DEVELOPING A COMPUTER INTERACTION TO ENHANCE STUDENT UNDERSTANDING IN STATISTICAL INFERENCE

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Prior investigation of student experiences with a computer interaction indicated that the simulation was only partly successful in facilitating developmental learning of statistical inference. The simulation was re examined in the light of subsequent multimedia design research and cognitive theory. A new simulation was developed with less extraneous information and reduced on screen text. In addition the new simulation incorporated audio narration and a higher degree of student control in progressing through signalled stages of development.

INTRODUCTION

There have been a plethora of interactives developed over the past twenty years, all with the purpose of helping students to develop an understanding of important statistical concepts (see, for example, Lipson, 1992; Rubin, 1990; Stirling, 2002). The promise offered by interactive software is that it enables processes such as sampling to be simulated and modelled in ways which make complex notions explicit. However, to date very little evidence has been presented supporting the effectiveness of these simulations. In fact, our own research has indicated that much of what we thought was being made explicit through computer based simulation remained a mystery to students (Lipson, Kokonis, and Francis, 2003). Students were exposed to a computer based activity designed to support the development of conceptual understanding of the role of the sampling distribution in hypothesis testing. By talking with students as they interacted with the software, we developed some understanding of the design shortcomings of the interactive, as well as insight into the cognitive stages which underpin the development of the concept of sampling distributions. Challenged with the notion of developing a better interactive based on our observations with students, we became aware that there were two quite distinct questions to be addressed, namely:

- What are the design features of an interactive which enable the students to gain maximum benefit from their experience with it?
- How can the interactive be structured to support knowledge development in statistical inference?

The first of these questions will be addressed in this paper.

PRINCIPLES OF MULTIMEDIA DESIGN

There has been a large body of research in the area of multimedia development (see, for example, Kalyuga, Chandler, and Sweller, 2000; Mayer and Chandler, 2001; Moreno and Mayer, 2000). Mayer (2002) suggests that knowledge of cognitive theory can inform multimedia design, based on three assumptions about how people learn from words and pictures:

- *The Dual Channel Assumption*: Human cognitive processing takes place along two distinct channels, the auditory-verbal channel (ears as input) and the visual-pictorial channel (eyes as input).
- *The Limited Capacity Assumption*: Working memory has a limited capacity for information and can easily become overloaded if too much material is presented at the same time.
- *The Active Processing Assumption*: Active processing within the auditory-verbal and the visual-pictorial channels leads to meaningful learning, and is more likely to occur if the working memory contains both types of representations.

These assumptions are brought together in the cognitive theory of multimedia learning, which proposes that pictures enter the cognitive system through the eyes, and the information in the pictures is reduced, synthesised and arranged into a mental representation in the working memory in a pictorial model (visuospatial thinking). Sounds are similarly selected and organised into a verbal model (verbal thinking). In working memory the pictorial model and the verbal model are integrated with knowledge in the long term memory, and potentially leads to meaningful learning.

Following on from this theory Mayer (2002) articulated eight principles of multimedia design:

1 *Multimedia principle*: Deeper learning occurs when pictures are added to a verbal explanation, since this enables the construction and linking of both verbal and visual models.

2 *Contiguity principle*: Deeper learning results from presenting words and pictures at the same time rather than successively. Simultaneous presentation enables the students to make links between the representations. This idea has links to the notion of the *split attention effect* proposed by Kalyuga, Chandler and Sweller (2000). They suggest that, although requiring students to mentally integrate two sources of information (such as a diagram and text) increases the cognitive load and so may reduce learning; the cognitive load is lessened if the two sources are physically integrated such as by putting the text in the diagram.

3 *Coherence principle*: Deeper learning occurs when extraneous words, sounds, or pictures are excluded. Adding irrelevant information, even if designed to generate student interest, does not enhance learning and sometimes hinders it. Research by Mayer, Heiser and Lonn (2001) showed that adding engaging details such as pictures, sentences and video clips resulted in poorer student performance. This is at odds with the *emotional interest hypothesis* which says that adding material to generate interest will increase engagement and hence overall learning. Mayer *et al*. (2001) found that extraneous information may distract the student from the prime focus of the activity, and "pinpoints the locus of coherence as attributable to priming of inappropriate assimilative schemas" (p. 196). Thus when designing an interactive only the material which is directly relevant to the content of the lesson should be included, nothing should be added purely for appeal or entertainment.

