Pedagogical Agent Signaling of Multiple Visual Engineering Representations: The Case of the Young Female Agent

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Abstract

Background Prior studies have shown that visual signaling improves learning from text or narration in conjunction with one depictive visual representation; however, engineering instruction typically employs multiple descriptive and depictive visual representations. Animated pedagogical agents (APAs) positively influence student attitudes about engineering. Whether APA signaling improves engineering learning and which APA characteristics are most conducive to learning is largely unknown.

Purpose We examined the effects of visual signaling in engineering learning materials with multiple descriptive and depictive visual representations. We compared visual signaling by a young female APA with arrow signaling.

Design/Method In the APA signaling condition, at appropriate points within a narration about electric circuits, the relevant areas in a circuit diagram, a sequence of equation calculations, and a Cartesian graph were signaled using APA gestures. In the arrow signaling condition, the same relevant areas were signaled using a dynamic arrow; the no-signaling (control) condition had no visual signaling. Student learning and perceptions were measured with a problem-solving posttest and a survey.

Results Results indicated an aptitude-treatment interaction. Low prior knowledge learners had higher learning gains in the APA signaling condition, compared with the no signaling condition; high prior knowledge learners did not benefit from visual signaling.

Conclusions Precollege students with low prior knowledge benefit from the signaling by a young female APA in instruction with multiple visual representations; high prior knowledge learners do not benefit from such support.

Keywords animated pedagogical agents; multiple visual representations; visual signaling

Introduction

Engineering learning materials commonly employ multiple visual representations. For instance, engineering textbooks often explain a concept or solution procedure with instructional text, mathematical equations, schematic diagrams, and plots. The textbooks rely on the explanatory text to direct attention of learners to the relevant representation.

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Computer-based learning modules, which have become popular as supplements to engineering textbooks and online courses, need better attention-directing mechanisms, which are referred to in cognitive studies of multimedia design as *visual signaling* or *attention guidance*. Research is needed to aid visual signaling design. There are only few studies on visual signaling in instruction with multiple visual representations, such as the recent studies by Moreno, Reisslein, and Ozogul (2010) and Ozogul, Reisslein, and Johnson (2011). In the present study, we examine several relevant research questions with precollege students, who are an important target audience for engineering instruction (see Cosentino de Cohen & Deterding, 2009; Orsack, 2003; National Academy of Engineering, 2009).

Visual signaling can be achieved with a variety of approaches, such as pointing with a simple arrow symbol or gesturing by an animated pedagogical agent (APA; Baylor, 2011). In addition to providing the visual signaling functionality, APAs may improve instructional effectiveness and perceptions of the learning experience through the so-called persona effect (Baylor, 2011; Lester, Converse, Kahler, Barlow, Stone, & Bhogal, 1997; Ryu & Baylor, 2005). Research is needed to examine those characteristics of an APA's persona, such as gender, age, and attire, which foster engineering learning and positive learner perceptions. While extensive draw-an-engineer studies have examined the preconceived notions of precollege students about the characteristics of practicing engineers (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Fralick, Kearn, Thompson, & Lyons, 2009; Karatas, Micklos, & Bodner, 2010; Knight & Cunningham, 2004), few studies have examined characteristics of effective APAs for engineering instruction (see, for example, Rosenberg-Kima, Baylor, Plant, & Doerr, 2008; Rosenberg-Kima, Plant, Doerr, & Baylor, 2010).

The present study examines the influences of a young, casually dressed, female APA on precollege-student engineering learning and learning perceptions. The following subsections provide theoretical and empirical background on instruction with multiple representations and on instructional APAs. We then state our research questions and hypotheses.

Instruction with Multiple Representations

Engineers use multiple representations of problems in their daily work; thus, to mirror real-life engineering practice, engineering instruction should include multiple representations (Jonassen, Strobel, & Lee, 2006). Engineering instruction typically combines descriptive representations, such as text and equations, with depictive representations, such as diagrams and plots. The use of these multiple visual representations in engineering instruction is broadly supported by studies on the multimedia learning effect (Mayer, 1989; Mayer & Anderson, 1991; Mayer & Gallini, 1990) and theoretical frameworks for multimedia learning (Ainsworth, 1999; Mayer, 2005). Further, according to the framework of Larkin and Simon (1987), descriptive representations, such as text and mathematical equations, are suited for comprehending temporality (e.g., steps in solving a problem and evaluating unknown quantities from given parameter values), whereas depictive representations, such as diagrams and plots, support perceptual processes related to understanding spatial relationships (e.g., the layout of an electrical circuit).

Signaling in Multiple Representation Instruction

For effective learning from multiple representations, the learner needs to select the relevant information from the representations and parts therein (Goldman, 2003; Meij & de Jong, 2006; Moreno & Mayer, 2007; Scheiter, Gerjets, & Catrambone, 2006; Schnotz & Bannert, 2003). Multiple representations without instructional support often require the student to undertake tedious search processes that are not beneficial to learning and can be considered extraneous cognitive load (de Jong, 2010; Sweller, van Merrienboer, & Paas, 1998). Visual signaling, also referred to as attention guidance, cueing, and mapping support, can effectively guide the learner in selecting relevant information, thus increasing learning outcomes (Boucheix & Lowe, 2010; de Koning, Tabbers, Rikers, & Paas, 2009; Jamet, Gavota, & Quaireau, 2008; Ozcelik, Arslan-Ari, & Cagiltay, 2010). However, few studies have examined the impact of visual signaling in instruction combining text with equations and diagrams (these include Berthold & Renkl, 2009; Moreno et al., 2010; Ozogul et al., 2011).

