The Effectiveness of Interactivity in Computer-Based Instructional Diagrams

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Abstract. This study investigates if interaction between a student and instructional diagrams displayed on a computer can be effective in significantly improving understanding of the concepts the diagrams represent over viewing animated or static instructional diagrams. Participants viewed either interactive, animated, or static versions of multimedia tutorials that taught how a simple mechanical system, a lock, worked and how a complex mechanical system, an automobile clutch, worked. Participants were tested on recall and comprehension to determine which presentation style; static, animated, or interactive; greater impacts learning, and whether that impact is mediated by the complexity of the mechanical system. Participants who studied from interactive multimedia presentations demonstrating how simple and complex mechanical systems work performed significantly better on comprehension tests for both mechanical systems than those who studied from static or animated presentations. However, all participants performed similarly on recall tests. Research on the effectiveness of computer learning environments and how to optimize their potential for effective instruction through improved multimedia design is important as computers are increasingly being used for training and education.

1 Introduction

Discovering ways to improve teaching effectiveness is an important area of research. Traditional instructional delivery methods, such as lecture and textbooks, are still popular choices for instruction, but they may not be the best methods for teaching students about systems with interacting components, such as mechanical systems. Computer-based learning tools have the potential to instruct students in a way that other materials cannot. Computers can provide multimedia instruction, engaging different senses with audio, visual displays, and physical interaction. Computers also allow for animation so that students can see objects moving on a display. For example, diagrams can be animated and drawn step-by-step for students as if a teacher was drawing the diagrams for them. In contrast to other forms of study aids, such as textbooks or guides, computers have the potential to offer unique capabilities and opportunities for interaction between the student and the subject matter, giving students the ability to manipulate objects on the display and see the subsequent outcomes. For example, students can learn how an automobile clutch works by dragging and dropping pictures of automobile clutch parts on a computer screen to assemble the entire clutch and see how the parts interact. In addition, the computer can provide feedback on the

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student's accuracy and level of understanding of the material in response to the student's interactions with the computer program. The effects of the capabilities of computers on instruction have yet to be fully explored and studied. Knowing more about how the capabilities of computers affect learning will allow the computer to be utilized to its greatest potential as a learning environment. The purpose of this current study is to determine if interactivity aids learning in computer-based instruction.

The results of this present study could have implications for the use of computers in instruction and training. Computers are quickly becoming a popular medium for instruction through the use of computer courseware, websites to supplement instruction and research, simulations to provide practice for training, and software applications that function as study aids. As computers continue to augment or replace classrooms and training facilities, research is needed on how to optimize the potential of computers as an instructional medium.

1.1 The Need for Computer-Based Instruction

Universities do not always have the capacity to accommodate all of the students who apply, or the flexibility to meet the needs of students who have other demands on their lives besides education. However, with developing technology, widespread access to computers and the Internet, and the use of electronic communication, computers present a potential solution [19]. With distance learning technology, universities can now expand to accommodate students who want to earn a degree, but cannot, or choose not, to attend traditional classroom sessions due to disabilities, traveling, or demands of work or family [6]. These universities can provide computer courseware accompanied with interaction from the professor through electronic mail, online chat sessions, bulletin boards, or in-class meetings. Distance learning is also utilized as a form of curriculum enrichment for elementary through high school students. Research has shown that these multimedia enhanced instructional programs are effective in motivating students and increasing their interest in learning [20].

Learning is no longer restricted to a traditional classroom setting. According to the National Science Board [16], the number of students taking courses and training, certificate, and degree programs online is escalating. From 1997 to 2001, enrollment in for-credit distance education courses more than doubled from 1.3 million to 2.9 million. During that time, the number of for-credit distance education courses also more than doubled from 47,500 to 118,000. With the demand for distance education courses and multimedia web-based instructional materials continuously rising, it is imperative that instructors know which forms of multimedia are optimal for teaching their students.

1.2 Multimedia Design in Computer-Based Learning

The human-computer interaction is unique in distance learning since the computer is assigned the role of instructor, while the user assumes the role of learner. The goal of this relationship is to allow the computer and user to interact in a way that will provide the most effective and efficient way of presenting and teaching the subject material to the user [10]. The design of multimedia instructional materials must be based on research that shows what types and uses of multimedia are beneficial for learning. The instructional effectiveness of a multimedia lesson should always be the design focus.

