Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Computers & Education xxx (2006) xxx–xxx
COMPUTERS & EDUCATION
www.elsevier.com/locate/compedu

The interactivity effect in multimedia learning

Chris Evans *, Nicola J. Gibbons

Centre for Educational Multimedia, Brunel Business School, Brunel University, Uxbridge, Middlesex UB8 3PH, UK

Abstract

The aim of this study was to determine whether the addition of interactivity to a computer-based learning package enhances the learning process. A sample of 33 (22 male and 11 female) undergraduates on a Business and Management degree used a multimedia system to learn about the operation of a bicycle pump. The system consisted of a labelled diagram of the pump, followed by a description of twelve stages in its operation. The sample was randomly divided into two groups who used either an interactive (I) or a non-interactive (NI) version involving both images and text. The I system differed from the NI system by the incorporation of control of pace, self-assessment questions and an interactive simulation. Students then undertook two different types of tests to assess their learning: one designed to evaluate their memory by recalling facts from the lesson, and another designed to assess their understanding through solving novel diagnostic problems. Students using the I system outperformed those using the NI system in the problem-solving test, and needed less time to complete both memory and problem-solving tests. This result is consistent with the hypothesis that interactive systems facilitate deep learning by actively engaging the learner in the learning process. This suggests that educational designers who seek to foster deep learning (as opposed to mere factual recall) should adopt the incorporation of interactivity as a design principle.

Keywords: Evaluation of CAL systems; Human-computer interface; Interactive learning environments; Multimedia/hypermedia systems; Pedagogical issues

* Corresponding author. Tel.: +44 1895 265243; fax: +44 1895 269775.
E-mail address: chris.evans@brunel.ac.uk (C. Evans).

0360-1315/$ - see front matter
doi:10.1016/j.compedu.2006.01.008

1. Introduction

The aim of this study was to determine whether there is evidence that interactivity enhances the process of learning from computer-based systems. Interactivity is frequently considered to be beneficial in the context of computer-based learning. For example, Drave (2000) suggests that the quality of interactivity is more important than content for the success of learning; Sim (1997) believes that interactivity plays a crucial role in knowledge acquisition and the development of cognitive skills. However, there have been few systematic studies that have attempted to establish whether the inclusion of interactivity actually enhances learner performance.

A number of principles have already been formulated for the design of multimedia learning systems consisting of words and images (Mayer, 2001). These include the *multimedia principle* (using both words and pictures), the *coherence principle* (avoiding extraneous media), the *modality principle* (using narration rather than text), the *spatial contiguity principle* (placing words and pictures close together), and the *temporal contiguity principle* (presenting words and pictures at the same time). The empirical evidence for these principles is strong.

The systems developed to establish these principles were generally non-interactive, i.e. they required no input from the learner in the form of mouse-clicking or key-pressing in order for a lesson to finish. Commonly the lessons consisted of uninterrupted narrated animations such as Mayer and Anderson's 30 s narrated computer-based pumps lesson (1991) and Mayer and Moreno's continuous 140 s narrated computer-based lightning lesson (1998).

From a cognitive perspective, the utility of incorporating interactivity in computer-based systems is that it allows the learner to influence the flow of information in terms of timing or content. For example, button-clicking can be used to allow the learner to indicate when they want the next portion of text to be displayed; and interactive multiple-choice questions can be used to provide meaningful feedback for self-assessment. This study aims to determine whether the provision of such interactivity can actually increase learning.

1.1. Interactivity and interactive computer systems

The term *interactivity* is used to describe a variety of learning activities including interactions between students (student–student interaction), interactions with the tutor (teacher–student interaction), and interactions with the teaching material itself (student–content interaction) (Moore, 1989; Schrum & Berge, 1997). When the teaching material takes the form of a multimedia computer system, two forms of student–content interactions can be distinguished: those initiated by the student, and those initiated by the computer system (Schär & Krueger, 2000). In the former, the student seeks some information from the content in a similar way to looking something up in a book or watching a television programme. In the latter, the system requires some input from the learner, such as pressing a button or answering a question by clicking on one of a number of options. The ability of the system to initiate interaction is unique to computer-based media (as opposed to, say, television broadcasts, films and distance learning texts (Laurillard, 2002)). The variety of forms of interaction often creates confusion over the meaning of the use of the word *interactivity*. In order to clarify what we mean by the term *interactive system*, we shall adopt the interaction model formulated by Evans and Sabry (2002).

According to their three-stage model of computer-initiated interactions, an interaction involves a sequence of three actions: initiation, response, and feedback. Each action involves an exchange of information between two agents. Initiation involves the first agent inviting input from the second. Response involves the second agent providing that input. Feedback involves the first agent passing back information as a consequence of the response. The three actions are connected: the response must be a direct consequence of the initiation, and the feedback must be in direct relation to the response. The feedback is thus intrinsic to the learner's response (Laurillard, 2002). In the case of computer-initiated interaction, the response action is carried out by the learner and the feedback action by the computer.