Animated Pedagogical Agents

An animated pedagogical agent (APA) is a humanlike or otherwise animated on-screen character appearing in a computer-based instructional module (Baylor, 2011). APAs can provide pedagogical assistance by directing attention (signaling), giving feedback, and presenting instruction (Heidig & Clarebout, 2011; Dehn & van Mulken, 2000; Moreno, 2005). They can also simulate social interaction that may promote engagement in the learning task (Kim & Baylor, 2006; Moreno, Mayer, Spires, & Lester, 2001). Several studies have tested the persona hypothesis, which posits that the visual presence of an APA in an interactive learning environment promotes student learning and positive perception of the learning experience (Lester et al., 1997; Mitrovic & Suraweera, 2000; Ryu & Baylor, 2005). However, research on APAs has commonly been criticized for being designed without adequate control conditions to establish their unique pedagogical or motivational benefits (Clark & Choi, 2005; Heidig & Clarebout, 2011). Without a control condition that provides identical pedagogical support, researchers cannot conclude that any observed differences between an APA condition and a non-APA condition are due to the agent per se (Dehn & van Mulken, 2000).

Results are mixed from studies designed with appropriate control to test APA effects (for review, see Heidig & Clarebout, 2011). Choi and Clark (2006) compared APA signaling with identical arrow signaling and demonstrated higher English grammar learning gains from APA signaling than arrow signaling for low prior knowledge students, but no effect for learners overall. On the other hand, for a similar comparison, Van Mulken, Andre, and Muller (1998) found an APA effect only for student attitudes, not for learning. Moreno et al. (2010) found that APA signaling with a young male agent led to higher posttest scores than arrow signaling, which in turn led to higher scores than no visual signaling. Ozogul et al. (2011; Experiment 1) found that signaling by both a young male APA and an arrow led to higher posttest scores and lower self-reported difficulty ratings than the no visual signaling control condition (but their results did not replicate the improved learning with APA signaling compared with arrow signaling from the Moreno et al. (2010) study). A second experiment demonstrated that learning was not promoted using an older male APA. An additional analysis demonstrated that learners from the agent condition in the young (peer) male agent experiment had significantly better learning outcomes than did the learners from the agent condition in the older (non-peer) male agent experiment.

Although some APA studies report positive effects of APA presence on student learning and attitudes, Heidig and Clarebout assert that "the question whether pedagogical agents generally facilitate the learning process is too broad" (2011, p. 30). APA research should therefore focus on establishing the conditions under which APAs are beneficial, such as what agent design characteristics (e.g., what gender, age, and appearance) facilitate learning for what types of students and knowledge domains. Furthermore, students' preconceived notions of the characteristics of engineers (Capobianco et al., 2011; Fralick et al., 2009; Karatas et al., 2010; Knight & Cunningham, 2004) may influence their perceptions of male or female APAs and ultimately impact learning about engineering with an APA. Indeed, some empirical evidence suggests that gender stereotypes transfer to computer environments and that learners regard information from male agents as more credible than that from female ones (Arroyo, Woolf, Royer, & Tai, 2009; Moreno et al., 2002). The present study examines whether the findings from Moreno et al. (2010) and Ozogul et al. (2011), which indicated a positive effect of visual signaling in a learning module with multiple visual representations using male APAs, extend to multimedia environments using a female APA and female voice.

Research Questions and Hypotheses

The Effect of Visual Signaling

In the present study, we address a central research question: In a computer-based learning module with multiple copresent descriptive and depictive visual representations, how does visual signaling affect learning outcomes, perceived difficulty, and perceptions about the module? The signaling conditions provide learners with assistance in selecting relevant information, thereby supporting the processes involved in integrating multiple representations and probably reducing extraneous cognitive load. We therefore hypothesized that the experimental conditions, which included visual signaling of relevant areas of the representations, would lead to higher posttest scores, reduced difficulty ratings, and higher positive judgments of the program.

The Effect of an APA

In order to establish the contribution of the APA to learning outcomes, perceived difficulty, and program ratings, we employed an experimental condition that uses a dynamic arrow to provide the identical visual signaling provided within the APA signaling condition. According to the persona hypothesis, this APA signaling condition will increase learner motivation, thus leading to increased learning and more positive perceptions of the learning experience. Therefore, we hypothesized that the APA signaling condition would lead to the highest posttest scores, lowest difficulty ratings, and most positive evaluations of the computer program, when compared with both the no signaling condition and the arrow signaling condition.

Aptitude-treatment Interaction

Because of prior evidence of aptitude-treatment interactions between prior domain knowledge and instructional aids (Kalyuga, Ayres, Chandler, & Sweller, 2003; Reisslein, Sullivan, & Reisslein, 2007), we augmented the preceding two main hypotheses as follows. We predicted that learners with low prior knowledge of electric circuit analysis concepts would benefit more from the visual signaling conditions. High prior knowledge learners were predicted not to demonstrate much benefit from the visual signaling conditions and, indeed, might experience detrimental effects from the visual signaling.