4 *Modality principle*: Presenting information as narration rather than on-screen text has the potential to result in deeper learning. This is because on screen text and pictures both use the visual-pictorial channel, and thus there is the possibility that this channel will be overloaded. Narration, however, uses the auditory-verbal channel and frees up the visual-pictorial channel for processing of the visual information. According to Mayer (2002) several studies have shown that "students learn more deeply from animation and narration than from animation and on-screen text" (p. 66).

5 *Redundancy principle*: Deeper learning occurs when words are presented as narration rather than as both narration and on-screen text. The theory suggests that adding text overloads the visual-pictorial channel. Kalyuga, Chandler and Sweller (2000) further established that the relationship between narration and on-screen text is more complex, and is dependent on the experience of the learner. They suggest

- Textual material should be presented in an auditory rather than written form.
- The same textual materials should not be presented in both auditory and written form.
- When presented in auditory form, textual materials should be able to be easily turned off or otherwise ignored.

6 *Interactivity principle*: In this context interactivity is used to mean simpler user interaction, including control over the rate at which the learner proceeds through the material. Deeper learning occurs when learners are allowed some control over the pace of the presentation, by inclusion of buttons such as *Click here to continue*. Mayer and Chandler (2001) propose that simple user interaction:

- Reduces the learner's cognitive load on working memory, since the user can proceed to the next piece of information when they have processed the current information.
- Consequently enables the learner to progressively build a sound mental model, since they are building sequentially on parts that they already understand.

As an extension of the interactivity principle, Mayer and Chandler (2001) investigated whether the whole presentation should be shown first (Whole-Part), followed by each segment separately or whether the segments should be shown first, and then the whole (Part-Whole). The principle of Whole-Part is that:

> …seeing the entire presentation allows the learner to build a context which is then elaborated on in the second presentation, during which the learner can focus on each part of the system. (p. 393)

Rationale for the Part-Whole model comes from cognitive load theory, which says that learners are more likely to experience cognitive overload if all the information is given first. Mayer and Chandler confirmed through their research that the Part-Whole model resulted in deeper understanding, and also suggest that it is appropriate to provide learners with experiences of each of the components separately before presenting an interactive which encompasses an entire complex system.

7 *Signalling principle*: Deeper learning occurs when key steps in the interactivity are signalled rather than non-signalled. Signalling in the narration, by using phrases such as "the first step is" and "the second step is" or speaking important words or phrases in a louder or deeper voice direct the attention of the learner to what is important, and this enables them to better integrate this information into their knowledge structures.

8 *Personalisation principle*: Deeper learning occurs when words are presented in a conversational style rather than a formal style. It is recommended that designers use conversational rather than expository style language, and the first and second person rather than the third person where appropriate. Mayer, Fennell, Farmer and Campbell (2004) suggest two possible explanations for the effectiveness of personalisation:

- Personalisation may increase interest which means that the learner makes more effort to engage in active cognitive processing, and this in turn results in deeper learning.
- Alternatively (or additionally) it may be that the personalised group made greater efforts to link the information to their prior knowledge, because the personalisation made the information seem personally relevant.

However, they also warn against going too far with the personalisation, as distracting and irrelevant information can be introduced which then contributes to the cognitive load.

In addition to these eight principles, Moreno and Mayer (2005) have more recently looked at the roles of guidance and reflection in an interactive designed to promote understanding. Applying the cognitive model of multimedia learning outlined earlier leads to two conditions for meaningful learning:

- The learner must engage in the process of selecting relevant information from the interactive.
- The learner must integrate the new material with their prior knowledge and organise it appropriately.

In guided discovery, the interactive may offer experiences which

> …guide or scaffold the process of knowledge construction by providing explanatory feedback on students' interactions with the program. (p 118)

Some guidance is recommended as the learner proceeds with the interactive, as research in science has shown that pure discovery often leaves students confused and frustrated, and they may develop misconceptions. Moreno and Mayer (2005) investigated a type of guidance called *explanatory feedback*, where an explanation is given as to why a certain choice is or is not correct. The expectation was that this form of guidance would enhance the cognitive process of selecting, and hence lead to more meaningful learning. They also suggested that reflection, where students are asked to provide an explanation of their answers, would improve student learning by enhancing the processes of organising and integrating information in their knowledge structures. Subsequently Moreno and Mayer conducted experiments to address these questions. They found that guidance significantly improved students' deep learning, and further that this was significantly greater when explanatory feedback rather than corrective feedback was given. Interestingly, however, they found that asking students to give explanations about their choices did not affect their learning. They suggest that directed reflection is not necessary with an interactive task because students are already engaged with the process, by having to explicitly make choices as they interact. Being asked to explain their answer did not help in the same way that it has been found to help students when reading text.