As Evans and Sabry (2002) point out, all forms of computer-initiated interactivity can be described in terms of this model. For example, a navigation or pacing interaction has the three actions:

1. Present button or control to learner (computer initiation).
2. Student presses button or uses control (learner response).
3. Present new information to learner (computer feedback).

A lesson in a computer-based learning system can now be described as non-interactive if it requires little or no computer-initiated interactivity in order for a lesson to be completed. By contrast, a computer-based learning system is said to be interactive if it uses computer-initiated interactivity as an intrinsic part of the lesson.

1.2. Active and passive learning hypotheses

In this section we consider two possible consequences of learning from interactive multimedia systems, deriving from two alternative hypotheses: the active-learning hypothesis and the passive-learning hypothesis. The active-learning hypothesis predicts that learning from interactive systems increases learning by engaging learners more closely with the material. The passive-learning hypothesis predicts that learning from interactive systems has no special effect on learning since the information content is no different from that contained in a non-interactive system.

The active-learning hypothesis derives from constructivist models of learning (Jonassen, 1992; Mayer, 1999, 2001). Under the constructivist model, the learning process involves learners constructing their own individual knowledge of a subject on the basis of their prior knowledge and new information that they receive. When they learn, students play an active role in receiving and processing information. When required to interact with a learning system, learners have to make decisions about when to receive information (e.g. by button clicking), and what information they receive (e.g. by selecting from a number of options). They thus have an active relationship with the material. As a consequence the active-learning hypothesis predicts that learning should increase when learners use interactive as opposed to non-interactive multimedia systems. We shall refer to this cognitive consequence as the *interactivity effect*.

Supporters of the constructivist model usually contrast it with the information or knowledge transfer model of learning (see e.g. Mayer, 1999, 2001). The passive learning hypothesis has its origins in this model. Under the information transfer model, the learning process involves the transfer of information from subject experts (e.g. through lectures or textbooks) to learners.

The role of the learner in this process is primarily as a passive recipient of knowledge, whose task is to simply store it in their memory. What matters is the quality of the content to which they are exposed. As a consequence, the passive-learning hypothesis predicts that for two systems with the same multimedia material, the level of learning should be the same regardless of whether the systems are interactive or non-interactive.

Previous studies on animation and personalisation have suggested that learner interaction may be beneficial. For example, Rieber (1990) found that students learning Newton's Laws of Physics scored higher in tests after receiving an animation followed by multiple-choice questions including feedback. Students also obtained higher scores after practice using a simulation in which they controlled a floating spaceship. Similarly, Moreno, Mayer, Spires, and Lester (2001) found that a plant-biology lesson including practice in selecting plant designs increased the performance of students in tests.

Direct evidence of an interactivity effect was found in a study by Mayer, Dow, and Mayer (2003) in which an electric-motor lesson, including interaction to select the timing and order of explanations, increased scores in problem-solving tests.

Our study contributes to this base of research. A comparison is made between the memory and understanding of students who received lessons as interactive systems and those who used non-interactive multimedia systems. Memory was assessed using retention (recall) tests. Understanding was assessed using transfer (problem-solving) tests.

In the experiment, learners were given a multimedia lesson on the operation of a bicycle pump, including text and images. The learning outcomes of students who used an interactive version (I) and those who used a non-interactive version (NI), were examined. The active-learning hypothesis predicts that students in the I group should do better in tests than students in the NI group on the basis of the interactivity effect. By contrast, the passive learning hypothesis predicts that there should be no statistically significant differences between the two group's scores.

2. Method

2.1. Participants

The participants were a class of 33 second-year undergraduates taking the Computing pathway in a B.Sc. in Business and Management at a university in London, UK. Twenty-two were male and eleven were female and their ages ranged from 19 to 25. Participants were all at the same level in their studies and had met the same pre-requisites. This sample was chosen for this study as none of the participants had a background in either physics or engineering and thus had low prior knowledge on the domain taught by the lesson.

2.2. Materials and apparatus

Two computer-based multimedia packages were developed. The I system included several interactive features contained in the lesson. The NI system had no interactive features in the lesson. Both systems described 12 stages of how a bicycle pump works, and followed this with a test involving a series of open-ended text-entry questions.

The NI system was a computer-based version of that described in Mayer and Gallini (1990). The first screen of the system contained a labelled diagram of a pump. Clicking a button then presented a single screen with static images and text annotations describing 12 stages in the operation of the pump. The screen contained two parts: on the left, the six stages in the down phase were illustrated; on the right, the six stages in the up phase were presented. This is illustrated in Fig. 1. This differs from the original in the addition of two extra stages accounting for the formation of a vacuum, and the compression of air in the cylinder. The motivation for this change was to develop the explanation so that learners would understand why air enters and exits the pump.

In the I system, three different forms of interactivity were incorporated. The first type of interactivity was pacing control. First, an unlabelled diagram of a pump was displayed. Then repeated clicking of a button revealed a text label for each of the pump's components. Information about each component was thus only given when the learner indicated their readiness by clicking the button. The next screen consisted of a series of 12 stages in the operation of the pump. Clicking the 'NEXT STAGE' button revealed part of an animation of the pump working, together with a written description. Each animation was also accompanied by sound effects corresponding to the movement of the piston or the opening and closing of the valves. This is illustrated in Figs. 2 and 3.