Method

Participants and Design

The participants were a total of 297 7th- and 8th-grade students in a public middle school in the Southwestern United States: 170 females and 127 males. The mean age of the participants was 12.8 years (*SD* = 0.84 years). One hundred and ninety-four (65.3%) of the students reported that they were Caucasian, 43 (14.5%) students reported they were Hispanic American, 21 students (7.1%) reported having multiple ethnicities, 14 students (4.7%) reported being of other ethnicities, 11 (3.7%) reported being African American, eight (2.7%) reported being Asian American, and six (2.0%) reported their ethnicity as Native American. The students had not received school instruction on electrical circuits prior to participating in this study.

To determine the effect of the different signaling methods, we manipulated the type of visual signaling students received in their program (APA signaling, arrow signaling, or no visual signaling). Dependent variables included performance on the posttest and student ratings of perceived difficulty and attitudes toward the instructional module. All participants were randomly assigned to one of the three experimental conditions. There were 101 students in the APA signaling condition, 99 students in the arrow signaling condition, and 97 students in the no visual signaling condition.

Materials and Apparatus

Computerized materials For each participant, the computerized materials consisted of an interactive program that included the following five steps: (1) a demographic questionnaire asking participants to report their gender, age, and ethnicity; (2) an introduction to the objectives of the instructional program; (3) an instructional session providing a brief conceptual overview of a single-resistor electrical circuit; (4) a simulation session; and (5) a program-rating questionnaire.

As shown in Figure 1, the presentation screen in the simulation session contained a circuit diagram depicting the considered circuit and a Cartesian graph that plotted the voltage as a function of the current in the considered circuit. The circuit diagram contained the equations specifying the given resistance and current values. In addition, the sequence of equation calculation steps for evaluating the voltage using the Ohm's law equation was given to the left of the voltage source symbol of the circuit diagram. In summary, the simulation session employed multiple representations, namely narration and mathematical equations (i.e., descriptive representations), as well as a schematic circuit diagram and a plot relating system quantities (i.e., depictive representations).

The simulation session first presented an electrical circuit with given default resistance and current values and explained how to obtain the voltage value by using the Ohm's law equation or the Cartesian graph of voltage as a function of current. Then, students were given three opportunities to select different current or voltage values and observe the outcome of their selection. For each of the selected current or voltage values, the simulation session explained how to use the corresponding Ohm's law equation and Cartesian graph and how to obtain the missing voltage or current value using both the Ohm's law equation and the Cartesian graph. More specifically, for a given circuit example, the simulation session first introduced the given circuit and then calculated the missing circuit quantity using the Ohm's law equation. Subsequently, the simulation session explained how to obtain the missing circuit quantity using the Cartesian graph, and finally related the result found in the Cartesian graph back to the result found with the Ohm's law equation and the given circuit.

The instructional program had three different visual signaling conditions. All conditions contained an identical introduction to the objectives presented by the APA (Step 2), and all conditions had identical narrated explanations and calculations using the Ohm's law