IMPLICATIONS OF THE PRINCIPLES OF MULTIMEDIA DESIGN

The interactive we used in our earlier study (Lipson *et al.*, 2003) was based on a real world example which was reported in the newspaper. The postal authority, Australia Post, had published a report in which they claimed that at least 96% of letters are delivered on time, and a journalist decided to test that claim by posting several letters. Of the 59 letters that he posted, he found that 52 (88%) were delivered on time, and thus he wrote an article in the newspaper with the headline “Doubt on Letters Promise.” In order to investigate whether the journalist’s claim could supported by the data, we used an interactive which was written expressly for this purpose (Stirling, 2002).

The working components of the computer screen with which the students interacted are shown in Figure 1. The screen is essentially divided into three sections. In the top left hand section the information about the population proportion and the sample size are given in text. On the top right hand side are two representations of the current sample proportion, a pie chart and a frequency table giving both numbers and proportions of letters delivered on time and late. Taking up the remainder of the screen is the empirical sampling distribution (shown in Figure 1 after 200 samples have been drawn). Samples where 52 or fewer letters have been delivered on time are depicted with a blue plus (+), the others with a black cross (x). This working component of the interactive was embedded in a large amount of written text, which explained the scenario and then gave instructions for using the interactive component. As all of the information was displayed from the start, it did not fit on a single screen, so that students had to scroll down to read the instructions and then scroll back up to apply them.

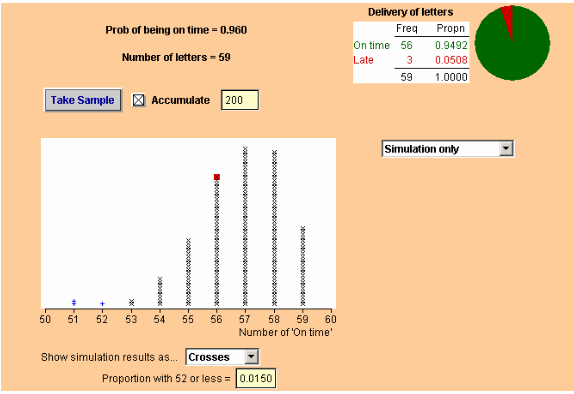


Figure 1: The computer simulation screen

What does the research on multimedia design tell us about the potential of this interactive to facilitate deep learning, and in particular, what directions does it give us for a new interactive? We will begin by applying Mayer’s eight principals of multimedia design. The analysis is summarised in the Table 1. Based on this analysis, we decided to design a completely new interactive. When designing the new interactive we had clearly defined aims for the conceptual understanding we wanted students to develop. These aims were based on our previous research (Lipson *et al.*, 2003). The interactive involves three stages. In the first stage the concept of a sampling distribution is developed. In the second stage a specific sample is compared to a known sampling distribution to explore the notion that an individual sample may be inconsistent with a particular population. In the third stage we look at the range of populations a specific sample might be consistent with, leading to the notion of confidence intervals. Consistent with the findings of Mayer *et al.* (2001) related to coherence, the context was kept very simple, so that students were not distracted from the prime focus of the activity. All stages of the interactive are based on a very simple scenario – taking samples of jelly beans from a jar containing both red and black jelly beans.

