Original Article

Using Virtual Peers to Guide Visual Attention During Learning

A Test of the Persona Hypothesis

Roxana Moreno[1], Martin Reislein[2], and Gamze Ozogul[2]

[1]University of New Mexico, Albuquerque, NM, USA, [2]Arizona State University, Tempe, AZ, USA

Abstract. This study tested the hypothesis that animated pedagogical agents (APAs) can effectively support students' learning by signaling visual information in multiple-representation learning environments. Novice students learned about electrical circuit analysis with an agent-based instructional program that included circuit diagrams and the corresponding Cartesian graphs. For some students, attention to relevant parts of the display was guided by an animated arrow (A group) or the deictic movements of a pedagogical agent (P group). A control (C) group learned with no visual attention-guiding method. Group P outperformed groups C and A on a posttest and gave lower difficulty ratings than group C. The findings suggest that a promising function of APAs is to support students' cognitive processing during learning.

Keywords: animated pedagogical agents, attention, learning, persona hypothesis

Interactive multimedia environments are widely recognized to hold great potential for improving learning in science, mathematics, and engineering (Moreno & Mayer, 2007). Examples of multimedia environments are abundant and usually combine verbal explanations of the knowledge to be learned with corresponding visual representations. Presenting multiple representations of the same concept or procedure (e.g., text, graphics, animations) can facilitate and strengthen the learning process by providing complementary information and engaging students in mapping the mutually referring sources of information (Ainsworth & Van Labeke, 2004; Brenner et al., 1997; Kozma, Russell, Jones, & Marx, 1996; Moreno & Mayer, 1999; Porzio, 1999).

On the other hand, a challenge presented by these learning environments is that each one of the representations needs to be fully understood and also mentally integrated with each other, which may pose heavy cognitive demands on the novice student (Ainsworth, 2006; Goldman, 2003). Despite the challenge, instruction rarely includes methods aimed at supporting the process of interpreting and integrating multiple representations during learning. The goal of this study was to examine whether using an animated arrow or rather the deictic movements of an animated pedagogical agent (APA) to guide students' visual attention might help them understand and map multiple representations of electrical circuit problems and promote learning. To this end, we asked a group of precollege students to learn about electrical circuit analysis with the help of an agent-based instructional program that included three simultaneous representations of worked-out problems: The word problem (in narrated format), a circuit diagram (using the traditional symbolic representations found in engineering textbooks), and a Cartesian graph showing the relationships among voltage, resistance, and current. In this program, an APA in the form of a three-dimensional "virtual peer" introduces the program to the student and then provides narrated explanations throughout the learning session.

To investigate the learning and affective consequences of using an animated arrow or the deictic movements of the agent to visually guide students' attention during learning, we randomly assigned the participants to one of the following conditions. A control group (C) learned with an instructional program in which the image of the APA is presented only during the introductory portion of the program. Afterwards, the image of the agent is removed from the screen, though students are guided by the voice of the APA during the lesson. The arrow group (A) learned with an identical program except that an animated arrow pointed to the elements of the display as they were being referred to by the spoken explanations of the pedagogical agent. The pedagogical agent (P) condition was identical to the A condition except that the animated arrow was replaced by the deictic movements of the virtual peer. For the A and P versions of the program the arrow or peer arm, respectively, pointed to the same visual information during instruction and for the same amount of time (see Figure 1).

Journal of Media Psychology 2010; Vol. 22(2):52–60
DOI: 10.1027/1864-1105/a000008

