range of class widths from as small as 3 to as large as 20. For the “Cigarettes” data set, select each class width and generate a chart for each. Take a look at the distribution that you see in each histogram that you generate.

Question 8. Taking all of the histograms together, which of the following provides the best description for the shape and number of peaks in the “Cigarettes” data set?

(a) The distribution is unimodal and skewed to the right.
(b) The distribution is multimodal and symmetrical.
(c) The distribution is multimodal and skewed to the right.
(d) The distribution is bimodal and symmetrical.

Select the “Grades” data set. Select a class width of “3” and click on the [Generate Charts] button. Now, select different class widths and generate the charts for each. Take a look at each of the histograms that are generated and answer the question below.

Question 9. Which of the following best describes the change in the distribution as you change the class width?

(a) The distribution is skewed to the left for all class widths, but appears to be bimodal with class widths of 9 or less and unimodal with class widths of 12 or more.
(b) The distribution is skewed to the left for class widths of 12 or less and symmetrical with class widths of 15 or more, whereas it appears to be bimodal for all class widths.
(c) The distribution is skewed to the left and bimodal for all class widths.
(d) The distribution is skewed to the left and bimodal for class widths of 5 or less and is symmetrical and unimodal for class widths of 9 or more.

The width of the classes in a stemplot is determined by the stems that are used. The width of the stems is typically fixed by the nature of the data whenever all but the first digit is used as the stem. Although there are other types of stemplots in which the class width can be varied, we will not consider them in this interactive. If we keep the width of the stems in the stemplot constant, as we do in this interactive, and vary the class width of the histogram, which class width will produce a distribution that is similar for the stemplot and histogram?

Select the “Hours” data set. Now select various class widths and generate the charts for each. Try to work out which class width in the histogram produces a similar distribution to that in the stemplot.

Question 10. The class width in the histogram that produces the most similar distribution in the stemplot for the “Hours” data is:

(a) 5
(b) 9
(c) 12
(d) 15
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