Research has shown that dual-mode presentation (audio and visual) of instructional information is more effective than single-mode presentation (visual alone) in teaching with static graphics [15] and animated graphics [13]. The authors concluded that these results were due to a reduction in cognitive load. Students do not experience cognitive overload in viewing verbal instruction with simultaneous audio because visual working memory and auditory working memory process independently of one another. However, visual working memory can become overloaded if there is competing visual stimuli, such as an animation and verbal instruction. In this situation, the student is forced to choose relevant pieces of information instead of being able to view and process all of it. This was demonstrated by Moreno and Mayer [14] who tested the effects of different narrated presentations of a multimedia scientific explanation of lightning formation. They found that learning comprehension was increased when verbal instruction was presented in both visual and audio formats, providing that the animation was not presented at the same time as the verbal information, and thus, not competing for processing in visual working memory. In addition, Czarkowski [5] found that students prefer audio and animation to static graphics and instructional materials without audio. Based on research on multimedia design for computer-based instruction, the instructional materials used in this current study presented verbal information about the systems visually with simultaneous auditory narration, preceded or followed by the diagram's animated demonstration or interactive mode.

Studies have shown graphical computer aids to enhance comprehension of complex subject matter [18], sparking further research studies in the effectiveness of computer-based instruction. Animated diagrams were found to be more effective than text alone in a study based on the instruction of tree diagrams [4]. Animated diagrams have been found to be more effective than static diagrams in a study that analyzed the effectiveness of instruction of computer algorithms [3]. Therefore, in the present study, it is predicted that students who view animated lessons about mechanical systems will outperform those who view static lessons on tests of recall and comprehension. However, Hegarty et al. [9] found that an animation did not facilitate comprehension of a mechanical system, a toilet, more than a static diagram. The authors proposed that this could be due to the nature of the mechanical system in the diagram. It was suggested that since the toilet consisted of two simultaneous causal chains it was more beneficial for the participants to comprehend the diagram by repeatedly mentally animating different sections of the toilet system at a time. It was proposed that animated diagrams might be more beneficial for learning comprehension of mechanical systems if the animations showed portions of the system and could be repeated. Thus, the diagrams used for this current study demonstrated the mechanical systems in both their entirety, as well as in segments, and the participants were allowed to view the diagrams and animations as much as they needed within a given period of time.

1.3 The Potential of Interactive Multimedia

A new question is whether the unique capabilities of interactive diagrams will provide increased effectiveness in instruction over animated and static diagrams that represent the same concepts. While animated diagrams have the capability to demonstrate instructional content in a way that facilitates learning through the illustration of life-like moving parts, interactive diagrams go beyond animated by enabling students to choose what they will learn. For example, students can choose when they want to see what happens when a clutch engages or disengages by clicking button by a diagram of a clutch. An interactive presentation can give students the most control over how they view the materials, allowing them to select when they view animations, what animations they want to see, and if they want to replay an accompanying audio narration. By being able to interact with the instructional presentation, a student is able to design the presentation based on how they want to study and their learning pace and preferences. The computer acts as a guide or tutor by showing the student what choices they have for material presentation modes, and allowing the student opportunities to enhance and customize their learning experience through the manipulation of their study materials.

Interactive diagrams may also help a user maintain interest in the subject, as well as provide motivation by discouraging passive learning and allowing the student to take a more involved and hands-on approach to grasping a concept. Research shows that active interaction with instructional materials is important to learning, and a valuable method for keeping students cognitively engaged in the instruction [12]. While the impact of interactive diagrams on learning have not been empirically tested in previous research, it has been predicted that they will be able to expand on the instructional potential of animated diagrams by allowing students to manipulate and control the animations in order to better perceive and comprehend them [22].