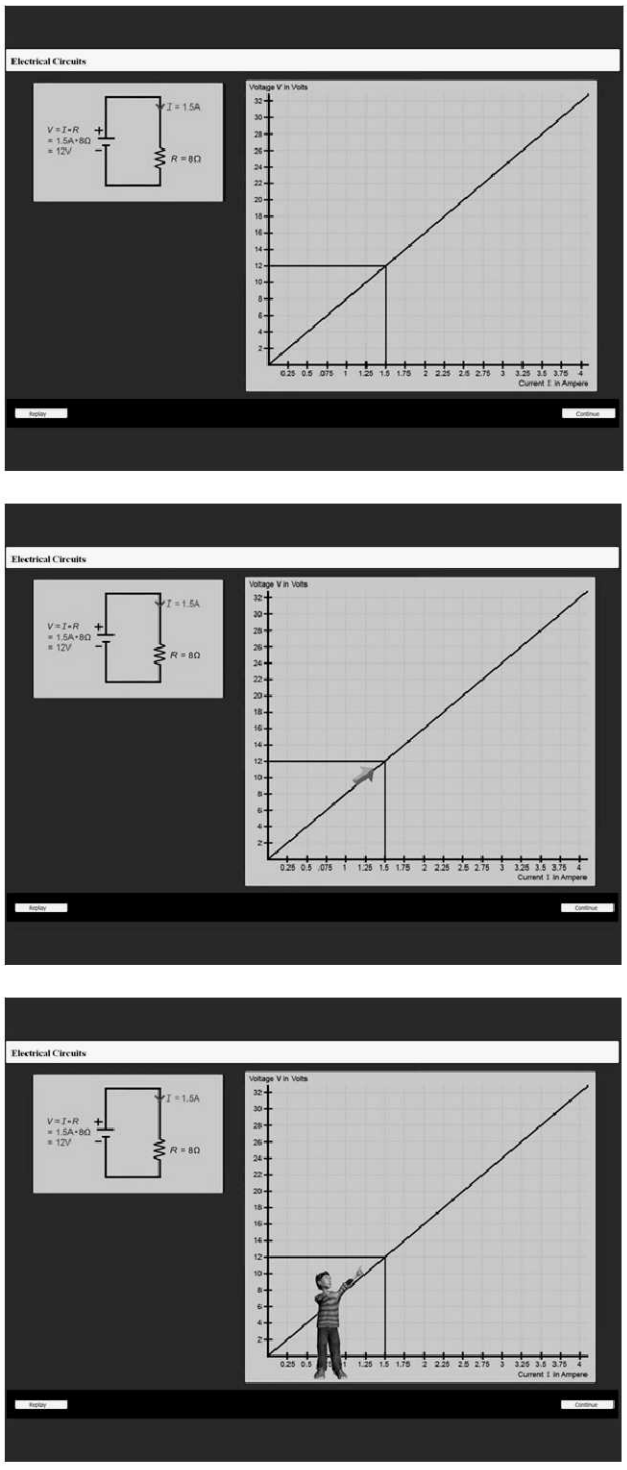

Figure 1. A sample frame from the instructional program used by the control, arrow, and virtual peer groups, from top to bottom, respectively.

We measured students' learning with a problem-solving transfer test where students needed to apply the principles learned in the multimedia lesson to solve a set of novel problems using symbolic and graphic representations. To assess the difficulty, we administered a self-report rating of the perceived difficulty of each condition. Lastly, we assessed the effects of the treatments on students' perceptions by asking them to describe what features of the instructional program they liked the most. The next section presents the theoretical framework and research that guided our study.

APAs and the Persona Hypothesis

APAs are a relatively recent technology application in education. They consist of lifelike on-screen characters designed to support learning in computer-based environments (Bradshaw, 1997). The most sophisticated APAs are two- or three-dimensional anthropomorphic (i.e., human-like) characters that advise and provide students with feedback as they interact in a learning environment (Johnson, Rickel, & Lester, 2000). Several studies have tested the persona hypothesis in the past – the idea that the visual presence of an APA in an interactive learning environment promotes students' positive perception of the learning experience and learning (Cassell, Sullivan, Prevost, & Churchill, 2000; Mitrovic & Suraweera, 2000).

For example, Lester, Towns, and Fitzgerald (1999) reported that students gave high ratings on an interest survey and showed increased learning when using an APA to learn botany. However, because a control group with no agent was not included in the study's design, the findings cannot conclusively support the persona hypothesis. Likewise, a study that compared learning with or without the image of *SmartEgg,* a cartoon-like character who provides students with written feedback about their actions did not lead to conclusive findings (Mitrovic & Suraweera, 2000). Students who were presented with the agent image gave higher ratings of enjoyment and usefulness than those who were not; however, the number of participants was too small to make statistical comparisons between groups on learning.

A few studies tested the persona hypothesis for static versus animated on-screen pedagogical agents. In one study, preservice teachers used a computer-based environment to design a plan for a case study with the assistance of a 3-D personal agent who gave spoken and written information upon request (Baylor & Ryu, 2003). Students were assigned to three different agent conditions: animated, static, and no-image. Compared to the no-image group, image groups gave higher agent credibility ratings and requested more advice; yet, no differences were found on the performance test across conditions.

Another study compared the perceptions and learning outcomes of students who learned either with an agent (image and voice) or a no-agent (no-image and no-voice) version of a mathematics instructional program (Moundridou & Virvou, 2002). Agent and no-agent groups showed no significant differences on pretest-to-posttest learning gains, though participants in the agent condition did report higher enjoyment levels and perceived the experience as less dif-

ficult than those in the no-agent condition. These results replicate the findings of Baylor and Ryu (2003), in that the benefits of APAs appear to be limited to students' perceptions of the learning experience. Yet, because the conditions differed along two factors, it is not possible to determine whether the perception differences are attributable to the image or the voice of the APA.

In an effort to distinguish between APAs' voice and image effects, Moreno, Mayer, Spires, and Lester (2001) conducted two experiments (one using a fictional agent and one using a real agent), where the image and modality of the agent's explanations (narration versus text) were manipulated separately using a 2-factorial design. Across both experiments, students performed better on tests of retention and problem-solving transfer and gave higher interest ratings and lower difficulty ratings when explanations were narrated. In contrast, the visual presence of the agent did not affect the dependent measures. Similar results were found in a later study in which students learned about electric motors by asking questions and receiving answers from an APA named Dr. Phyz (Mayer, Dow, & Mayer, 2003). A comparison of the learning outcomes of students who learned with or without Dr. Phyz's on-screen image showed no differences between the groups.

