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Supporting multimedia learning with visual signalling and animated pedagogical agent: moderating effects of prior knowledge

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Abstract

An experiment examined the effects of visual signalling to relevant information in multiple external representations and the visual presence of an animated pedagogical agent (APA). Students learned electric circuit analysis using a computer-based learning environment that included Cartesian graphs, equations and electric circuit diagrams. The experiment was a 2 (visual signalling, no visual signalling) × 2 (visual APA presence, no visual APA presence) between-subjects design, resulting in four experimental conditions: visual signalling with APA presence (APA + S), visual signalling without APA presence (S), no visual signalling with APA presence (APA) and no visual signalling without APA presence (C). Signalling was provided via gestures of the APA in the APA + S condition and via dynamic arrows in the S condition. To investigate potential moderating effects of prior knowledge on APA presence and visual signalling factors, middle school students were grouped into low prior knowledge (LPK) and high prior knowledge (HPK) groups using scores on a domain pre-test. Results revealed that LPK students had higher post-test scores after learning with visual signalling, resulting in equivalent post-test performance to their HPK counterparts. LPK students also had higher post-test scores, higher ratings of graphics understanding and lower perceived difficulty ratings in conditions that included the visual image of the APA. Conversely, HPK students had better post-test scores after learning without the APA. These results indicate that the effectiveness of visual signalling techniques and the visual presence of an APA is dependent on learner characteristics, including prior domain knowledge.

Keywords: animated pedagogical agents, learner characteristics, multiple external representations, visual signalling.

Introduction

Computer-based learning environments have enormous potential for cost-effective education that can easily scale to large learner audiences due to the combination of technological progress in mobile computing and the benefits of flexible anytime-anyplace learning. Such learning environments typically employ multiple external representations (MERs), including narration or written text, schematic diagrams and graphs. The multimedia effect, established through extensive empirical investigations, demonstrates that students learn more from verbal and visual information combined than from either in isolation (Mayer, 1989, 2008; Moreno & Mayer, 1999; Van Merrienboer & Kester, 2005).

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Although MERs offer learners unique advantages, novice students often struggle to identify relevant information in visual representations when accompanied by verbal information. In particular, learners may find it difficult to allocate visual attention to essential visual elements corresponding to fleeting spoken narration in multimedia instruction. Visual signalling can be used to direct learners' attention to diagram and graph elements, which correspond to the current segment of narration. Thus, visual signalling may assist learners to understand interrepresentational relationships among disparate sources of information, permitting successful mental integration (De Koning, Tabbers, Rikers, & Paas, 2009). Such visual signalling can be implemented using simple techniques, such as colour coding, highlighting or arrows, or through more sophisticated computer-based features, such as animated pedagogical agents (APAs).

An APA is an on-screen character providing pedagogical assistance during computer-based instruction. APAs are becoming more and more common within computer-based learning environments. Proponents of APAs assert that they can promote learning by increasing learner engagement and offering pedagogical assistance to the learner (Baylor, 2009; Choi & Clark, 2006; Lane *et al*., 2013; Lester *et al*., 1997; Lindström, Gulz, Haake, & Sjödén, 2011; Moreno, 2005; Ozogul, Johnson, Atkinson, & Reisslein, 2013). However, research on APAs has been criticized for often not including appropriate controls to establish unique effects of APAs (Dehn & van Mulken, 2000; Heidig & Clarebout, 2011). The research reported in the current paper was devised to contribute to the understanding of unique pedagogical and motivational benefits of APAs and visual signalling in learning with MERs. Thus, the experiment implemented two approaches to signalling relevant information in visually rich multimedia learning environments: dynamic gestures via an APA and dynamic pointing via a simple arrow.

Cognitive theory of multimedia learning

The cognitive theory of multimedia learning (CTML; Mayer, 2005; Mayer & Moreno, 1998) involves three primary assumptions. First, the human cognitive system is divided into two separate processing channels: one for visual/pictorial information and another for auditory/verbal information (dual-coding assumption; Paivio, 1986). Second, each of these two processing channels has a limited capacity for processing incoming information (limited capacity assumption; Baddeley, 1986; Miller, 1956; Sweller, 1999). Third, learners actively engage in the learning process through three fundamental cognitive processes: selection, organization and integration. The process of selection involves paying attention to relevant visual and auditory information presented to the learner. During organization, learners build structural relations among selected words to construct a verbal mental representation and among selected images to construct a pictorial mental representation. During integration, learners build connections between verbal and visual mental representations and between information in working memory and associated knowledge structures stored in long-term memory. Integration is the most cognitively demanding process, and requires learners to recognize associations between incoming information and existing knowledge representations. In order to capitalize on working memory and to enable learners to achieve this difficult integration, computer-based learning environments should include instructional features that mitigate cognitive overload.

Cognitive load theory

Closely related to the limited capacity assumption of the CTML, cognitive load theory (CLT) supports the widely accepted principle that working memory capacity is limited (Sweller, 1999; Sweller, van Merrienboer, & Paas, 1998; Van Merriënboer, Kirschner, & Kester, 2003). The active learning processes of organization and integration (from CTML) are both generative processes related to germane cognitive load. In order for such germane processes to be enacted, extraneous load imposed through unproductive, unnecessary cognitive processing, should be reduced. Physically integrating corresponding text within graphical representations (Chandler & Sweller, 1991; Moreno & Mayer, 1999) and removing unnecessary or redundant information (Mayer, Heiser, & Lonn, 2001; Moreno & Mayer, 2000) are examples of instructional techniques to reduce extraneous load, as is visual signalling.