The second type of interactivity involved two interactive self-assessment questions (ISAQs). These required the learner to choose an answer from five options by dragging the chosen segment of text to the answer box. If the selected answer was correct, the text snapped into place and descriptive feedback was presented, confirming why the answer was correct. If the answer was

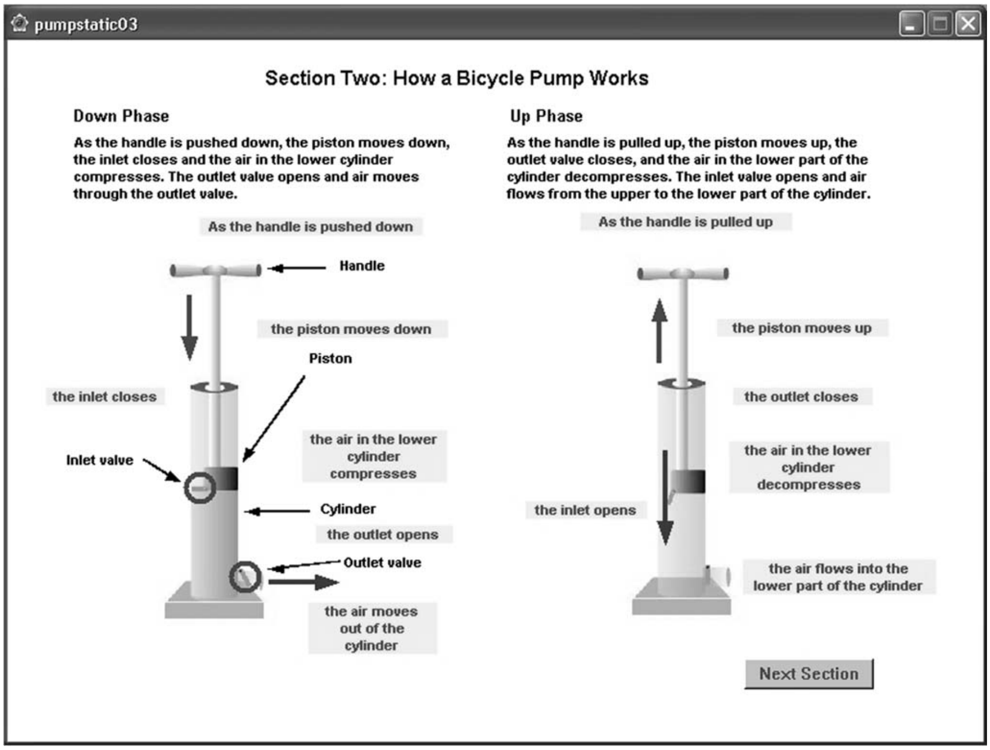

Fig. 1. The non-interactive lesson.

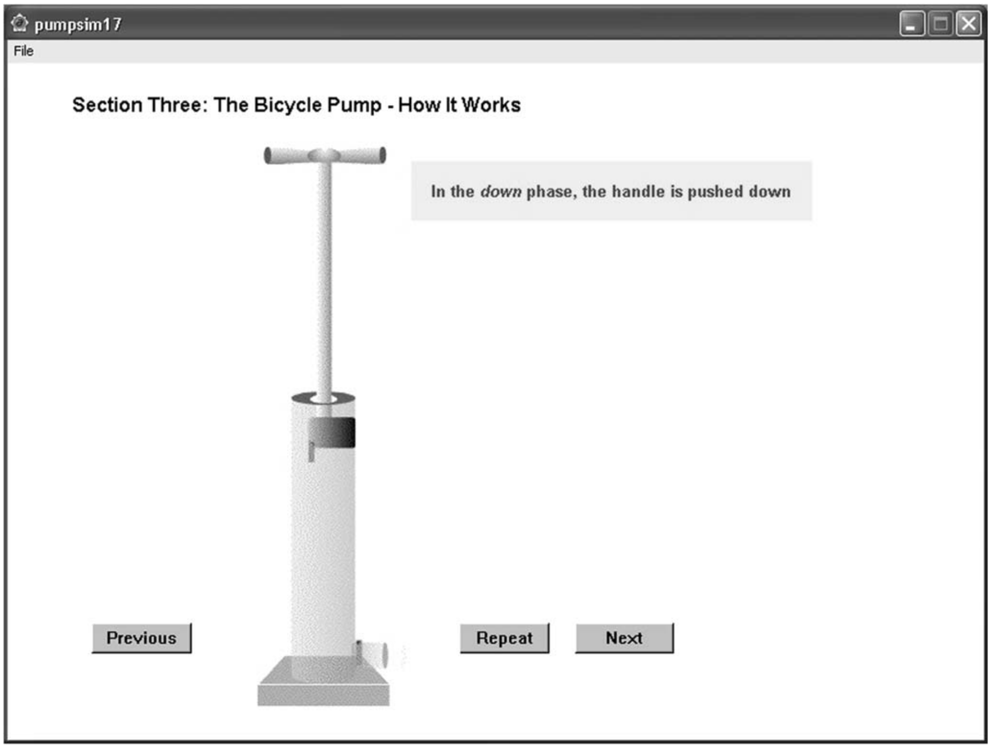

Fig. 2. Interactive pacing in the interactive lesson.