In sum, the reviewed research shows that many of the studies aimed at testing the persona effect present methodological shortcomings that limit the interpretation of their results. The few studies in which adequate controls were included in the design support the conclusion that the mere visual presence of an agent does not provide an advantage for students' learning (Moreno, 2005; Woo, 2009), and that "their contribution to the efficiency and effectiveness of learning continues to be an open research agenda" (Mahmood & Ferneley, 2006, p. 154). In the next section, we examine theory and research that are closely related to the hypothesis to be tested in the present study, namely, that the image of APAs can effectively promote learning when used to signal relevant on-screen visual information.

The APA Signaling Hypothesis

The APA signaling hypothesis is based on the idea that the visual presence of pedagogical agents promotes learning when it supports or enables cognitive processing that is necessary for learning. In particular, the present study focuses on using an APA to facilitate students' selection of relevant visual information during the meaning-making process by means of *signaling*, which consists of directing students' attention to key variables and visual information using color, flashing, or zooming techniques (Land, 2000).

Signaling is intended to help students make referential connections between the verbal (explanation) and visual (diagrams, graphs) representations in the lesson and map the multiple representations with each other (Paivio, 1986). This method is consistent with cognitive theories of learning according to which mutually referring pieces of information need to be attended to first and then held in working memory at the same time while students construct meaningful connections between them (Baddeley, 1992; Clark & Paivio, 1991; Moreno & Mayer, 2007).

As argued in the introduction, one of the benefits of multimedia instruction is its ability to integrate several knowledge representations for the same concept or principle to be learned. Yet, the complex nature of graphic representations combined with the need to mentally integrate the multiple representations with each other may pose a threat to novice learners who lack appropriate domain knowledge to guide the selection of relevant visual information during learning. Studies in a variety of domains have shown that novice learners tend to focus on irrelevant visual information when learning in multimedia environments (Kettanurak, Ramamurthy, & Haseman, 2001; Lowe, 2003; Moreno & Morales, 2008) and to draw inaccurate conclusions from visual representations (Chinn & Brewer, 1993; Land & Hannafin, 1996).

In the present study, we operationalized signaling in two ways: by using an animated arrow to point to the variables and elements of the visual display that the pedagogical agent refers to during his narrated explanations (group A), and by using the pedagogical agent's arm movements for the same purpose (group P). Past research shows evidence for the effectiveness of signaling methods in multimedia learning environments. Craig, Gholson, and Driscoll (2002) asked students to learn about the process of lightning formation with a static agent, an animated agent, or no agent. Additionally, the visual representation of the scientific system was varied so that key elements of the system were animated or presented with sudden onset highlighting as they were referred to by the agent's explanations. A control group learned with nonsignaled representations of the scientific system. No differences were found between the different agent representations on students' perceptions or learning. This is not surprising considering that the image of the agent fulfilled no cognitive support function. On the other hand, the two attention-drawing techniques used to signal relevant elements of the system led to the best learning outcomes.

Further evidence in support of the signaling method comes from a study in which students were asked to learn how to solve word problems in one of three conditions: by listening to the explanations of an animated, anthropomorphized parrot, by listening to the narrated explanations alone, or by reading on-screen text explanations (Atkinson, 2002). Participants in the APA-plus-voice group outperformed the other groups on learning and affective measures. Although on the surface the findings seem to support the persona hypothesis, as Atkinson himself notes, "the agent appeared to function as a visual indicator – by using gesture and gaze to guide learners' attention to the relevant material" (p. 426). A more recent study showed similar results (Dunsworth & Atkinson, 2007). Specifically, students who learned about science with an APA that focused learn-

ers' attention on relevant visual information in a multimedia learning environment outperformed those who learned with identical narrated explanations but no agent presence.

Two studies merit special attention as they purposefully sought to investigate whether the agent's deictic movements would be more effective than an animated arrow in guiding students' visual attention when learning with a multimedia program. In one study, college students were asked to learn about technical and nontechnical topics either with an APA that used his arm to point to the multimedia materials while giving narrated explanations or with identical explanations and an arrow serving the same signaling function (van Mulken, Andre, & Muller, 1998). The findings showed no differences in learning; yet, participants found it easier and more entertaining to learn the technical materials when the agent's image was present. In the second study, Choi and Clark (2006) asked a group of college students to learn about English relative clauses with a multimedia program that signaled visual information with either an APA or an electronic arrow. The results showed a significant learning benefit for low prior-knowledge learners in the APA condition but no differences for intermediate or high prior-knowledge learners.

A contribution of the present study is to investigate the effectiveness of APA signaling using a control condition in which students learn with an identical instructional program but no signaling methods. Because the two studies previously described lacked a no-signaling control in their design, conclusions about the added value of the signaling method itself were not possible.

Predictions

Because of the added cognitive support provided by the two signaling conditions, we expected that groups A and P would outperform the control group on the posttest and would report lower difficulty perceptions during learning. When visual search demands are high, such as in the case of our multiple representation learning environment, visual signals can promote learning by avoiding the unnecessary processing that results from scanning the computer screen in search for relevant referents (Jeung, Chandler, & Sweller, 1997).

Although efforts were made to equate the amount of time and position of the arrow and agent arm during signaling, we speculated that the bigger and more colorful appearance of the pedagogical agent would increase the effectiveness of the APA signaling as compared to the arrow signaling. Based on this reasoning, and on Choi and Clark's (2006) finding that a signaling agent was more effective than a signaling arrow for low-knowledge students (such as the participants of our study), we predicted that group P would produce higher scores on the posttest and report lower difficulty perceptions than group A.