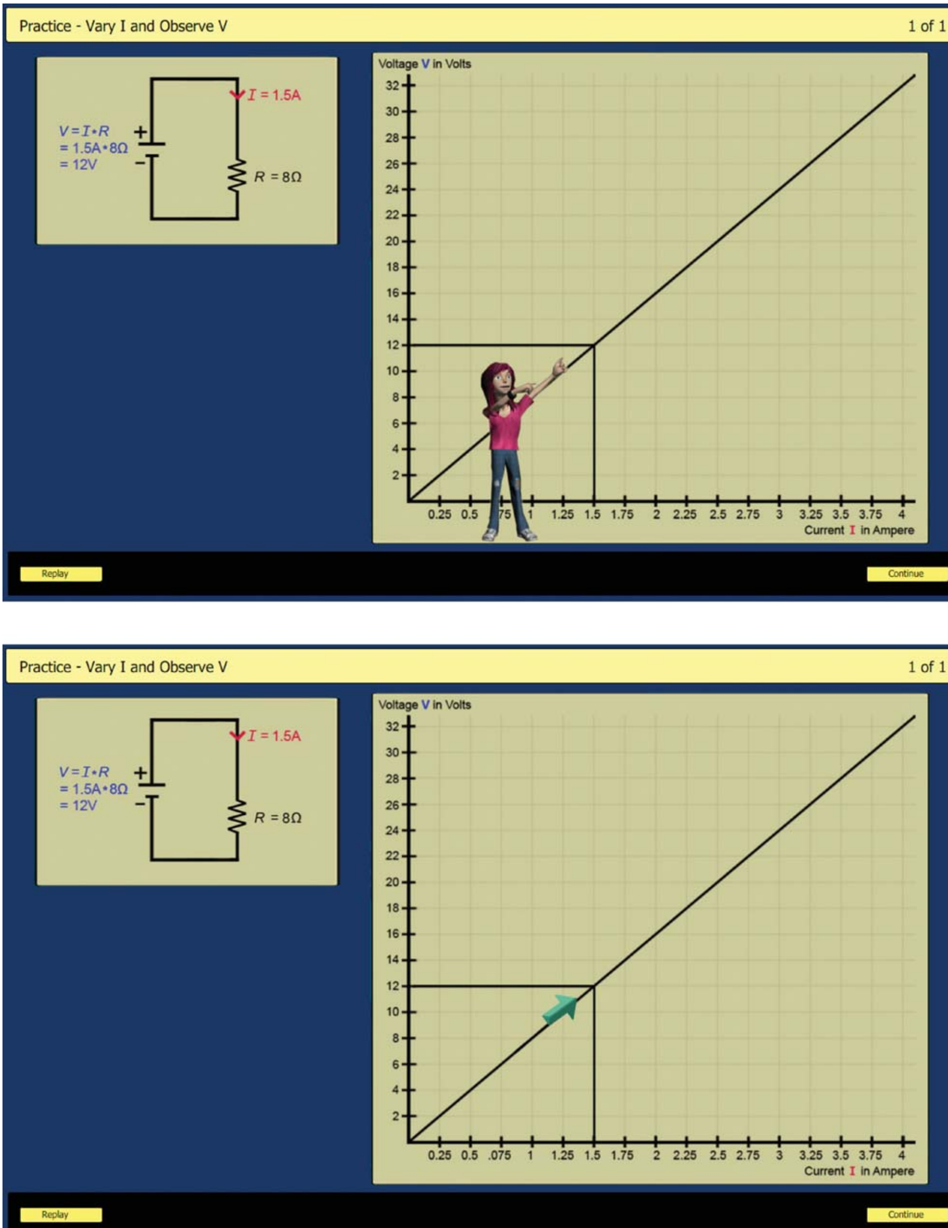

Figure 1 Sample screen shots of multiple representation display screen with Ohm's law equation calculations, a circuit diagram, and a Cartesian graph of voltage as a function of current used in the simulation session. (Top) Animated pedagogical agent signaling condition. (Bottom) Arrow signaling condition. [Color figure can be viewed in the online issue, which is available at wileyonlinelibrary.com.]

equation as well as identical depictive representations, including the circuit diagram and the Cartesian graph in the instructional session (Step 3) and the simulation session (Step 4).

The versions differed only during the simulation session (Step 4): In the APA signaling condition, an APA appeared on the screen to dynamically point to the visual element of the multiple representations in the display screen that corresponds to the passage in the narrated explanation. The APA pointed to the visual element through deictic gestures, for example, pointing with arms and fingers, as illustrated in Figure 1(top). The APA was a young female, approximately of the same age as the student participants, and was dressed casually, similarly to the students. The design of the APA was inspired by several similar avatars found in games that are popular among precollege students. More specifically, the APA was a 3D computer agent created with Autodesk 3D Studio Max 5, a software program for building, animating, and rendering 3D models and characters. The narration voice files were applied to the APA using the Ventriloquist program, which uses a collection of 12 phonemes to animate the agent's mouth and facial expressions in correlation to the speech. Additional facial expressions of eyebrow motions, eye movements, and head nods, as well as animated body and hand movement, were added. These animated movements were cued within 3D Studio Max to the speech of the agent. Completed APA animations were rendered by 3D Studio Max as video files, which were imported into Adobe After Effects CS2 to be layered onto the static image of the multiple representation screen.

In the arrow signaling condition, a single arrow was used to provide identical dynamic pointing, as in the APA condition. For instance, in the example in Figure 1, when the narration introduces the given circuit with the given resistance value, the APA or arrow points to the resistor symbol with the $R = 8\ \Omega$ equation in the circuit diagram. When the narration explains the Ohm's law equation calculations, the APA or arrow points to the respective line of the sequence of equations. As the narration explains the solution procedure in the Cartesian graph, the APA or arrow dynamically points to the presently relevant areas of the graph and traces the lines drawn to find the missing circuit quantity (see the example screen shots in Figure 1). The APA or arrow moved around the screen to provide this visual signaling in the different representations. The no signaling condition did not include any visual signaling.

The last step in the computer program was a program-rating questionnaire, which was a 12-item Likert instrument asking participants to rate their learning perceptions on a 5-point scale ranging from 0 (strongly disagree) to 4 (strongly agree). The questionnaire was a revised version of a 16-item survey that the authors had developed in collaboration with experts in computer-based engineering education (Moreno, Reisslein, & Ozogul, 2009; Reisslein, Moreno, & Ozogul, 2010). For the present study, 12 items relating to perceptions of the program and content matter and two items relating to the perceived cognitive load (a scale previously developed by Paas and Van Merrienboer [1994]) were retained. The construct validity of the revised survey was assessed with the judgment of subject matter experts in electrical engineering instruction.

To examine the reliability of the program-rating instrument in the present study, we conducted a factor analysis using principal axis estimation, with all 12 items from the program-rating instrument. Results demonstrated that two factors accounted for 62.1% of the variance for student ratings. Extraction of two factors was based on an eigenvalue threshold of 1. The two identified factors related to (1) positive evaluations of the program or content matter (10 items, such as "I would recommend this program to other students" and "I would like to learn more about electrical circuits," with factor loadings ranging from .56 to .81) and (2) difficulty ratings (two items, "The lesson was difficult" and "Learning the material in the lesson required a lot of effort," with factor loadings .91 and .70). The internal reliability of the positive evaluation scale and difficulty rating scales was .91 and .81, respectively, as measured by Cronbach's alpha (Allen, Reed-Rhoads, Terry, Murphy, & Stone, 2008). A program-rating score and a perceived difficulty score were computed by averaging the ratings from the respective sets of ten and two questions that loaded highly on these factors.