With interaction, students also have the opportunity to practice what they are learning since, through manipulation of objects on the display, they can reinforce concepts, such as dragging and dropping parts of a clutch to assemble it on the screen. The diagram can then be used and manipulated as many times as the user feels they need to practice in order to practice applying their knowledge and achieve mastery of the concept. In problem solving, more practice has been found to increase the long-term understanding of a subject matter [21].

Interactive diagrams also have the advantage of being able to offer feedback on the student's level of mastery of the concepts presented, and the application of their knowledge. Students receive immediate feedback on their progress by seeing the results of their manipulations and having the computer check if the outcome is correct. For example, students can assemble an automobile clutch diagram themselves by dragging the clutch's parts into place while learning about the individual parts and their roles in the functioning of the clutch. The computer gives the student immediate feedback if they are assembling the parts in the correct order or not. Feedback given by an instructional computer program in response to a user's manipulation of the display allows the user to determine their progress in acquiring knowledge and achieving mastery of a concept.

Thus, previous research supports the idea that interactive diagrams may facilitate learning like a tutor, guiding the student and allowing them to choose what they learn, practice what they learn, and receive feedback on their learning progress, unlike static and animated diagrams that simply present information. Based on these ideas, interactive lessons should prove helpful for students who are learning about simple mechanical systems, defined as having 10 or fewer moving parts, such as a common door lock mechanism, and complex mechanical systems, defined as having 11 or more moving parts, such as an automobile clutch. Previous studies have shown the effectiveness of actively engaging students in the learning process and how computers can assist in this capacity, but empirical research has not been previously conducted on interactive computer-based diagrams and their effectiveness in instruction. This present study expands upon previous research findings by exploring the instructional effectiveness of static, animated, and interactive presentations of instructional diagrams that represent simple and complex concepts. This study explores the effects of interactivity on recall and comprehension of mechanical systems. If interactivity lives up to its potential, then participants should have higher performance levels of recall and comprehension after studying from interactive instructional materials over static or animated instructional materials. To test these hypotheses, college students were given either interactive, animated or static lessons about a simple door lock and an automobile clutch. They were then tested on recall and comprehension.

2 Method

Participants were 90 undergraduate students from California State University, Northridge who received class credit for participating. The participants were screened to ensure that they did not have high levels of prior knowledge of the concepts represented in the instructional diagrams. All participants had at least a minimal level of experience with using a computer so that they knew how to point and click a mouse and drag objects on the display using a mouse. After being screened for color blindness [7], none of the participants were found to have deficient color vision. The participants were also given a spatial reasoning test that consisted of 20 questions of varying difficulty [2].

This study used a 3 X 2 mixed factorial design. Diagram presentation style (static, animated, and interactive) was the between-subjects factor, and complexity (simple, complex) was the within-subjects factor. The dependent variables were recall and comprehension.

Participants were randomly assigned to view either the static, animated, or interactive version of the tutorials for the simple and complex systems. The order of presentation for the two systems was counterbalanced to minimize order effects. Participants were allowed to spend ten minutes studying the simple system and fifteen minutes studying the complex system. The participants were able to repeat the audio in the static presentations, repeat animations in the animated presentations, and interact multiple times with the interactive diagrams as they saw fit to properly study the material, but they were limited in the amount of time that they could spend viewing the entire presentation.

After studying the presentation of the first system, the participants received the tests for recall and comprehension on the system that they just learned. The participants were told to complete the test to the best of their ability, to be as thorough and detailed in answering the questions as possible, and to write down as many facts, solutions, and reasoning behind their answers that they could. The participants were allowed to spend as much time as they needed to complete the tests. When a participant completed the tests, they were collected by the researcher and the participants then viewed the instructional materials for the other system of the same presentation style (static, animated, or interactive). After studying the materials for that system, the participants were again tested for recall and comprehension using the same procedures as for the first system.

Simple system. All three versions of the instructional presentations of the simple system; static, animated, and interactive; consisted of five slides that each included a diagram of the basic cylinder lock, verbal information describing the diagram and how the 6 different parts of the lock work and interact with each other, navigation buttons on the bottom of the screen that allowed the participants to return to the previous slide and advance to the next slide, and another button that, in the static presentation, replayed the audio for the current slide or, in the animated and interactive presentations, replayed the animation on the current slide. The descriptions of the diagrams were presented beside the diagrams so that they could be read, and the participants could also hear the descriptions being read through headphones to assist in reading or to allow the participant to look at a diagram while listening to the descriptions.