Method

Participants and Design

The participants were a total of 159 middle-school students, 92 females and 67 males. The mean age of the participants was 12.97 years (SD = 0.56 years). 114 (71.7%) reported that they were Caucasian, 16 students (10.1%) reported having multiple ethnicities, 13 students (8.2%) reported that they were Hispanic American, 5 students (3.1%) reported that they were Asian American, 5 students (3.1%) reported being of other ethnicities, 4 students (2.5%) reported that they were African American, and 2 students (1.3%) reported being Native American. There were 49 students in the C group, 55 students in the P group, and 55 students in the A group. Comparisons were made among the groups on performance on posttest and program ratings.

Materials and Apparatus

Computerized Materials

For each participant, the computerized materials consisted of an interactive program that included the following steps: (1) a demographic questionnaire in which students were asked to report their gender, age, and ethnicity; (2) an introduction to the program and learning objectives; (3) an instructional session providing a conceptual overview of a single-resistor electrical circuit; (4) a simulation session showing the relationships between electrical current, voltage, and resistance in a single-resistor electrical circuit, both through Ohm's Law equation and a voltage-current graph; and (5) a program rating questionnaire.

After entering the demographic information (step 1), all students were introduced to the program and learning objectives by an APA that had the form of a virtual peer (step 2). The image of the agent was removed after the introduction, but his voice continued to guide students' learning throughout the program. The instructional session (step 3) first presented the students with the concepts and units of electrical current, voltage, and resistance. Then, the session presented how Ohm's Law relates current, voltage, and resistance in a single resistor circuit, and how the electrical voltage can be plotted as a function of the electrical current for a fixed resistance value in a graph.

The simulation session (step 4) first presented an electrical circuit with given default resistance and current values and showed how to obtain the voltage value by using Ohm's Law equation and by using the voltage-current graph. In particular, the screen showed a circuit diagram on the left and a Cartesian graph showing the relationships among voltage, resistance, and current on the right. The solution steps for obtaining the voltage using Ohm's Law were embedded in the circuit diagram. The Cartesian graph

contained the diagonal line whose slope corresponds to the given resistance value, as well as a vertical line at the given current value, and a horizontal line leading to the sought voltage value. The pedagogical agent's voice explained how to find the voltage using Ohm's Law equation, how to obtain the voltage by following the vertical and horizontal lines, and how both solution approaches led to the same voltage value.

The students were then asked to select one out of three possible larger current values. For the selected current value, the module showed the corresponding circuit diagram and voltage-current diagram and narrated how to obtain the voltage value both using Ohm's Law and the graph. Next, the students were asked to select one out of three possible smaller current values. For the selected current value, the module presented the two ways of obtaining the voltage value. Next, the module presented the students with an electrical circuit with default voltage and resistance values and showed how to obtain the current value using Ohm's Law equation and using the voltage-current graph. Finally, the students were asked to select one out of six possible other voltage values. After selecting the value, the simulation demonstrated how to obtain the corresponding current value with Ohm's Law and with the graph. The simulation session had three different visual signaling versions, which are illustrated in Figure 1.

In the C condition, the simulation session was presented in the form of static images in conjunction with narration but no visual signaling methods were used to guide students' selection of relevant visual information from the screen. In the P condition, the APA shown in the introduction appeared on the screen to point to the key variables, symbols, and visual elements of the display as the narrated explanation progressed. In the A condition an animated arrow pointed to identical information and for the same duration as the agent did in the P condition. The narration was identical for all three treatments. The session lasted approximately 60 minutes.

The last section in the computer program (step 5) presented a program questionnaire, which included a 2-item instrument asking participants to rate their difficulty and mental effort perceptions on a 5-point scale which ranged from 0 – *strongly disagree* to 4 – *strongly agree* (Paas, 1992). In addition, the questionnaire included an open-ended question aimed at examining what students liked best about the instructional program. The purpose of this question was to help interpret the results of our quantitative analyses by providing additional information about the potential factors affecting students' learning.

Paper and Pencil Materials

The paper and pencil materials consisted of a pretest and a posttest. The pretest consisted of eleven multiple-choice questions and was designed to assess students' prior knowledge. The posttest included four electrical circuit problems and was designed to assess students' ability to solve novel problems both in symbolic and graphic ways.

Apparatus

The computer program used in the study was developed using Adobe Flash CS3 software, an authoring tool for creating web-based and standalone multimedia programs. The apparatus consisted of a laptop computer system, with a screen size of 1680 × 1050 pixels, and headphones.