incorrect then it was visually rejected from the answer box and returned to its original location. Descriptive feedback was provided to explain why the chosen answer was incorrect. Repeated selections could be made until the correct answer was chosen, as illustrated in Fig. 4. The feedback comprised material from the preceding lesson, so that the information content of both systems remained the same.

The third type of interactivity consisted of an interactive simulation. A balloon was inflated by repeated clicking on the handle of the pump, simulating the pushing and pulling, until the balloon burst. The piston would move up and down, and the valves open and close, corresponding to the stages described previously. The simulation was also accompanied by sound effects for the piston and valve motion. A snapshot of the interactive simulation is given in Fig. 5.

For both versions of the system, the pre-test consisted of a single on-screen request: ''Please type an explanation of how a bicycle pump works. Pretend that you are writing to someone who does not know much about pumps.'' The learner was required to type the answer into a fixed-size text field.

The post-test consisted of five open-ended questions: two retention questions, and three transfer questions. These are identical to those used in Mayer (2001) with one modification. The additional two stages added to the explanation of how a pump works mean that one of the transfer questions now has to be reclassified as a retention question since the answer is given as part of the lesson.

The two retention questions were then:

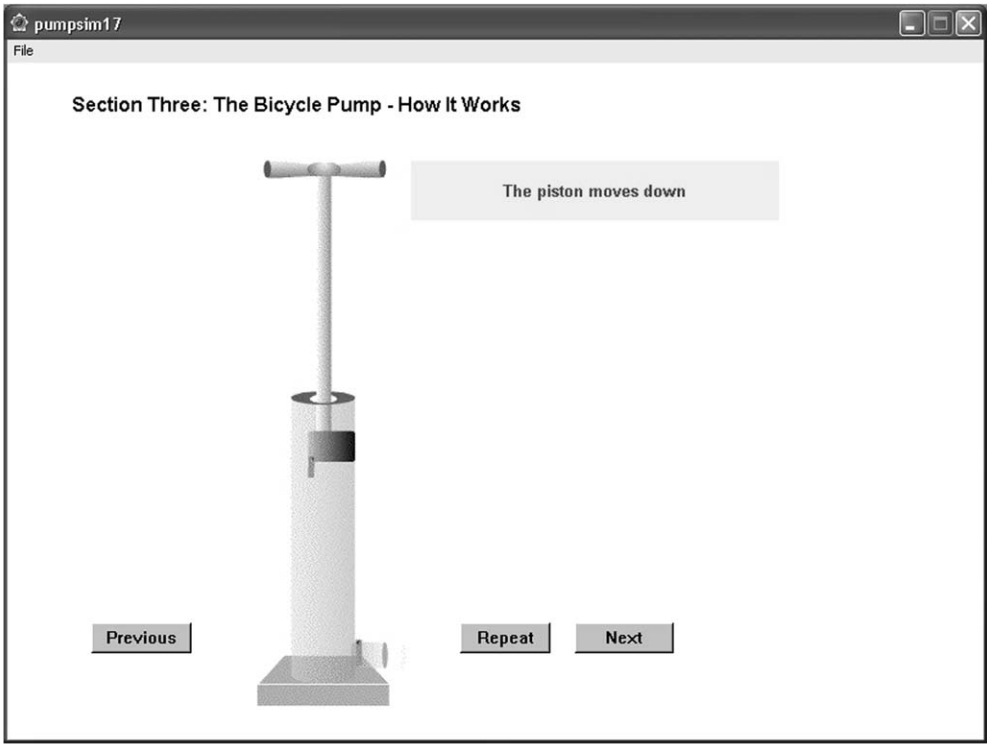

Fig. 3. Interactive pacing in the interactive lesson.

1. Please type an explanation of how a bicycle pump works. Pretend that you are writing to someone who does not know much about pumps.
2. Why does air enter a pump? Why does air exit from a pump?

Question 1 is marked out of 12 and required the learner to recall each of the 12 stages detailed in the lesson. Question 2 was marked out of 2 and required the learner to recall the information about compression and the creation of a vacuum.

The three transfer questions were:

1. What could be done to make the pump more reliable – that is, to make sure it would not fail?
2. What could be done to make the pump more effective – that is, to make it move air more rapidly?
3. Suppose you push down and pull up the handle of a pump several times but no air comes out. What could have gone wrong?

Each of the transfer questions was marked out of 2.

Both systems were constructed using Authorware™ 7 (Macromedia, 2003). They automatically recorded the time taken by learners to complete each of the tests as well as different sections of the lesson.