The program-rating questionnaire also included two open-ended questions to capture what students liked best and least about the computer-based instructional module. Responses to the open-ended items were categorized according to which features of the instructional module were noted. Four categories emerged from examination of the two open-ended responses: issues related to agents (e.g., "I liked the appearance of the girl"); signaling (e.g., "I liked best the way the program taught you how to follow along the axis"); learning ("It helped me learn a lot"); and entertainment (e.g., "I liked that this program is entertaining").

The computer-based learning module used in the study was developed using Adobe Flash CS4 software, an authoring tool for creating web-based and standalone multimedia programs. The module provided log files, including participant responses to the demographic and program-rating questionnaires and interaction data (e.g., time on task). The equipment consisted of a set of laptop computer systems, each with a resolution of 1680 $\times$ 1050 pixels, and headphones.

Paper and pencil materials The paper and pencil materials consisted of a pretest and a posttest on electric circuit analysis. The pretest was an 11-item multiple-choice test on students' domain-specific prior knowledge (internal reliability, $\alpha = .69$), and the posttest included 13 novel single-resistor electrical circuit problems to be solved with both the symbolic approach using the Ohm's law equation and the graphical approach using the Cartesian graph (internal reliability, $\alpha = .97$). A sample posttest problem was presented as a circuit diagram of a single-resistor circuit with given voltage of $V = 20$ V and resistance $R = 5\ \Omega$ and asked to find the current in the circuit (a) using the Ohm's law equation and (b) using the provided Cartesian graph. Both pretest and posttest were designed and printed using the same color and layout scheme as the computer program. Two independent scorers, who were blind to the conditions of the participants, scored the pretest and posttest (inter-rater reliability, .99).

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-based module 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 module. Once the computer-based 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.

Table 1 Descriptive Statistics for Pretest Scores, Posttest Scores, Difficulty Ratings, and Program Ratings

Signaling type	Pretest (max 11) *M* (*SD*)	Posttest (max 13) *M* (*SD*)	Difficulty ratings (max 4) *M* (*SD*)	Program ratings (max 4) *M* (*SD*)
Animated pedagogical agent ($N = 101$)	4.60 (2.16)	7.44 (4.46)	1.59 (1.28)	2.16 (0.91)
Arrow ($N = 99$)	4.58 (2.29)	7.45 (4.48)	1.34 (1.21)	2.28 (0.85)
No visual signaling ($N = 97$)	4.38 (2.36)	6.96 (4.59)	1.72 (1.17)	2.16 (0.87)
Total	4.52 (2.26)	7.29 (4.50)	1.55 (1.23)	2.20 (0.88)

Results

Table 1 displays the means and standard deviations for pretest scores, posttest scores, difficulty ratings, and program ratings, by experimental condition. An alpha level of .05 was used for all statistical tests. An initial ANOVA on pretest scores showed no significant differences among groups, $F(2, 294) = 0.28$, $MSE = 5.15$, $p = .76$. The participants spent on average 8.4 minutes ($SD = 1.6$ minutes) on the demographic questionnaire, introduction, and instructional session (Steps 1–3) and on average 10.2 minutes on the simulation session (Step 4). An ANOVA on the total time spent on the computer-based module (Steps 1–4) indicated no significant effect for signaling condition, $F(2, 294) = 0.04$, $MSE = 9795.2$, $p = .96$.

Analyses of variance (ANOVAs) were conducted on students' posttest scores, difficulty ratings, and overall program ratings using treatment condition and domain-specific prior knowledge as between-subject factors. We first conducted a median split using the pretest scores to divide all participants into low and high prior knowledge groups. Any participant who scored at or below the median (overall median = 4) was categorized as a low prior knowledge (LPK) participant, and any participant who scored above the median was categorized as a high prior knowledge (HPK) participant. The descriptive statistics for all dependent variables, for LPK and HPK participants, by experimental condition, are displayed in Table 2.

A series of 2 (LPK and HPK) $\times$ 3 (experimental condition) univariate analyses of variance were conducted to determine whether there was a main effect of prior knowledge, a main effect of experimental condition, or an interaction between prior knowledge level and experimental condition on each of the dependent variables. The ANOVA on posttest scores indicated a significant main effect for prior knowledge level, $F(1, 291) = 80.18$, $MSE = 15.74$, $p < .001$, $\eta^2 = .22$. Participants with high prior knowledge (as categorized by the pretest median split) scored higher on the posttest than those with low prior knowledge. No significant main effect of experimental condition was evident, $F(2, 291) = 0.17$, $p = .85$. However, a significant interaction between prior knowledge and experimental condition was revealed, $F(2, 291) = 4.81$, $p < .01$, $\eta^2 = .03$. To ascertain where the interaction was operating, separate analyses on the two groups of prior knowledge level participants were conducted. For the LPK participants, results demonstrated a significant effect of experimental condition on the posttest scores, $F(2, 155) = 3.50$, $MSE = 16.67$, $p = .03$, $\eta^2 = .04$. The LPK participants scored higher on the posttest after using the APA signaling condition, compared with the no signaling condition, $p < .03$. However, for the HPK participants, the analyses did not detect a significant effect for

Table 2 Descriptive Statistics for Experimental Condition for Prior Knowledge by Signalling Type

