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Multimedia Learning in an Interactive Self-Explaining Environment: What Works in the Design of Agent-Based Microworlds?

[Articles]

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Abstract

Students learned about electric motors by asking questions and receiving answers from an on-screen pedagogical agent named Dr. Phyz who stood next to an on-screen drawing of an electric motor. Students performed better on a problem-solving transfer test when Dr. Phyz's explanations were presented as narration rather than on-screen text (Experiment 1), when students were able to ask questions and receive answers interactively rather than receive the same information as a noninteractive multimedia message (Experiments 2a and 2b), and when students were given a prequestion to guide their self-explanations during learning (Experiment 3). Deleting Dr. Phyz's image from the screen had no significant effect on problem-solving transfer performance (Experiment 4). The results are consistent with a cognitive theory ofmultimedia learning and yield principles for the design of interactive multimedia learning environments.

How can we help foster constructivist learning in Web-based multimedia environments, such as a site designed to explain how an electric motor works? One approach is to create a self-explaining interactive environment—such that when a learner clicks on a part of the system and asks a question, an on-screen agent comes on the screen and provides an answer using words, illustrations, and animation. For example, consider the following scenario. A student sits at a computer, selects a multimedia encyclopedia, and clicks on *electric motor*. On the screen appears a graphic depicting the parts of the electric motor—the battery, the wires, the commutator, the wire loop, and the magnet—such as shown in Frame 1 of Figure 1. The student can click on any part, such as the battery, and a list of questions appears in the upper right corner of the screen, such as shown in Frame 2 of Figure 1. If the student clicks on a question, an on-screen agent named Dr. Phyz appears and provides an explanation in words, illustrations, and animation, such as shown in Frames 3 and 4 of Figure 1.

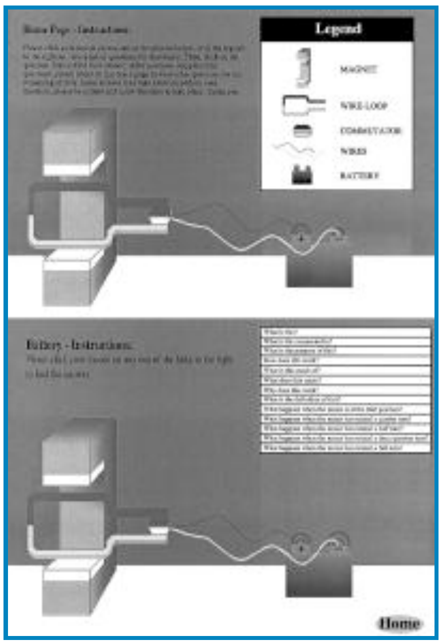

Figure 1. Frames from an interactive multimedia program about how an electric motor works.

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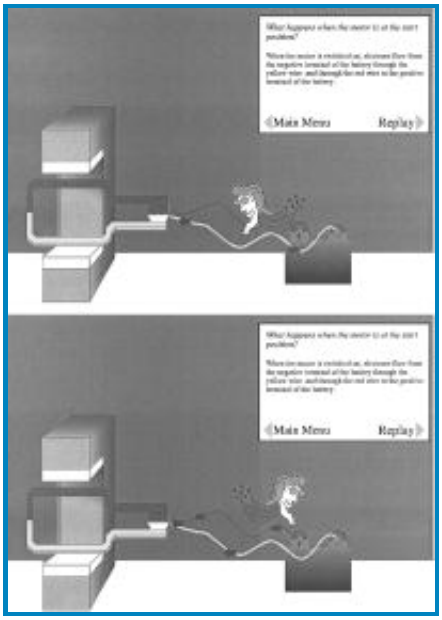

Figure 1. *(continued)*

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Instructional designers call for basic interactivity features in educational technology, such as learner control of the pace and order of a computer-based lesson (Clark, 1999; Mayer & Chandler, 2001; Reigeluth, 1999; Sweller, 1999; Van Merrienboer, 1997; Williams, 1996), but there is also a need for research on how to promote deep learning in the next generation of highly interactive computer-based environments. Thus, in the present studies, we focus on the pedagogic features of agent-based microworlds—that is, computer-based environments containing on-screen agents with which the learner may interact, such as the Dr. Phyz environment featured in Figure 1.