Complex system. There were static, animated, and interactive versions of the complex system presentation, including diagrams of the 11 different parts of an automobile clutch, their functions and relationships, and the purpose of the clutch in the operation of an automobile. Descriptions of the diagrams were presented beside the diagrams so that they could be read easily. The participants could hear audio recordings of the descriptions to assist in reading or to allow the participant to look at a diagram while listening to the descriptions. The instructional presentation of the simple system consisted of thirteen slides that each included a diagram of part of the automobile clutch, written and auditory information describing the diagram, and buttons on the bottom of the screen that allowed the participants to return to the previous slide, advance to the next slide, and replay the audio for the current slide in the static presentation or replay the animation in the animated presentation.

Recall tests. The recall tests included an open-ended question that prompted the participants to recall and write as much information and detail that they could remember about the system that they learned. Students received 1 point for each concept that they wrote down that was presented in the tutorial on that system. The recall tests also included a picture of a diagram of the system presented with blank labels for the participants to fill in the appropriate names of each of the system's parts. For the recall test on the simple system, participants received 1 point for labeling each of 6 parts of a lock discussed in the instructional presentation. For the recall test on the complex system, participants received 1 point for labeling each of 11 parts of a clutch discussed in the instructional presentation. The overall recall test score was the total number of points earned from the open-ended question answers and the labels for the diagram.

Comprehension tests. For the comprehension tests, the participants were presented with four problems, and asked to provide plausible solutions based on the knowledge of the systems that they gained from the tutorials. The comprehension tests were scored by assigning 1 point for each acceptable solution to the trouble-shooting problems that could have been inferred from the instructional presentation. The total points collected were used as an overall score to compare problem-solving testing performance across conditions.

3 Results

Removing cases due to prior knowledge of the mechanical systems or spending insufficient time to view the presentations reduced the usable sample size to 74 for the simple system and 72 for the complex system.

It was hypothesized that participants would recall more information about both simple and complex mechanical systems after studying interactive instructional multimedia presentations than after studying animated or static presentations. It was also hypothesized that participants who studied from animated presentations would recall more items than those who studied from static presentations. A 2-way mixed design analysis of variance (ANOVA), with recall as the dependent variable, indicated no significant interaction for performance on the recall tests between the simple and complex mechanical systems, $F(2, 68) = 0.165$, $p < 0.05$. No significant main effect on recall was found for presentation style, $F(2, 68) = 0.011$, $p > 0.05$. The analysis also indicated no significant main effects for complexity, $F(1, 68) = 0.593$, $p > 0.05$. Participants recalled a similar number of items about the simple mechanical system and the complex mechanical system whether they studied from the interactive presentation, the animated presentation, or static presentation.

It was also hypothesized that participants' performance in tests of comprehension of both simple and complex mechanical systems would be significantly better after studying interactive instructional multimedia presentations over animated or static presentations since the interactive diagrams provide practice in manipulating the diagrams and encourage active processing of relationships between the parts of the systems represented in the diagrams. A 2-way mixed design ANOVA, with comprehension as the dependent variable, found no interaction between presentation styles and complexity, $F(2, 68) = 0.298$, $p > 0.05$. The analysis indicated a significant main effect for presentation style, $F(2, 68) = 4.453$, $p < 0.05$. A Tukey HSD post-hoc analysis showed that comprehension test performance was significantly better for participants who studied the simple and complex mechanical systems from the interactive presentations ($M = 5.738$, $SD = 0.374$), over both the animated ($M = 4.442$, $SD = 0.336$), $p <$ .05, and static presentations ($M = 4.375$, $SD = 0.350$), $p < .05$.