Scoring

A pretest score was computed for each student by adding the number of correct answers produced in the pretest. Each problem in the posttest was scored using a rubric which was previously developed by an expert in the electrical circuit domain. Students could receive up to one point for the complete solution of the problem in symbolic form and up to one point for the complete solution of the problem in graphic form, leading to a maximum possible score of eight points (Cronbach's α reliability of .93). Two engineering instructors who were blind to the participants' treatment conditions scored the pretests and posttests (interrater reliability 99% both on pretest and posttest). A perceived difficulty rating was computed for each participant by averaging the two ratings checked in the program questionnaire. Finally, two independent scorers coded students' response to the open-ended question asking "What did you like the best about the instructional program?" into the following categories: the graphics (e.g., "I liked how it showed graphics," "I really liked the graphics," "Learning about graphing the current and volts"); the agent (e.g., "The way the guy pointed out things when he was talking about them," "I liked that the guy helped you learn the lesson," "I liked that it has a person that helps you learn more"); the arrow (only one student in group A responded "I liked the floating arrow"); having learned (e.g., "How I learned about voltage," "That it taught you about electricity," "How it told us about Ohm's law and how to use it"); and other miscellaneous reasons (e.g., "Working with my own laptop," "The program was entertaining," "That it taught me step by step"). From this data, we computed scores for each participant and category by counting the number of answers produced in each respective category (interrater reliability 97%).

Procedure

Each participant was provided with a laptop, headphones, and two closed envelopes, which contained the paper-based pretest and posttest. The subject identification number was written on the envelope, and the letter representing the condition of the student was written on the assigned laptop. The

envelopes and laptops were randomly distributed to the students. First, the researcher instructed students to start working on the pretest envelope. Once they were done with the pretest and returned the pretest back to the envelope, the researcher had the students start the respective version of the computer program by entering the combination of identification number on the envelopes and the condition letter on the cover of the laptop. They were then instructed to put on their headphones and work independently on all sections of the program. Once the learning session was over, participants were instructed to open the posttest envelope, and complete the posttest. After completing the posttest, the students returned the posttest to the envelope, and closed it. The researcher then collected all the laptops and the pretest and posttest envelopes for scoring and data analysis.

Results

Table 1 shows the means and standard deviations for each of the three treatment groups on the pretest, posttest, and difficulty ratings. Preliminary analyses showed no differences between groups on pretest scores, $F(2, 156) = 1.03$, $MSE = 4.12$, $p = .36$ or time-on-task (recorded by the computer system), $F(2, 156) = 0.15$, $MSE = 3262.62$, $p = .86$.

Separate analyses of variance (ANOVA) were conducted on students' posttest and difficulty ratings using treatment condition as between-subject factor. The first ANOVA revealed a main treatment effect on the posttest, $F(2, 156) = 5.14$, $MSE = 58.70$, $p = .007$, $\eta^2 = .06$. Posthoc Tukey tests showed that the P group produced significantly higher posttest scores than the A group ($p = .023$) and the C group ($p = .002$). No other significant differences were noted. The second ANOVA showed a marginal difference among the three treatments on perceived difficulty, $F(2, 156) = 2.62$, $MSE = 3.13$, $p = .076$, $\eta^2 = .03$. Posthoc Tukey tests showed that the C group produced significantly higher difficulty ratings than the P group ($p = .03$) and marginally higher than the A group ($p = .07$). No other significant differences were noted.

Finally, ANOVAs were conducted on each of the categories produced by the qualitative analysis of students' responses to the program questionnaire open question using treatment condition as between-subject factor. None of the categories showed significant differences among treatments with the exception of the "liked the agent the most" category, $F(2, 156) = 4.27$, $MSE = 0.56$, $p = .016$, $\eta^2 = .05$. Posthoc Tukey tests showed that the P group gave significantly more responses in this category than the A group ($p = .004$) and marginally higher than the C group ($p = .07$).

Table 1. Mean score and standard deviation on pretest, posttest, and difficulty ratings for three groups

	Pretest		Posttest		Difficulty	
Group	*M*	*SD*	*M*	*SD*	*M*	*SD*
C	4.49	1.71	3.55	0.48	1.72	1.02
A	4.96	2.24	4.15	0.46	1.34	1.16
P	5.00	2.00	5.60	0.46	1.26	1.09

Note. Scores ranged from 0 to 11 for the pretest, from 0 to 8 for posttest, and from 0 to 4 for the difficulty ratings.

Discussion

This study tested the APA signaling hypothesis, which states that APAs can effectively promote learning by supporting students' selection of relevant visual information in multiple-representation environments. To this end, we asked a group of novice students to learn about electrical circuit analysis with an instructional program that included circuit diagrams and corresponding Cartesian graphs either without signaling or with signaling in the form of an animated arrow or the deictic movements of an APA. The findings of this research support the APA signaling hypothesis in the following ways. First, they show that using the deictic movements of an APA to guide students' visual attention promotes better learning than not using a signaling method. This was demonstrated by the higher posttest scores of group P as compared to group C. Additional support for the APA signaling hypothesis comes from students' difficulty ratings. Specifically, group P perceived the learning experience to be significantly easier than the group that learned with no signaling method. Due to the added cognitive support of the signaling arrow, we also expected group A to produce higher posttest scores and report lower difficulty ratings than group C. However, this was not the case. On both measures, group A showed a trend in the expected direction (descriptively higher posttest and lower difficulty ratings than those of group C); yet, no significant differences between groups A and C were found.