Two typical screens from stage 3 of the interactive are displayed in Figure 2, together with the audio narration. Stage 3 of the interactive begins by reintroducing the sampling

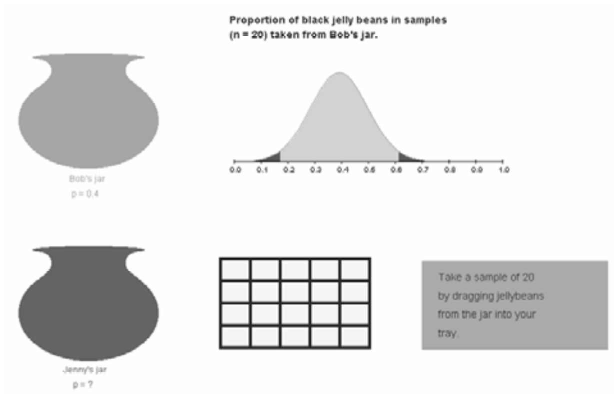
Design Principal	Existing Interactive	New Interactive
Multimedia	No audio, so does not support the construction of a verbal model.	Audio should be included
Contiguity	Visually, the words and pictures are separated, meaning the learner needs to scroll to see both.	Audio should synchronise with pictures, and any written text should be close to diagrams.
Coherence	A real world context was used to generate student interest and facilitate engagement, with exactly the effect predicted by the coherence principle. Students were distracted by the context, and this interfered with their learning.	Include only information which is relevant to the content of the interactive, and do not embed the activity in a complex real world context.
Modality	Since there was no narration then the auditory-verbal channel was not used.	Appropriate narration should be added to the interactive.
Redundancy	Whilst there was only written text, the amount of text together with the pictures severely overloaded the learners' working memory.	Use the narration to supply verbal explanations and have little text on screen. Allow the learner to turn on/turn off the narration.
Interactivity	The learner was given no control over the pace at which the material was presented, as it was almost all there from the beginning.	Step the learner through a sequence of staged experiences, with the learner able to control both forward and backward movement. Give students prior opportunity to develop their understanding of component concepts before introducing more complex ideas.
Signalling	While there was no verbal signalling, written signalling was also quite inadequate. It was difficult, if not impossible, for the learner to navigate through the interactive, and to determine what to pay attention to.	Give clear guidance about how to proceed through the interactive, and what to pay attention to.
Personalisation	While the language is fairly informal there is no use of the first person and limited use of the second person.	The style of both narration and written text should be conversational and use the first and second person.

Table 1: Applying the principles of multimedia design

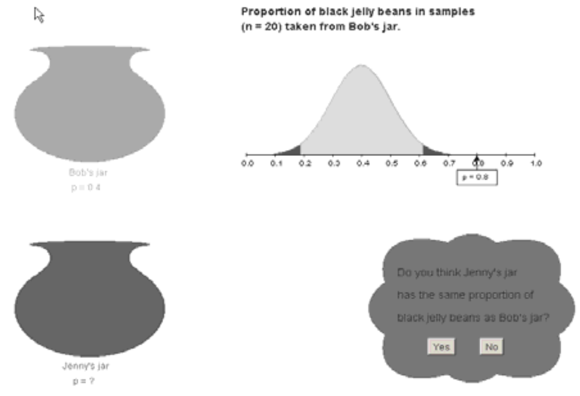
distribution developed in stage 1 and used in stage 2. At this point students are already familiar with this sampling distribution, so it does not add to the cognitive load (Kalyuga *et al*., 2000). Note that no extraneous information is included on the screen, but instructions and questions *requiring a student response* are given on screen. These are close to the relevant diagram to avoid the split attention effect, and no scrolling is required. Student action or response is always required before the next screen is displayed, so that students have control over the timing of the presentation. In line with the findings of Moreno and Mayer (2005) on the benefits of explanatory feedback, after students give a response to a question, and regardless of whether their response is correct, an audio explanation of the correct answer is given.

CONCLUSION

There is a growing body of research which addresses how best to use the power of computer based technology as a pedagogic tool. Cognitive psychology has led to a clear set of principles of multimedia design, and it is important to apply these principles in order to maximise the potential of an interactive to support deep learning in our students. However, perhaps more importantly, any interactive which is designed to facilitate cognitive development in our students must be built on external representations which have been designed to support the development of appropriate internal mental representations in the learner. We must continue to be in close dialogue with learners as they work with any interactive, modifying and developing the activity in response to their experiences, as ultimately it is its effectiveness with students which is the primary criterion by which the interactive should be evaluated.



AUDIO: *Suppose Bob's youngest sister Jenny also Has a jar of jelly beans.*



AUDIO: You're right. When we took samples of 20 jelly beans from Bob's jar none of the samples had a proportion of black jelly beans as high as 0.8. So Jenny's jar appears to be different to Bob's.

Figure 2: Two typical screens from the new interactive

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