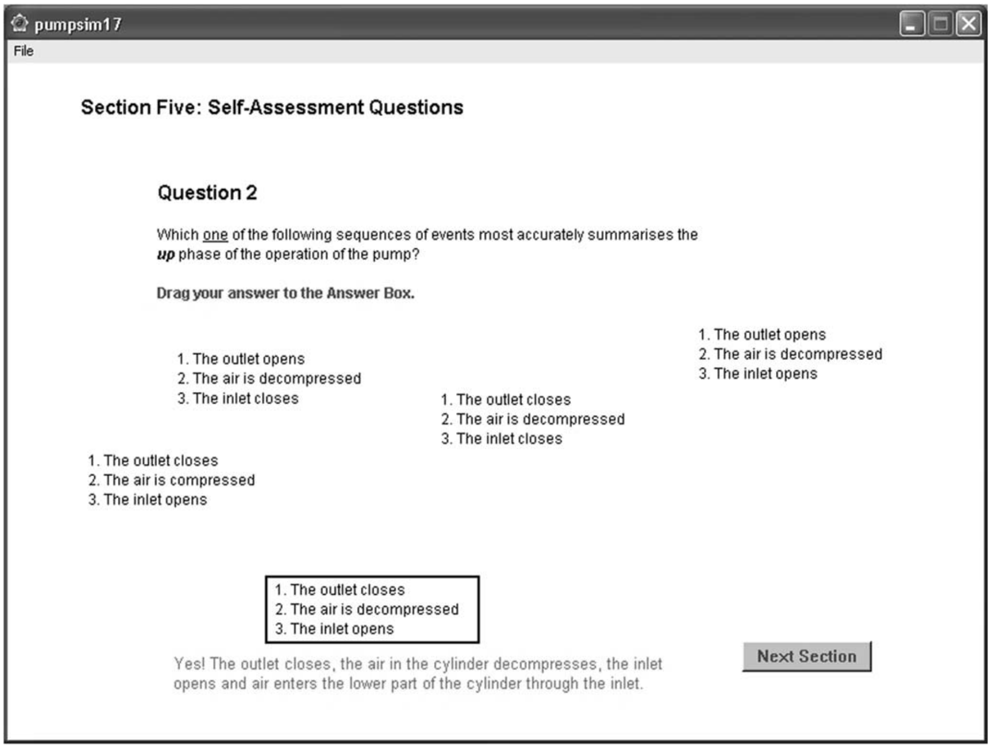

Fig. 4. An example of feedback from an ISAQ.

The apparatus consisted of two computer laboratories, one containing 30 Apple Macintosh™ G4 or eMac™ computers running Mac OS X 10.2, and the other containing 30 Viglen PCs running Windows™ 2000. Both laboratories used 17 in. screens. The packages were initialised prior to the experiment, minimising the potential effect of differing operating systems.

2.3. Procedure

The class was randomly divided into two groups to undertake the two different systems I and NI. Random allocation resulted in the I group consisting of sixteen participants, thirteen were male and three were female, and the NI group of seventeen participants, nine were male and eight were female.[1] Both groups had a similar age-range and had all completed the same first-year of their Business and Management degree. The groups were placed in different computer laboratories and took the lesson and test at the same time. The groups were given approximately 1 h in which to complete both the lesson and the tests. After both groups had completed the lesson and the post-test, their scores were double marked. Significant differences between their scores

[1] Whilst there were fewer females in the treatment group, there were no differences between test scores for males and females for either retention, unpaired Student's *t*-test, $t(31) = -0.878$, two-tailed, ($p = \text{ns}$) or transfer, unpaired Student's *t*-test, $t(31) = 1.175$, two-tailed, ($p = \text{ns}$).