Several interpretations of the findings suggest productive venues for future research. First, as argued in the introduction, the fact that the APA was perceptually larger and more salient than the animated arrow due to its larger and colorful appearance may have better gained and maintained students' attention during the learning experience. Manipulations of the perceptual characteristics of anthropomorphic and symbolic signals could be used to test this idea. It is also possible that the humanoid characteristic of the APA naturally draws more attention than an abstract symbol. There is evidence from both developmental psychology and neuropsychology that humans have innate mechanisms to preferentially attend to social stimuli (Gamé, Carchon, & Vital-Durand, 2003; Pinsk, Desimone, Moore, Gross, & Kastner, 2005). The qualitative analysis of students' open responses to the program questionnaire is consistent with this interpretation. Only one student in group A reported liking the animated arrow the best, leading to no significant differences among groups in this "like most" category. In contrast, a significantly larger number of students in the P group reported that what they liked the

best about the learning experience was the APA. This result hints that group P noticed the APA more than group A did the arrow. Nevertheless, this conclusion should be taken with caution because attention was not directly measured in our study. Future studies on APA signaling should include eye-tracking methodologies to investigate the effects of APAs on students' visual attention.

A second interpretation of the results is that the learning advantage of the P treatment resulted from the greater motivation elicited by the APA. This is consistent with the persona hypothesis proposed by advocates of highly visible lifelike agents (Cassell et al., 2000; Lester et al., 1999; Mitrovic & Suraweera, 2000) and with a cognitive-affective theory of learning with media, according to which motivational factors mediate learning by increasing or decreasing cognitive engagement (Moreno, 2009). In the present study, however, we only measured motivation indirectly, by asking students to rate their perceived learning difficulty and report what they liked best about the program. Perceptions of lower difficulty may reflect higher self-efficacy, a motivation construct that has been shown to be associated with learning performance (Bandura, 1997). In addition, the only "like most" category in which significant differences among groups were found was the pedagogical agent category, which was reported significantly more by group P than group A. Yet, this question was only aimed at exploring the different factors that may have contributed to students' learning so it is not an adequate measure for comparing the motivation outcomes elicited by the different learning conditions. Moreover, it is possible that the APA produced a novelty effect, which may promote students' cognitive engagement in the short term but fail to motivate students when asked to learn with the same method repeatedly (Clark & Sugrue, 1991). Longer interventions using APA signaling methods and sound motivational measures should be used to investigate the motivation effects that APA signaling may produce.

An open question that also needs further investigation is whether the advantage of group P can be attributable to the specific characteristics of the APA. A well-known finding in educational research is that self-efficacy and learning increase when a student of the same age shows another student how to solve problems (Baker, Gersten, Dimino, & Griffiths, 2005; Davenport, Arnold, & Lassmann, 2004). Although our findings support a signaling hypothesis for APAs, it is less clear whether the age of the agent may have influenced the results. Therefore, a direction for future research is to compare the signaling effects of peer and non-peer APAs.

In sum, the findings suggest that APAs are a promising way to deliver sound instructional methods that can take advantage of their highly visible nature. The goal of the present study was to examine one such method, namely, signaling. Another method that was found to successfully promote learning and which requires the visual presence of the pedagogical agent is modeling. Several studies have demonstrated that APAs can effectively demonstrate skills in virtual learning environments (Graesser, Jeon, & Dufty, 2008; McNamara, Levinstein, & Boonthum, 2004; Moreno & Ortegano-Layne, 2008). Yet, because the participants of our study were students who lacked significant prior knowledge in electrical circuit analysis, an additional question for future research is whether the positive effects of the APA's signaling will diminish, disappear, or even revert as students gain competency in the domain. For example, it is reasonable to expect diminishing APA signaling effects as students gain competency in their ability to map multiple representations during problem solving. In addition, according to the expertise-reversal literature, methods that promote learning for low-knowledge students (i.e., worked example instruction) can impair the learning of high-knowledge students (Kalyuga, Ayres, Chandler, & Sweller, 2003). This hypothesis seems to be supported by the research conducted by Choi and Clark (2006), in which low-knowledge students but not moderate and high prior-knowledge students benefited from the APA's signaling. More research with students of various levels of prior knowledge is needed to better understand the relationship between expertise and the effectiveness of the APA signaling method.

Lastly, the conclusions we have drawn are limited among other things by the specific learning materials, the content domain, the student population, and the fact that participants did not work in authentic classroom settings. Therefore, in the future, it might be useful to explore other content domains using a variety of learning scenarios inside and outside of the classroom.

Acknowledgments

This material is based upon work supported by the National Science Foundation under EEP Grant No. 0648568. Any opinions, findings, conclusions, or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the funding agency.

References

Ainsworth, S. (2006). DeFT: A conceptual framework for considering learning with multiple representations. *Learning and Instruction, 16*, 183–198.

Ainsworth, S., & Van Labeke, N. (2004). Multiple forms of dynamic representation. *Learning and Instruction, 14*, 241–255.

Atkinson, R. K. (2002). Optimizing learning from examples using pedagogical agents. *Journal of Educational Psychology, 94*, 416–427.

Baddeley, A. (1992). Working memory. *Science, 255*, 556–559.