Condition	Posttest (max 13) *M* (*SD*)	Difficulty ratings (max 4) *M* (*SD*)	Program ratings (max 4) *M* (*SD*)
Animated pedagogical agent signaling			
Low prior knowledge ($N = 55$)	6.23 (4.30)[a]	1.85 (1.21)	2.15 (0.90)
High prior knowledge ($N = 46$)	8.89 (4.25)	1.29 (1.30)	2.18 (0.93)
Arrow signaling			
Low prior knowledge ($N = 50$)	5.64 (4.25)	1.52 (1.16)	2.29 (0.86)
High prior knowledge ($N = 49$)	9.30 (3.96)	1.16 (1.25)	2.27 (0.85)
No visual signaling			
Low prior knowledge ($N = 53$)	4.20 (3.67)	1.85 (1.09)	2.11 (0.99)
High prior knowledge ($N = 44$)	10.28 (3.16)	1.57 (1.25)	2.23 (0.70)
Total			
Low prior knowledge	5.36 (4.15)	1.74 (1.16)	2.18 (0.92)
High prior knowledge	9.47 (3.85)	1.33 (1.27)	2.23 (0.83)

[a]Significantly higher than the no visual signaling condition.

experimental condition, $F(2, 136) = 1.57$, $MSE = 14.69$, $p = .21$. The line graph in Figure 2 plots the interaction between prior knowledge and experimental condition.

The ANOVA on difficulty ratings indicated a significant main effect for prior knowledge level, $F(1, 291) = 7.95$, $MSE = 1.46$, $p < .01$, $\eta^2 = .03$. Participants with LPK rated the

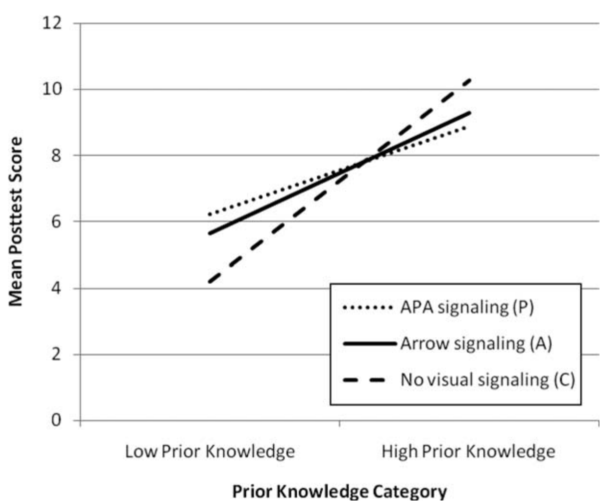

Figure 2 Interaction between prior knowledge and experimental condition. Low prior knowledge learners achieve higher posttest scores with animated pedagogical agent signaling than without visual signaling.

program significantly more difficult than those with HPK. The results indicated no significant main effect of experimental condition, $F(2, 291) = 2.30$, $p = .10$, nor a significant interaction between prior knowledge level and experimental condition, $F(2, 291) = 0.33$, $p = .72$.

The ANOVA on program ratings did not indicate a significant main effect for prior knowledge level, $F(1, 291) = 0.20$, $MSE = 0.78$, $p = .65$, nor a significant main effect of experimental condition, $F(2, 291) = 0.54$, $p = .59$, nor a significant interaction between prior knowledge level and experimental condition, $F(2, 291) = 0.15$, $p = .86$.

We also examined whether the signaling by a female agent was more effective for the female participants than their male counterparts, following the recent findings by Rosenberg-Kima et al. (2008, 2010). A 2 (participant gender: male or female) × 3 (experimental condition) univariate ANOVA on posttest scores indicated no significant main effect of participant gender, $F(1, 291) = 0.20$, $MSE = 20.50$, $p = .65$; no significant main effect of condition, $F(2, 291) = 0.36$, $p = .70$; and no significant interaction between gender and condition, $F(2, 291) = 0.24$, $p = .79$. Similarly, no significant main effects or interactions were demonstrated in analogous ANOVAs using difficulty ratings and overall program ratings as the dependent variables.

Chi-square tests of independence were conducted to explore the relationships between experimental condition, prior knowledge level, and the four open-ended response categories. First, a series of 3 (experimental condition) × 2 (participant noted feature as most liked aspect: yes or no) chi-square tests of independence were conducted to explore the relationship between experimental condition and participants' liking for these features. For LPK participants, results indicated a significant relationship between experimental condition and learners' liking of the agent, $\chi^2(2) = 15.02$, $p < .001$. No relationship between condition and liking for the agent was demonstrated for HPK participants, $\chi^2(2) = 2.83$, $p = .24$. To further determine which conditions differed in liking of the agent, a series of three follow-up 2 (experimental condition *a* vs. experimental condition *b*, whereby *a* and *b* denote any distinct two of the three signaling conditions) × 2 (noted or did not note liking) chi-square tests were used on LPK participants. Results from these analyses indicated that more LPK participants in the APA signaling (P) condition liked the agent, compared with both the no visual signaling (C) condition, $\chi^2(1) = 11.32$, $p < .001$, and the arrow signaling (A) condition, $\chi^2(1) = 6.31$, $p = .01$ (see Table 3).

For HPK participants, there was a significant relationship between condition and dislike toward the agent, $\chi^2(2) = 6.40$, $p = .04$. No such relationship was demonstrated for LPK participants, $\chi^2(2) = 2.50$, $p = .29$. Follow-up analyses revealed that, compared with the arrow signaling condition, more HPK participants in the APA signaling condition, $\chi^2(1) = 5.04$, $p = .03$, and in the no visual signaling condition, $\chi^2(1) = 5.56$, $p = .02$, noted the animated agent as their least favorite aspect of the program. No other significant results were revealed from the analysis of the open-ended responses.