In a set of studies, we examined four features of self-explaining environments that might affect how well learners understand a scientific explanation—whether the words are spoken or printed on the screen, whether the learner can control the pace and order of presentation, whether the learner receives a sample test question before the presentation, and whether the agent's image is present on the screen. One goal of this work is to determine whether a set of multimedia design principles, based on research in noninteractive multimedia environments (Mayer, 2001), would also apply to an interactive multimedia environment. A second goal of this work was to test the generality of a cognitive theory of multimedia learning that is based on the assumption of dual channels for visual and verbal processing, limited capacity in each channel, and active learning involving the mental coordination of visual and verbal representations (Mayer, 2001).

Experiment 1

Experiment 1 examined the role of the agent's voice (i.e., modality effect) by comparing the learning outcomes of students who learned from a version in which Dr. Phyz's answers were spoken words (i.e., narration) with a version in which Dr. Phyz's answers were printed words (i.e., on-screen text). According to the cognitive theory of multimedia learning (Mayer, 2001), the visual information processing channel may become overloaded when students must process on-screen graphics and on-screen text at the same time. However, when words are presented as narration, words can be processed in the verbal channel, thereby reducing the cognitive load in the visual channel. Thus, in the graphics-with-narration condition, students can apply more cognitive capacity to making sense of the presented material. On the basis of the cognitive theory of multimedia learning as well as previous findings in noninteractive multimedia environments (Moreno & Mayer, 1999; Mousavi, Low, & Sweller, 1995; Sweller, 1999), we predict that students who learn from graphics and narration will learn more deeply and therefore perform better on problem-solving transfer tests than will students who learn from graphics and on-screen text.

Method

Participants and design

The participants were 52 college students at the University of California, Santa Barbara, who received course credit for their participation, with half serving in the narrated group and half serving in the text group.

Materials and apparatus

The computer-based materials consisted of two versions of an interactive multimedia program designed to teach students how an electric motor works. The narrated version begins with a home page showing a color illustration of an electric motor including the battery (with positive and negative terminals), wires (i.e., a red wire and a yellow wire connecting the battery terminals to the top and bottom of the commutator), commutator (consisting of a top and bottom side), wire loop, and magnet (consisting of a north and south pole). When the learner clicks on any of the five parts, the part becomes brighter than the others and a list of 13 questions appears in the upper right corner of the screen. For example, if the learner clicks on the battery, the questions include “What is this?” “What is this connected to?” “What is the purpose of this?” “How does this work?” What is this made of?” “What does this cause?” “Why does this work?” “What is the definition of this?” “What happens when the motor is at the start position?” “What happens when the motor has rotated a quarter turn?” “What happens when the motor has rotated a half turn?” “What happens when the motor has rotated three quarters of a turn?” and “What happens when the motor has rotated a full turn?” When the learner clicks on a question, an on-screen cartoon character named Dr. Phyz appears on the screen, his voice provides the answer, the character moves or points in coordination with the narration, and (for some answers) a short animation sequence is provided that corresponds to the narration. Each answer consists of one to five sentences. Following the answer, the learner may click on the *Replay* button to see the animation again (if there was an animation) or the *Main Menu* button to return to the screen showing the electric motor along with the list of 13 questions for the targeted part. The learner can then click on another question or on the *Home* button, which produces the home page where the learner can click on any of the five parts. Learners can click on a part and on a question as many times as they like. The text version was identical to the narrated version, except that the answers were presented as on-screen text in the upper right corner of the screen. Both versions were constructed using Flash 5.0 (Macromedia, 2000) and were based on a simplified version of the Dr. Phyz environment developed at the Intellimedia Lab at North Carolina State University under the direction of James Lester (Brent, Bares, Callaway, & Lester, 1999; Towns, Callaway, & Lester, 1998). The answers for each of the 13 questions about the battery are listed in the Appendix.

The paper-based materials consisted of a participant questionnaire and seven problem-solving transfer test sheets, each typed on a separate 8.5 × 11-in. sheet of paper. The participant questionnaire solicited information concerning the participant's age, gender, and SAT scores; the participant questionnaire also contained an experience survey in which participants rated their knowledge of household repair on a 5-

point scale and checked each of nine electrical-related activities they had engaged in (yielding a total possible experience score of 14). Each problem-solving sheet had one of the following questions printed at the top: “What could you do to increase the speed of the electric motor, that is, to make the wire loop rotate more rapidly?” “What could you do to increase the reliability of an electric motor, that is, to make sure it would not break down?” “Suppose you switch on an electric motor, but nothing happens. What could have gone wrong?” “What could you do to reverse the movement of an electric motor, that is, to make the wire loop rotate in the opposite direction?” “Why does the wire loop move?” “If there was no momentum, how far would the wire loop rotate when the motor is switched on?” and “What happens if you move the magnets further apart? What happens if you connect a larger battery to the wires? What happens if you connect the negative terminal to the red wire and the positive terminal to the yellow wire?” The problem-solving transfer questions constitute a test of near transfer and were designed on the basis of pilot testing.