Baker, S., Gersten, R., Dimino, J. A., & Griffiths, R. (2005). The sustained use of research-based instructional practice: A case study of peer-assisted learning strategies in mathematics. *Remedial and Special Education, 25*, 5–24.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Baylor, A. L., & Ryu, J. (2003). Does the presence of image and animation enhance pedagogical agent persona? *Journal of Educational Computing Research, 28*, 373–395.

Bradshaw, J. M. (Ed.). (1997). *Software agents*. Menlo Park, CA: AAAI/MIT.

Brenner, M. E., Mayer, R. E., Moseley, B., Brar, T., Durán, R., Reed, B. S., & Webb, D. (1997). Learning by understanding: The role of multiple representations in learning algebra. *American Educational Research Journal, 37*, 663–689.

Cassell, J., Sullivan, J., Prevost, S., & Churchill, E. (Eds.). (2000). *Embodied conversational agents*. Cambridge, MA: MIT.

Chinn, C., & Brewer, W. (1993). The role of anomalous data in knowledge acquisition: A theoretical framework and implications for science instruction. *Review of Educational Research, 63*(1), 1–49.

Choi, S., & Clark, R. E. (2006). Cognitive and affective benefits of an animated pedagogical agent for learning English as a second language. *Journal of Educational Computing Research, 34*, 441–466.

Clark, J. M., & Paivio, A. (1991). Dual coding theory and education. *Educational Psychology Review, 3*, 149–210.

Clark, R. E., & Sugrue, B. M. (1991). Research on instructional media, 1978–1988. In G. J. Anglin (Ed.), *Instructional technology: Past, present, and future* (pp. 327–343). Englewood, CO: Libraries unlimited.

Craig, S. D., Gholson, B., & Driscoll, D. M. (2002). Animated pedagogical agents in multimedia educational environments: Effects of agent properties, picture features, and redundancy. *Journal of Educational Psychology*, *94*, 428–434.

Davenport, S. V., Arnold, M., & Lassmann, M. (2004). The impact of cross-age tutoring on reading attitudes and reading achievement. *Reading Improvement, 41*, 3–12.

Dunsworth, Q., & Atkinson, R. K. (2007). Fostering multimedia learning of science: Exploring the role of an animated agent's image. *Computers and Education*, *49*, 677–690.

Gamé, F., Carchon, I., & Vital-Durand, F. (2003). The effect of stimulus attractiveness on visual tracking in 2- to 6-month-old infants. *Infant Behavior and Development*, *26*, 135–150.

Goldman, S. R. (2003). Learning in complex domains: When and why do multiple representations help? *Learning and Instruction, 13,* 239–244.

Graesser, A. C., Jeon, M., & Dufty, D. (2008). Agent technologies designed to facilitate interactive knowledge construction. *Discourse Processes: A Multidisciplinary Journal*, *45*, 298–322.

Jeung, H., Chandler, P., & Sweller, J. (1997). The role of visual indicators in dual sensory model instruction. *Educational Psychology, 17*, 329–433.

Johnson, W. L., Rickel, J. W., & Lester, J. (2000). Animated pedagogical agents: Face-to-face interaction in interactive learning environments. *International Journal of Artificial Intelligence in Education, 11,* 47–78.

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist, 38,* 23–31.

Kettanurak, V. N., Ramamurthy, K., & Haseman, D. (2001). User attitude as a mediator of learning performance improvement in an interactive multimedia environment: An empirical investigation of the degree of interactivity and learning styles. *International Journal of Human-Computer Studies, 54*, 541–583.

Kozma, R. B., Russell, J., Jones, T., & Marx, N. (1996). The use of multiple, linked representations to facilitate science understanding. In S. Vosniadou, E. DeCorte, R. Glaser, & H. Mandl (Eds.), *International perspectives on the design of technology-supported learning environments* (pp. 41–60). Mahwah, NJ: Erlbaum.

Land, S. M. (2000). Cognitive requirements for learning with open-ended learning environments. *Educational Technology Research and Development*, *48*(3), 61–78.

Land, S. M., & Hannafin, M. J. (1996). A conceptual framework for the development of theories-in-action with open-ended learning environments. *Educational Technology Research & Development, 44*(3), 37–53.

Lester, J. C., Towns, S. G., & Fitzgerald, P. J. (1999). Achieving affective impact: Visual emotive communication in lifelike pedagogical agents. *International Journal of Artificial Intelligence in Education, 10*, 278–291.

Lowe, R. K. (2003). Animation and learning: Selective processing of information in dynamic graphics. *Learning and Instruction*, *13*, 157–176.

Mahmood, A., & Ferneley, E. (2006). The use of animated agents in e-learning environments: An exploratory, interpretive case study. *ALT-J: Research in Learning Technology*, *14*, 153–168.

Mayer, R., Dow, G., & 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.

McNamara, D. S., Levinstein, I. B., & Boonthum, C. (2004). iSTART: Interactive strategy trainer for active reading and thinking. *Behavioral Research Methods, Instruments, and Computers*, *36*, 222–233.

Mitrovic, A., & Suraweera, P. (2000). Evaluating an animated pedagogical agent. *Lecture Notes in Computer Science, 1839*, 73–82.

Moreno, R. (2005). Multimedia learning with animated pedagogical agents. In R. Mayer (Ed.), *Cambridge handbook of multimedia learning* (pp. 507–524). New York: Cambridge University Press.