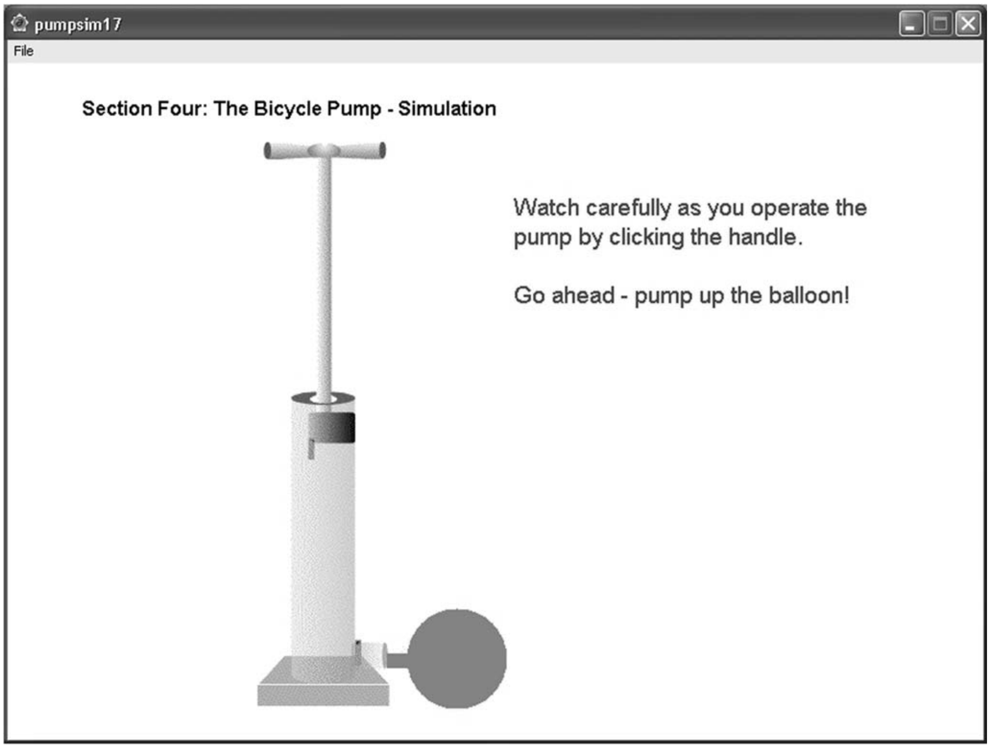

Fig. 5. The interactive simulation.

and timings were assessed using one-tailed statistical tests where we had prior hypotheses predicting a difference in one direction, and two-tailed tests otherwise. Correlations were assessed using the Pearson coefficient. All statistical tests were performed with an α value of 0.05.

3. Results

3.1. Post-test scores

There is no significant difference in the overall post-test results, (given in the first pair of columns in Table 1; unpaired Student's t-test, $t(31) = 1.69$, one-tailed, $p = \text{ns}$). There is also no

Table 1
3Post-test scores

System	Overall		Retention		Transfer	
	Mean (out of 20)	Standard deviation	Mean (out of 14)	Standard deviation	Mean (out of 6)	Standard deviation
I ($n = 16$)	11.4	2.8	8.9	2.8	2.5*	0.9
NI ($n = 17$)	11.9	2.6	10.1	2.1	1.8	1.0

* $p < .05$.

Table 2
Lesson and post-test time results (in seconds)

System	Lesson time (s)		Retention-test time (s)		Transfer-test (s)		Total post-test time (s)	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
I	1583.0*	395.7	435.5	176.6	349.9	165.6	785.5	297.7
NI	498.7	124.7	568.5**	189.6	592.3*	249.9	1160.8*	313.5

* $p < .001$.
** $p < .05$.

significant difference in the retention test results (given in the second pair of columns in Table 1; unpaired Student's *t*-test, $t(31) = 1.35$, one-tailed $p =$ ns). However, students that used the interactive lesson, performed significantly better in the transfer test than those using the non-interactive lesson, unpaired Student's *t*-test, $t(31) = 2.11$, one-tailed, $p < .05$. The effect size is 0.7.

3.2. Lesson and test timings

In Table 2, students using the interactive system took significantly less time to complete the post-test than those using the non-interactive system, unpaired Student's *t*-test, $t(31) = 3.52$, one-tailed, $p < .001$. The effect size is 1.19. This is true for both the retention questions (unpaired Student's *t*-test, $t(31) = 2.06$, one-tailed $p = .02$) and for the transfer questions (unpaired Student's *t*-test, $t(31) = 3.30$, one-tailed, $p = .001$), the effect sizes are 0.7 and 0.96, respectively.

As would be expected, given the difference between the two systems, the students using the interactive system spent significantly more time on the lesson than those students using the non-interactive system, unpaired Student's *t*-test, $t(31) = 10.48$, one tailed, $p < .001$. The effect size is 8.69.

3.3. Relation between scores and timings

Fig. 6 illustrates that there is no significant correlation between time on lesson and transfer test scores (Pearson, two-tailed, $r = 0.254$, $p =$ ns).

Fig. 7 illustrates that there is also no significant correlation between time on lesson and total time on test across both groups (Pearson, two-tailed, $r = -0.310$, $p =$ ns). This result also holds for the separate retention- and transfer-test timings (Pearson, two-tailed, $r = -0.181$, $p =$ ns; and $r = -0.310$, $p =$ ns, respectively). However, there is a positive correlation between lesson time and overall test time for the I group separately (Pearson, two-tailed, $r = 0.532$, $p = .03$).

4. Discussion

The test scores suggest that adding interactivity to a computer-based lesson increases the depth of learning or understanding. This increases the ability of learners to transfer their knowledge to solve diagnostic problems like those given in the transfer test. However, the increase in understanding is not necessarily accompanied by an increase in the breadth of learning or memory.