For each question, we generated a list of acceptable answers, such as the following answers for the third question about what went wrong: the wire loop is stuck, the wire is severed or disconnected from the battery, the battery fails to produce voltage, the magnetic field does not intersect the wire loop, or the wire loop does not make contact with the commutator. Students did not get credit for vague answers such as “something is wrong with the magnet,” but they did get credit for correct answers that were worded differently than the lesson such as “the magnet does not create a magnetic field.” Students received 1 point for each correct answer, so it was possible to receive more than 1 point on each question. Irrelevant or incorrect answers received no points. The transfer test was scored by tallying the number of acceptable answers (regardless of wording) across all seven problem-solving test sheets.

The apparatus consisted of four Macintosh G3 computer systems with 15-in. monitors and Sony earphones.

Procedure

Students were tested in groups of 1 to 4 per session, with each student randomly assigned to a treatment group. Each student was seated in an individual cubicle. First, participants filled out the participant questionnaire at their own rates. Second, the experimenter gave instructions for how to use the multimedia program, and participants interacted with the multimedia program at their own rates. Participants received either the narrated version or the text version. After the learning session, which lasted approximately 20 min, participants answered the problem-solving transfer questions, one at a time, with 3 min given for each. Then, the participants were debriefed and thanked for their participation.

Results and Discussion

In Experiment 1, students in the narrated group generated significantly more answers on the problem-solving transfer test (M = 8.43, SD = 2.56) than did students in the text group (M = 6.54, SD = 2.22), $t(54) = 2.96$, $p = .0046$. The effect size was 0.85. This result supports the *modality principle*—people understand a multimedia explanation better when the words are presented as speech rather than as on-screen text. Thus, the modality principle, which has been found in noninteractive multimedia environments (Mayer & Moreno, 1998; Moreno & Mayer, 1999; Mousavi et al., 1995; Sweller, 1999), can be extended to interactive multimedia environments. This result also is consistent with the dual-channel aspect of the cognitive theory of multimedia learning (Mayer, 2001; Sweller, 1999): Presenting on-screen text and animation can overload the visual channel, whereas presenting narration and animation allows for offloading some processing from the visual channel to the verbal channel.

Experiment 2a

Experiment 2a examined the role of the interactivity (i.e., interactivity effect) by comparing the learning outcomes of students who learned from a version in which Dr. Phyz answered each question with a version in which the identical information was presented as a noninteractive multimedia message. A basic feature of interactivity is learner control of the pace of a multimedia presentation (Williams, 1996). For example, Mayer and Chandler (2001) found that students learned better when they were allowed to control the pace of presentation of a narrated animation on lightning formation by clicking a button to continue after each segment. According to the cognitive theory of multimedia learning (Mayer, 2001), a continuous presentation can overload the learner's cognitive system. In contrast, when the learner can control the onset of each segment, the learner is able to completely process one segment before moving on to the next one. Thus, the learner has more cognitive capacity to make connections among the pieces of material in the presentation. On the basis of this analysis, we predict better transfer performance when students are able to control the pace and order of information presentation.

Method

Participants and design

The participants were 37 college students recruited in the same way as in Experiment 1, with 18 serving in the interactive group and 19 serving in the noninteractive group.

Materials and apparatus

The materials and apparatus were identical to Experiment 1, except the two versions of the program were interactive and noninteractive. The interactive version was identical to the narrated version used in Experiment 1, except that only the last five questions were listed for each part. The noninteractive version began with the same home page; when the learner clicked on the *Start* button on the home page, a continuous narrated animation was presented consisting of the same sentences, agent movements, and animation sequences as were used in the interactive version.

Procedure

The procedure was identical to Experiment 1, except participants received either the interactive or noninteractive version of the program.

Results and Discussion

In Experiment 2a, students in the interactive group generated significantly more answers on the problem-solving transfer test (M = 7.95, SD = 2.27) than did students in the noninteractive group (M = 5.72, SD = 3.18), $t(35)$ = 2.46, p = .0189. The effect size was 0.70. This result provides evidence for an instructional design principle that can be called the *interactivity principle*—people understand a multimedia explanation better when they are able to control the order and pace of presentation. This is additional support for the limited capacity aspect of the cognitive theory of multimedia learning (Mayer, 2001), that is, interactivity reduces cognitive load by allowing learners to digest and integrate one segment of the explanation before moving on to the next.