Moreno, R. (2009). Learning from animated classroom exemplars: The case for guiding student teachers' observations with metacognitive prompts. *Journal of Educational Research and Evaluation, 15,* 487–501.

Moreno, R., & Mayer, R. E. (1999). Multimedia-supported metaphors for meaning making in mathematics. *Cognition and Instruction, 17*, 215–248.

Moreno, R., & Mayer, R. E. (2007). Interactive multimodal learning environments. *Educational Psychology Review, 19,* 309–326.

Moreno, R., & Morales, M. (2008). Studying master paintings to promote painting skills: The role of visualization, copying from memory, and spatial ability. *Empirical Studies of the Arts, 27,* 131–154.

Moreno, R., & Ortegano-Layne, L. (2008). Using cases as thinking tools in teacher education: The role of presentation format. *Educational Technology Research and Development, 56,* 449–465.

Moreno, R., Mayer, R. E., Spires, A. H., & 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*, 177–213.

Moundridou, M., & Virvou, M. (2002). Evaluating the persona effect of an interface agent in a tutoring system. *Journal of Computer Assisted Learning, 18*, 253–261.

Paas, F. (1992). Training strategies for attaining transfer of prob-

lem-solving skill in statistics: A cognitive-load approach. *Journal of Educational Psychology, 84*, 429–434.

Paivio, A. (1986). *Mental representations: A dual coding approach*. Oxford: Oxford University Press.

Pinsk, M., Desimone, K., Moore, T., Gross, C., & Kastner, S. (2005). Representations of faces and body parts in macaque temporal cortex: A functional MRI study. *Proceedings of the National Academy of Sciences of the United States of America, 102*(1), 6996–7001.

Porzio, D. (1999). Effects of differing emphases in the use of multiple representations and technology on students' understanding of calculus concepts. *Focus on Learning Problems in Mathematics, 21*(3), 1–29.

van Mulken, S., Andre, E., & Muller, J. (1998). The persona effect: How substantial is it? In H. Johnson, L. Nigay, & C. Roast (Eds.), *People and Computers XIII: Proceedings of HCI'98* (pp. 53–66). Berlin: Springer-Verlag.

Woo, H. L. (2009). Designing multimedia learning environments using animated pedagogical agents: Factors and issues. *Journal of Computer Assisted Learning*, *25*, 203–218.

Date of acceptance: February 1, 2010

Roxana Moreno is an Associate Professor in Educational Psychology at the University of New Mexico. Her research interests are in applying cognitive and motivation theories to educational technology with a special focus on learning, higher-order cognition, and individual differences. Among her awards are the Presidential Early Career Award in Science and Engineering, the American Psychological Association Richard E. Snow Award for Early Contributions to Educational Psychology, and the University of New Mexico Regent's Lecturer Award (2003 and 2008). She was ranked one of the 20 most prolific individual scholars conducting educational psychology research (Jones et al., 2009; Smith et al., 2003). As the principal investigator of two National Science Foundation grants, she is currently evaluating a virtual classroom system for teacher education and peer avatar environments for precollege engineering education. Dr. Moreno serves as an Editorial Board Member for *Educational Psychology Review, Educational Psychologist*, and *Educational Researcher*. She is also an appointed scientist for the U. S. Department of Education and has been recognized as a Fulbright Senior Specialist in the areas of Education and Instructional Media Design.

Roxana Moreno
Educational Psychology Program
MSC05–3040
1 University of New Mexico
Albuquerque, NM 87131-0001
USA
E-mail moreno@unm.edu

Martin Reisslein is an Associate Professor in the School of Electrical, Computer, and Energy Engineering at Arizona State University (ASU), Tempe, AZ, USA. He received his Dipl.-Ing. (FH) degree from the Fachhochschule Dieburg, Germany, in 1994, and an M. S. E. degree from the University of Pennsylvania, Philadelphia, PA, USA, in 1996, both in electrical engineering. He received his Ph.D. in systems engineering from the University of Pennsylvania in 1998. During the academic year 1994–1995 he visited the University of Pennsylvania as a Fulbright scholar. From July 1998 through October 2000 he was a scientist with the German National Research Center for Information Technology (GMD FOKUS), Berlin, and lecturer at the Technical University Berlin. From October 2000 through August 2005 he was an Assistant Professor at ASU. From January 2003 through February 2007, he was Editor-in-Chief of the *IEEE Communications Surveys and Tutorials*. He maintains an extensive library of video traces for network performance evaluation, including frame size traces of MPEG-4 and H.264 encoded video, at http://trace.eas.asu.edu. He is a member of the ASEE and a senior member of the ACM and the IEEE.

Gamze Ozogul is a postdoctoral research associate in the Department of Electrical Engineering at Arizona State University. She received her Masters of Science degree in computer education and instructional technology in 2002 from Middle East Technical University, Ankara, Turkey, and her Ph.D. in educational technology in 2006 from Arizona State University, Tempe, AZ, USA. Her research interests include educational evaluation, instructional design, teacher education, and engineering education. She has published in leading journals and presented at many conferences. She has several years of college-level teaching experience and has served as an evaluator on many large-scale, funded evaluation projects.