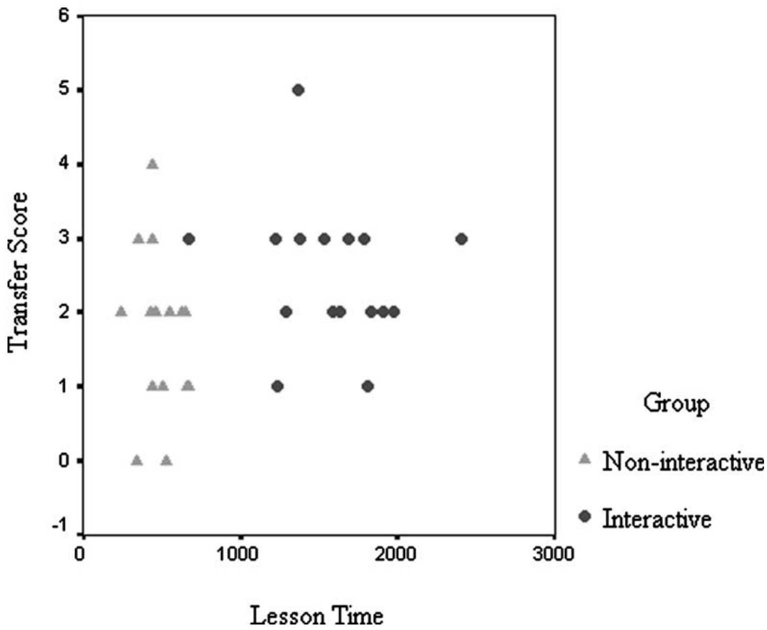

Fig. 6. Correlation between time spent on lesson and transfer score.

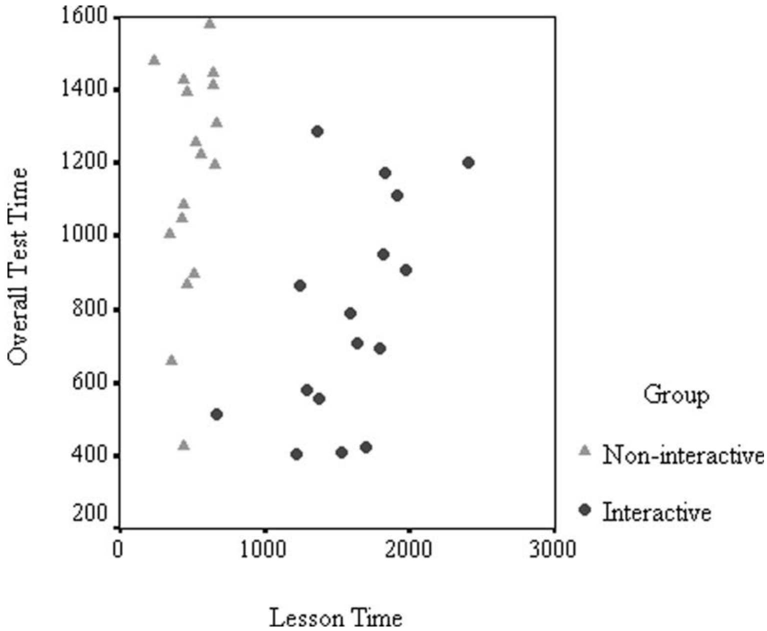

Fig. 7. Correlation between time spent on lesson and time spent to complete post-test.

Thus, learners using the interactive system did not significantly increase their retention of material when given a recall test. These results are consistent with the active learning hypothesis which predicts that learning should increase when interactivity is added because it helps learners develop an active relationship with the material. The increase in learning in the form of understanding is inconsistent with the passive-learning hypothesis which predicts that there should be no difference in group performance since the information content of the two systems are the same.

Mayer and Chandler (2001) found a similar result in their study of the effect of simple user interaction. In an experiment to investigate the effects of double presentation, they had two groups of students: for one group, the lesson was interactive and for the other, it was non-interactive. The interactivity took the form of a button which would reveal the next stage of the lesson when pressed. The presentation was given twice in order that they could assess the effect of varying the form of one of the two presentations. They found that both groups' subjective judgements of the difficulty of the interactive and non-interactive lessons were the same. However, the transfer-test scores were significantly higher for the group using the interactive system. The explanation they gave for this was that the ability to interact to control the pace of the double presentation enabled students to reduce the cognitive load on their working memory.

The time analysis here shows that students using the I system spent significantly more time on the lesson than the students using the NI system. This result is predicted since the I group experienced two additional activities, although the information content of the two systems remained the same. The additional time on task cannot account for the increase in transfer-test scores, however. Whilst students using the I system spent more time on the lesson and obtained better scores, the results show that there is no overall correlation between the time learners spend on the lesson and their test score. It may be that students using the interactive system, since they are actively engaged in the learning from the material, adopt a different learning strategy from those using the non-interactive system. Regardless, it appears to be interactivity rather than time on task that produces the effect.

Our study also considered the time that learners needed to complete the two tests. The results suggest that interactivity reduces the time that learners need to answer questions. The most likely explanation for the reduction in answering time is that it reflects an increase in learning: students with greater learning do not need as long to construct answers to open-ended questions. This result applies equally to both retention and transfer tests. It thus provides further evidence in support of the active-learning hypothesis in the form of an interactivity effect for understanding and also for memory.