Experiment 2b

A possible criticism of Experiment 2a is that the test was immediate, so it is not clear whether the effects of interactivity would persist for more than a few minutes. To address this criticism, we replicated Experiment 2a, using a delayed test, which occurred 1 week following learning.

Method

Participants and design

The participants were 41 college students recruited in the same way as in Experiment 2a, with 22 serving in the interactive group and 19 serving in the noninteractive group.

Materials and apparatus

The materials and apparatus were identical to Experiment 2a.

Procedure

The procedure was identical to Experiment 2a, except that the test was administered 1 week after the learning session.

Results and Discussion

In Experiment 2b, students in the interactive group generated significantly more answers on the problem-solving transfer test (M = 6.41, SD = 2.92) than did students in the noninteractive group (M = 3.68, SD = 2.65), $t(39) = 3.109$, $p = .0035$. The effect size was 1.03. This result is consistent with the result of Experiment 2a, with the effects of interactivity substantial on both immediate and delayed tests. The results of Experiment 2b are additional evidence for the interactivity principle, namely, the idea that people learn better when they can control the order and pace of a multimedia presentation.

Experiment 3

Experiment 3 examined the role of the learner's cognitive processing activity during learning (i.e., self-explanation effect) by comparing the learning outcomes of students who were or were not given a prequestion before the program. The cognitive function of a prequestion is to cognitively engage the learner through “elaborative interrogation” (Wood, Pressley, & Winne, 1990). The task of having to answer a conceptually demanding question orients the learner toward deeper processing of the presented material and encourages the learner to engage in making “self-explanations” during learning (Chi, 2000). According to this self-explanation hypothesis, students who receive prequestions are expected to learn more deeply and therefore perform better on transfer tests than are students who do not receive prequestions.

Method

Participants and design

The participants were 54 college students recruited as in Experiment 1, with 29 in the prequestion group and 25 in the no-prequestion group.

Materials and apparatus

The materials were identical to Experiment 1, except that only the narrated version of the program was used and there were two prequestion sheets, each typed on 8.5 × 11-in. sheets of paper. Each sheet contained instructions for the participant “to gather information so that you will be able to write an answer for the following question" followed by either the speed question (i.e., the first test question) or the reliability question (i.e., the second test question).

Procedure

The procedure was identical to Experiment 1, except that all participants received the narrated program used in Experiment 1 either preceded by instructions to be able to answer the speed question or reliability question (prequestion group) or preceded by general instructions that a test would follow (no-prequestion group). Participants in the prequestion group were told that after the lesson they would be expected to answer the question they had been given. We choose prequestions that required deep conceptual processing and integration of the presented material rather than retention of specific facts. Although participants in the prequestion group received a problem-solving transfer question before the lesson, they were not asked to provide a written answer for this question until the test. For all participants, the test included the prequestion and all of the other problem-solving transfer questions, presented in the same order as in Experiment 1 and with the same time limit as in Experiment 1.

Results and Discussion

In Experiment 3, students in the prequestion group generated significantly more answers on the problem-solving transfer test (M = 8.90, SD = 2.50) than did students in the no-prequestion group (M = 6.24, SD = 3.20), $t(52) = 3.45$, $p = .0011$. The effect size was 0.83. It is important to note that within the prequestion group, the subgroup that received a prequestion about how to increase the speed of the wire loop and the subgroup that received a prequestion about increasing the reliability of the motor did not differ significantly on any of the transfer test items. Thus, the facilitating effect of prequestions was not specific to the prequestion given during learning. Overall, there was support for the *self-explanation principle*—people learn better when they are prompted to provide explanations during learning. The findings are consistent with the predictions of the self-explanation hypothesis in which priming cognitive activity during learning results in better transfer performance. These results complement those concerning self-explanations in learning from text (Chi, 2000) and point to the importance of priming active cognitive processing during learning.

Experiment 4

Experiment 4 examined the role of the agent's on-screen image (i.e., presence effect) by comparing the learning outcomes of students who learned from a version in which Dr. Phyz's image was or was not on the screen. Proponents of using life-like images of on-screen agents argue that learners enjoy them and therefore pay more attention (Cassell, Sullivan, Prevost, & Churchill, 2000). However, Dr. Phyz's image on the screen provides little or no instructional content because the on-screen animations include movement, arrows, and highlighting that guide the learner's processing. Thus, Dr. Phyz's image—although entertaining and interesting—may serve to distract the learner from the relevant aspects of the electric motor. In short, Dr. Phyz's image may serve as a *seductive detail*, that is, an interesting but irrelevant part of the presentation (Harp & Mayer, 1998). According to this seductive-details hypothesis, students will not learn more deeply when Dr. Phyz's image is included.