The spatial reasoning ability of participants did not have a significant effect on the effects that presentation style had on comprehension or recall test performance. Students who studied the mechanical systems from the animated presentations did perform better on the comprehension tests than those that studied from the static presentations, but not by a significant amount. The 2-way mixed design ANOVA indicated a significant main effect for complexity, $F(1, 68) = 23.389$, $p < 0.05$. Students performed significantly better on the comprehension tests for the simple system (M = 5.604) than the comprehension tests for the complex system (M = 4.100). Table 1 shows the means and standard deviations for comprehension test performance on the simple mechanical system and the complex mechanical system.

Table 1. Comprehension Test Performance

	Simple System		Complex System	
Presentation Style	*M*	*SD*	*M*	*SD*
Static	5.259	2.551	3.500	1.445
Animated	5.039	2.358	3.963	1.911
Interactive	6.524	2.400	4.952	2.224

4 Discussion

This study was designed to investigate if interaction between a student and computer-based instructional diagrams results in improved performance on recall and comprehension tests over studying from animated and static diagrams that represent the same concepts. No significant interaction was found between recall or comprehension test performance and complexity of the mechanical system being taught. Students performed significantly better on the comprehension tests for the simple system than the comprehension tests for the complex system. Participants performed similarly on recall tests after studying from static, animated, and interactive instructional presentations of simple and complex mechanical systems. Participants who studied from animated presentations did not perform significantly better on the tests than students who studied from static presentations. However, as hypothesized, participants who studied from interactive presentations performed significantly better on tests of comprehension for both simple and complex mechanical systems than participants who studied from animated or static presentations.

Past research has shown that animated diagrams can be more effective than static diagrams for teaching some subject material [3]. However, in a study conducted by Hegarty et al. [9], participants who viewed animated diagrams of a mechanical system did not show significantly better comprehension over those who viewed static diagrams. Similarly, the results of this present study demonstrated that animated presentations did not facilitate comprehension or recall of the mechanical systems more than static presentations. However, results of this study did show that interactive presentations were effective in significantly improving comprehension of simple and complex mechanical systems over static and animated presentations. This suggests that animated diagrams are not as beneficial for teaching mechanical systems as they are for teaching other subject matter, but interactive diagrams are an effective method for teaching mechanical systems.

Participants who viewed the interactive presentations showed significantly better comprehension of the mechanical systems over those who viewed static or animated instructional presentations, supporting previous research that predicted interactivity would be able to help students perceive and comprehend diagrams better than animation by providing students with the ability to manipulate and control the diagram [22] and allowing students to be more actively engaged in the instructional material through interactivity [12], thus engaging students in deep-level cognitive processing through behavioral processes [11].

The results of this study could have implications for many applications of computer- and web-based instruction. Computers are quickly becoming a popular medium for instruction through the use of computer courseware, websites to supplement instruction and research, simulations to provide practice for training, and software applications that function as study aids. As computers continue to augment or replace classrooms and training facilities, it is imperative to conduct research on how to optimize the potential of computers as an instructional medium. With the demand for distance education courses and multimedia web-based instructional materials continuously rising, it is helpful for instructors to know which forms of multimedia design are optimal for teaching their students before they invest resources and time in training and materials.

Further research is needed to discover the best methods for designing instructional multimedia presentations that increase comprehension of various subjects other than mechanical systems. This study showed that for the purpose of teaching mechanical systems, it is worth the time, resources, and effort of instructors to offer multimedia presentations that include interactive diagrams for maximum learning comprehension of the subject matter. Interactive diagrams may also be the most effective method for teaching other subject material, including topics similar to mechanical systems, such as physics and engineering. Further research is needed to show how interactivity can improve comprehension of other instructional content.

Further research can also expand on the findings of this study by exploring optimal ways of designing interactive diagrams. This present study utilized interactions that included controlling, selecting, and repeating animations, as well as hovering the mouse over objects to reveal labels, and dragging and dropping parts of an automobile clutch in the proper order to assemble the entire system. Further research can explore different types of interaction with diagrams that may improve recall as well as comprehension, or that are most beneficial for teaching certain subject matter.

Students can benefit significantly from interacting with diagrams, which improves comprehension by allowing students to choose what they want to learn, practice what they learn, and receive feedback on their learning progress. If the goal of an educational multimedia presentation is to promote comprehension of mechanical systems, then interactivity holds exciting promise.

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