Discussion

Arrow Signaling

Our experimental results did not indicate a significant beneficial effect of visual arrow signaling on posttest performance, nor on difficulty or program ratings. More specifically, while the low prior knowledge (LPK) participants tended to have higher posttest scores with arrow signaling ($M = 5.64$, $SD = 4.25$) than no visual signaling ($M = 4.20$, $SD = 3.67$), there was no significant main effect of arrow signaling when averaging across

Table 3 Participant Preferences for Signaling Type by Prior Knowledge Type

Signaling type	Liked best	Liked least
Low prior knowledge		
Animated pedagogical agent (*N* = 55)	13	7
Arrow signaling (*N* = 50)	3	10
No visual signaling (*N* = 53)	1	5
High prior knowledge		
Animated pedagogical agent (*N* = 46)	5	13
Arrow signaling (*N* = 49)	5	5
No visual signaling (*N* = 44)	1	13
Total		
Animated pedagogical agent (*N* = 101)	18	20
Arrow signaling (*N* = 99)	8	15
No visual signaling (*N* = 97)	2	18

all learners, nor an aptitude-treatment effect. It is possible that the instructional intent of the dynamic arrow was too ambiguous to significantly aid the middle school students in selecting relevant information. The results suggest that the use of an arrow to assist selecting relevant information from multiple copresent descriptive and depictive visual representations of electrical circuits does not significantly benefit precollege students.

APA Signaling

While the results did not reveal a beneficial effect of the APA signaling when averaging across all learners, an aptitude-treatment interaction showed that LPK learners benefited from the APA signaling. In particular, the APA signaling promoted learning for the LPK students, leading to significantly higher posttest scores than did the no signaling condition. With the arrow signaling, these LPK learners did not score significantly higher than in the no signaling condition. These results indicate that the APA signaling provided effective support to these learners, whereas the arrow signaling did not.

The finding that LPK students significantly benefit from APA signaling, but not from the same signaling provided by an arrow probably derives from features of the APA. First, the visual presence of an APA may induce a persona effect, in which learners' focus and motivation are maintained through the animated agent, leading to increased learning outcomes and more positive perceptions of the learning experience (Atkinson, 2002; Baylor, 2011; Lester et al., 1997; Mitrovic & Suraweera, 2000). The analysis of learners' open-ended responses concerning their favorite aspects of the program provides some support for this conclusion. Among LPK participants, participants in the APA condition noted the animated agent more frequently as their favorite part of the program compared with participants in both the arrow signaling and no signaling conditions.

Next, the APA may make the purpose of visual signaling more explicit. Learners who receive APA signaling may grasp more clearly that the agent's pointing gestures are intended to guide attention to relevant areas of the visual display, whereas the purpose of the arrow may be more ambiguous. Precollege students are very accustomed to the pointing gestures teachers use to indicate where to look on chalkboards or whiteboards and thus may more easily comprehend the intentions of an APA's pointing gestures than those of a symbolic dynamic arrow. Finally, developmental psychology and neuropsychology suggest that humans give priority to social stimuli (Game, Carchon, & Vital-Durand, 2003; Pinsk et al., 2009; Taylor, Wigget, & Downing, 2007) and may therefore follow the APA more attentively.

Aptitude-treatment Interaction

Here we discuss the aptitude-treatment interaction result more closely. While the LPK students in the APA signaling condition had significantly higher posttest scores than did the LPK students in the no visual signaling condition, for the HPK students, there was no significant difference among the experimental conditions. This finding supports our prediction concerning the moderating effect of prior domain knowledge on the impact of APA signaling.

A possible explanation of these results is that the visual APA signaling promoted learning for the LPK students by facilitating the essential process of selecting relevant information within the multiple visual representations. Because the LPK learners had assistance in selecting relevant information, they were aided in organizing the relevant information into coherent mental representations and, ultimately, integrating information from multiple representations into long-term memory. From a cognitive load perspective, the LPK learners benefited from the APA visual signaling because this technique reduced extraneous load due to the searching of multiple representations (Jeung, Chandler, & Sweller, 1997).

The visual signaling was not necessary for HPK learners because they could rely on existing knowledge to facilitate the learning process of selection and did not require any additional aid. Although the results did not reveal a statistically significant full expertise reversal effect (Kalyuga, Ayres, Chandler, & Sweller, 2003), the means indicated a trend in the expected direction. That is, descriptively, the HPK students had the highest posttest scores in the no visual signaling condition ($M = 10.28$, $SD = 3.16$), and the lowest scores in the APA signaling condition ($M = 8.89$, $SD = 4.30$). Analysis of the open-ended responses from HPK participants indicates that more participants in the APA signaling condition than in the arrow signaling condition considered the APA their least favorite aspect of the program. This result suggests that HPK learners consider the APA to be a distraction from the relevant information. Cognitive load theory would predict that the HPK students would experience an inhibitory effect of the visual signals because the additional information is unnecessary and potentially detracts from learning processes (Schnotz & Kurschner, 2007; Schnotz & Rasch, 2005).

Overall, the interaction between prior domain knowledge and experimental condition provides evidence for the claim that the effectiveness of a particular instructional format can depend on the individual characteristics of the learner (Kalyuga et al., 2003). More specifically, the results demonstrate that learners' prior knowledge can impact the efficacy of APA signaling in learning from multiple visual representations in engineering.