It is interesting to consider again whether the time on the lesson influences the time on the test. It is possible, for instance, that the mechanism by which interactivity has an effect includes increasing the time learners spend on the lesson. This increase in learning might then be reflected in the observed reduction in the time it takes learners to complete the tests. However, considering both groups, there is no significant correlation between the time on lesson and the time on test. The additional time spent on lesson cannot account for the decrease in time needed to complete the tests. Confining consideration to the I group since it is the group in which the reduction in time is most marked, reveals a *positive* correlation between lesson time and overall time spent on the tests. Learners who spent longer on the interactive lesson, also took *longer* to complete the tests. This implies that the mechanism by which interactivity enhances learning cannot be reduced simply to time on task. It appears that learners who take advantage of the interactive features of the lesson to spend more time on it, also take advantage of the interactive features of the test, to spend more time on that as well. In other words, some learners simply prefer to work through the lesson and test more slowly than others.

Rieber (1990) found that animation improves learning only when accompanied by the opportunity to practice the theory. In our study this practice was provided by both ISAQs and an interactive simulation making our findings consistent with those of Rieber.

Our study thus provides evidence of an interactivity effect for deep learning (understanding), as shown both by improvement in transfer test scores and reduced time needed to complete transfer test questions. However, it provides only weak evidence of the same effect for memory, as shown by the reduced time needed to complete retention tests. The weaker effect for memory compared with understanding is consistent with previous multimedia learning studies (summarised in Mayer, 2001) which suggest that effects are more pronounced in transfer tests than in retention tests.

The experiment considered a lesson on engineering taught to a sample of Business and Management students with little scientific or engineering background. Further studies are being conducted to establish whether a similar result can be obtained for lessons on non-scientific subjects and younger learners (aged 8–11).

Further research is also required to identify whether the interactivity effect for memory is reproducible and whether a different design to the interactive system might be able to amplify it. Further studies are also planned to distinguish between the effects of each of the three different types of interactivity incorporated in the system: pacing, practice (using ISAQs) and simulation to establish the importance of learner engagement rather than cognitive load in producing the interactivity effect.

The effect of interactivity in increasing learning has important implications for the design of the next generation of e-learning systems. As indicated in the introduction, until recently, most systematic studies of computer-based learning have used systems which were non-interactive. This study provides compelling reasons for courseware authors who wish to foster deep learning, to incorporate interactive features into the design of their systems at an early stage.

Acknowledgements

This research was supported by Brunel University's Virtual University Project which is partially funded by Brunel University's Learning and Teaching Development Unit and the Brunel Enterprise Centre. The authors would also like to thank Vimal Dalal for help with conducting the experiment.

References

Drave, W. (2000). *Teaching online*. River Falls, WI: LERN Books.

Evans, C., & Sabry, K. (2002). Evaluation of the interactivity of web-based learning systems: principles and process. *Innovations in Education and Teaching International, 40*(1), 89–99.

Jonassen, D. (1992). Objectivism versus constructivism: do we need a new philosophical paradigm? *Education Technology Research and Development, 39*, 5–14.

Laurillard, D. (2002). *Rethinking university teaching* (second ed.). London: Routledge.

Macromedia (2003). *Authorware 7.0* [Computer software]. San Francisco: Author.

Mayer, R. E. (1999). Designing instruction for constructivist learning. In C. M. Reigeluth (Ed.), *Instructional design theories and models* (pp. 141–159). Mahwah, NJ: Erlbaum.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge University Press.

Mayer, R. E., & Anderson, R. B. (1991). Animations need narrations: an experimental test of a dual-coding hypothesis. *Journal of Educational Psychology, 83*, 484–490.

Mayer, R. E., & Chandler, P. (2001). When learning is just a click away: does simple user interaction foster deeper understanding of multimedia messages? *Journal of Educational Psychology, 93*, 390–397.

Mayer, R. E., Dow, G. T., & Mayer, S. (2003). Multimedia learning in an interactive self-explaining environment: What works in the design of agent-based microworlds? *Journal of Educational Psychology, 95*, 806–813.

Mayer, R. E., & Gallini, J. (1990). When is an illustration worth ten thousand words? *Journal of Educational Psychology, 82*, 715–726.

Mayer, R. E., & Moreno, R. (1998). A split-attention effect in multimedia learning: evidence for dual processing systems in working memory. *Journal of Educational Psychology, 90*, 312–320.

Moore, M. G. (1989). Editorial: three types of interaction. *The American Journal of Distance Education, 3*, 1–6.

Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction, 19*, 177–214.

Rieber, L. (1990). Using computer animated graphics in science instruction with children. *Journal of Educational Psychology, 82*, 140–145.

Schär, S., & Krueger, H. (2000). Using new learning technologies with multimedia. *IEEE Multimedia, 7*(3), 40–51.

Schrum, L., & Berge, Z. (1997). Creating student interaction within the educational experience: a challenge for online educators. *Canadian Journal of Educational Communication, 26*(3), 133–144.

Sim, R. (1997). Interactivity: a forgotten art? *Computers in Human Behavior, 13*(2), 157–180.