Method

Participants and design

The participants were 39 college students recruited as in Experiment 1, with 20 serving in the agent group and 19 serving in the no-agent group.

Materials and apparatus

The materials and apparatus were identical to Experiment 1, except that the two versions of the computer program were agent and no agent. The agent version was the same as the narrated version used in Experiment 1, whereas the no-agent version was the same, except the agent's image was deleted from the screen. The apparatus consisted of five ibook computers with Sony headphones.

Procedure

The procedure was identical to Experiment 1, except that up to 5 participants were tested in each session.

Results and Discussion

In Experiment 4, students who learned with an agent present on the screen did not generate significantly more answers on the problem-solving transfer test (M = 6.60, SD = 3.28) than did students who learned with no agent present on the screen (M = 5.95, SD = 3.52), $t(37)$ = .55, p = .5835. Consistent with a previous study involving an educational science game (Moreno, Mayer, Spires, & Lester, 2001), we found evidence for a *presence principle*—people do not learn better when an agent is physically present on the screen. Although the agent's voice is important for improving learning, the agent's physical image is not. In Experiment 4, arrows signaled the movement of the current, the direction of magnetic field, and the spinning of the loop so the agent's presence on the screen added no instructional information. Apparently, the agent's image on the screen may act as a sort of seductive detail (Harp & Mayer, 1998)—an interesting but extraneous element that either is ignored (and has no effect) or is examined (and has a distracting effect).

General Discussion

On the educational side, these results are consistent with several instructional design principles: the modality principle, the interactivity principle, and the self-explanation principle. When designing a multimedia presentation that is intended to explain how something works (i.e., a model), instructional designers should annotate the animation with spoken rather than printed text, allow the learner to control the pace and order of presentation, and encourage the learner to answer conceptual questions during learning.

On the scientific side, there is support for the three major assumptions of the cognitive theory of multimedia learning. The modality effect can be explained in terms of the dual channel assumption, the interactivity effect can be explained in terms of the limited capacity assumption, and the self-explanation effect can be explained in terms of the active processing assumption. Overall, this research contributes to understanding how to design effective Web-based multimedia learning environments and contributes to a cognitive theory of multimedia learning.

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Appendix

Full Text of Answers Given by Dr. Phyz to Each Question for the Battery

What is this? This is a battery, which includes a negative terminal and a positive terminal.

What is this connected to? The negative terminal is connected to a wire running on the bottom, which I have colored yellow. The positive terminal is connected to a wire running on the top, which I have colored red.

What is the purpose of this? The purpose of a battery is to store electricity.

What does this do? When the motor is switched off, no electrons flow from the battery through the negative terminal and no electrons flow into the battery through the positive terminal. When the motor is switched on, electrons flow out of the battery through the negative terminal and electrons flow into the battery through the positive terminal.

What is this made of? The battery includes a metal container, usually made of zinc; a center post inside the container, usually made of carbon; and a paste between them called electrolyte.

What does this cause? The electrons flowing from the negative terminal cause a flow of electrons through the yellow wire.

How does this work? The battery creates a flow of electrons from the negative terminal—along a path—to the positive terminal.

Why does this work? The battery continually creates an excess of negatively charged particles at the negative terminal and an excess of positively charged particles at the positive terminal. Electrons flow from an area with many electrons to an area with fewer electrons.

What is the definition of this? A battery is a device for storing electricity.

What happens when the motor is at the start position? When the switch is turned on, electrons flow from the negative terminal of the battery through the yellow wire to the end of the yellow wire. Electrons flow from the red half of the commutator to the end of the red wire and through the red wire to the positive terminal of the battery.

What happens when the motor has rotated a quarter turn? While the circuit is broken, electricity temporarily stops flowing from the negative terminal to the positive terminal of the battery.

What happens when the motor has rotated a half turn? Electrons flow from the negative terminal through the yellow wire to the yellow half of the commutator. Then, electricity flows from the red half of the commutator through the red wire to the positive terminal of the battery.

What happens when the motor has rotated three quarters of a turn? While the circuit is broken, electricity temporarily stops flowing from the negative terminal to the positive terminal on the battery.

What happens when the motor has rotated a full turn? When the wire loop has rotated a full 360 degrees, it is back to its original position, where the whole process repeats again and again until the switch is turned off. [Context Link]

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