In addition to the key finding regarding the differential impact of APA visual signaling on learners with varying prior knowledge, results indicated that LPK participants (across all experimental conditions) scored lower on the posttest and rated the instructional material as more difficult than did the HPK participants. This result indicates that the division of participants into LPK and HPK learners was successful and is in accordance with cognitive load theory: LPK learners had fewer existing mental representations relevant for the domain; thus, they were less capable of relying on mental schema to organize and "chunk" incoming information – leading to higher perceptions of difficulty and, in the view of cognitive load theory, higher intrinsic cognitive load (Sweller et al., 1998).

APA Characteristics for Precollege Engineering Education

We expected that female learners would benefit more from the APA signaling condition, given that the animated agent used in this condition was a young female, similar to our female participants. Earlier work has suggested that matching agents to characteristics of the learners can lead to greater changes in attitudes (Rosenberg-Kima et al., 2010). The 56 female students in our APA signaling condition had only nonsignificant tendencies to improved posttest scores ($M = 7.55$, $SD = 4.45$), difficulty ratings ($M = 1.48$, $SD = 1.26$), and program ratings ($M = 2.21$, $SD = 0.87$) compared with the 45 male students in the APA condition (posttest $M = 7.30$, $SD = 4.52$; difficulty rating ($M = 1.73$, $SD = 1.29$; program rating $M = 2.10$, $SD = 0.97$). Thus, our results did not support the hypothesis that a female agent would provide significant benefits specifically to the female students. More research is necessary to determine whether matching agent gender to learner gender may have positive, or even negative, impacts on learning and learner perceptions.

Previous work exploring effects of agent signaling and arrow signaling demonstrated the positive impact of a young male agent signaling for all learners, not only LPK students (Moreno et al., 2010; Ozogul et al., 2011, Exp. 1). Our present results indicate that the positive influence of the young female agent held only for the LPK students. Students often hold stereotypical views concerning the suitability of females for engineering (Capobianco et al., 2011; Cech, Rubineau, Silbey, & Seron, 2011; Fralick et al., 2009; Karatas et al., 2010). These biased notions about women in engineering may weaken the perceived importance or validity of instructional messages delivered via female APAs, especially for those students who have some preexisting domain-specific knowledge.

Also, Ozogul et al. (2011; Exp. 2) found no benefit of agent signaling using an older male agent, whereas the present experiment indicated increased learning for a young female agent signaling condition. This result may indicate that students see themselves as more similar to the young agents than to the older agents (cf. Rosenberg-Kima et al., 2008), thereby increasing motivation toward imitation and achievement in the domain. Further, this finding is consistent with learning gains that have been observed for instructional assistance by peers of the same age (Baker, Gersten, Dimino, & Griffiths, 2005; Davenport, Arnold, & Lassmann, 2004; Robinson, Schofield, & Steers-Wentzell, 2005).

Practical Implications

Our experimental results indicate that computer-based engineering instruction with multiple copresent descriptive and depictive visual representations should be tailored to the individual characteristics of the learners. In particular, LPK learners require instructional features that guide their attention to relevant areas of the different visual representations, while HPK learners do not require such features. Pretesting and embedded assessment may be implemented at various points within computer-based instruction, allowing the presented multimedia to be adapted according to the existing and developing expertise of each learner. As learner expertise develops, the need for instructional aids of various forms diminishes. Specifically, our experimental results indicate that as learners gain more knowledge of electrical engineering, multimedia presentations no longer require visual signaling through APAs. On the other hand, LPK learners should be provided with visual signaling until sufficient domain knowledge is accumulated. Once learners have this adequate domain knowledge, they will require less assistance in the form of visual signaling. If agent visual signaling is continued once a learner has a significant amount of domain knowledge, this unnecessary instructional aid may detract from the generative germane learning processes (Schnotz & Kurschner, 2007).

Limitations and Future Directions

This investigation into the effects of visual signaling with multiple visual representations was undertaken with limited subject selection, a specific domain, and in a single region of the United States. Such limitations often occur in experimental research, and conclusions drawn from this experiment may not apply to diverse populations, various other engineering topics, or other geographical regions. Future studies should attempt to replicate our findings using different populations, domains, and geographical regions.

Additionally, we conclude that the visual signaling facilitated the selection of relevant information. However, without process data (e.g., eye-tracking data) to substantiate this claim, it is difficult to definitively identify the cause of the beneficial impact of visual signaling. It is possible that the simple visual presence of the animated agent enhanced the LPK participants' motivation toward the learning task, increasing overall attentiveness and learning outcomes. Since the LPK students did not significantly benefit from visual signaling presented through the arrow, the benefit from the APA signaling condition possibly derives from a combination of a persona effect and the highly visible signaling provided by the APA. A future study with an additional condition in which an APA is present but does not provide visual signaling would provide further insight on the benefits of the persona effect and the visual signaling provided by the APA.

Finally, although this study investigated the overall effect of the female APA, it is an open research question whether matching the gender of the learner to that of the APA, as in the Rosenberg-Kima et al. (2008, 2010) studies on student attitudes and beliefs, would lead to enhanced learning outcomes or an overall beneficial effect of the agent signaling. We encourage future investigation on the impact of visual signaling using APAs to explore how matching characteristics of the learner and the agent might influence the impact of such techniques.

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