Visual signalling

Numerous studies on MERs have found benefits for a variety of visual signalling techniques, including colour coding, zooming, highlighting, flashing and arrows (e.g., Amadieu, Mariné, & Laimay, 2011; Bartholome & Bromme, 2009; Berthold & Renkl, 2009; Jeung, Chandler, & Sweller, 1997; Kalyuga, Chandler, & Sweller, 1999; Lin & Atkinson, 2011; Nelson, Kim, Foshee, & Slack, 2014; Tabbers, Martens, & van Merrienboer, 2004; Zhang, 2013). According to the CTML, the cognitive process of selection is the first and crucial step in effective mental integration of multiple representations. Only after selection can the learner organize and integrate the representations. Visual signalling can highlight relevant elements in the representations and thus guide the selection process (De Koning *et al.*, 2009). Eye-tracking results from De Koning, Tabbers, Rikers, and Paas (2010) revealed that visual cueing of an animation led to more fixations and greater fixation time on cued elements in the animation, supporting the assumption that visual signalling impacts the selection process.

Unlike single representation formats, multimedia requires learners to not only identify relevant information within one representation, but from two (or more) representations, and to make referential connections among those representations. For example, search processes for corresponding information in a diagram, while simultaneously listening to a narration, may hinder mental integration, because the integration requires verbal and visual information to be simultaneously active in working memory. In multimedia learning, visual signalling can guide the process of integration by explicitly pointing out corresponding information among separate sources of information, such as narrations and diagrams (De Koning *et al.*, 2009). Thus, signalling techniques may have a more substantial impact on multimedia learning, compared with learning from a single representation. From the perspective of cognitive load, visual signalling reduces extraneous load by reducing the search efforts for relevant and corresponding information. Eye-tracking results by Ozcelik and colleagues (Ozcelik, Arslan-Ari, & Cagiltay, 2010; Ozcelik, Karakus, Kursun, & Cagiltay, 2009) support the assumption that visual signalling assists learners in identifying correspondences among representations. First, Ozcelik *et al.* (2009) demonstrated that learners who were presented with colour-coded instructional materials had shorter intervals between fixations on text elements and their corresponding visual elements in diagrams. Next, Ozcelik *et al.* (2010) revealed that visual signalling of diagrams during narrations led to longer total fixation times on the corresponding elements in the diagrams and more prompt fixations on these corresponding elements.

If signalling techniques can support learners in lower level selection processes, extraneous cognitive load may be reduced, thereby freeing cognitive resources for germane (productive) cognitive processing of the multiple representations to form a coherent mental structure (Mautone & Mayer, 2001). Berthold and Renkl (2009) found that high school students who learned about probability using colour-coded instructional materials had lower subjective ratings of cognitive load, compared with the group who learned without colour coding. Kalyuga *et al.* (1999) also found a marginally significant difference between colour-coded and non-colour-coded conditions, with lower mental load ratings for the colour-coded condition.

Although visual signalling techniques have shown some promise, often effect sizes are small (e.g., Bartholome & Bromme, 2009; Berthold & Renkl, 2009) or do not extend to transfer tasks (e.g., Tabbers *et al.*, 2004). Additionally, some evidence suggests that visual signalling may only promote learning when the instructional material is sufficiently complex (Jeung *et al.*, 1997). Moreover, a relatively small set of studies has compared the efficacy of more than one signalling approach (Atkinson, Lin, & Harrison, 2009; Huk & Steinke, 2007; Jamet, Gavota, & Quaireau, 2008; Johnson, Ozogul, Moreno, & Reisslein, 2013; Moreno, Reisslein, & Ozogul, 2010). The current study thus seeks to determine relative efficacy of two forms of signalling (i.e., APA gestures or arrows) in multimedia learning, compared with non-signalled conditions.

APAs

One of the unique advantages of computer-based learning environments (Hartley, 2010; Kester, Kirschner, & Corbalan, 2007; Merchant *et al.*, 2013; Schroeder & Adesope, 2014) is the opportunity to employ an APA to facilitate the learning processes. APAs can support and stimulate cognitive processes through a variety of instructional support strategies (Moreno, 2005, 2006; Woo, 2009). For example, an APA can provide visual signalling (via gestures) to relevant information in presented visual representations, thereby reducing demands associated with *selection* of relevant information, that is, reducing extraneous cognitive load (Craig, Gholson, & Driscoll, 2002; Johnson, Ozogul, Moreno, *et al*., 2013; Moreno *et al*., 2010). Several APA studies (e.g., Atkinson, 2002; Craig *et al*., 2002; Dunsworth & Atkinson, 2007; Lusk & Atkinson, 2007; Yung, 2009) found that the combination of visual APA presence and instructional support strategy, such as signalling, provided by the APA, improved learning over a control condition that had neither visual APA presence nor instructional support.

In addition to the cognitive benefits of instructional support provided by APAs, agents can also influence motivational factors, such as making the learning experience more interesting or believable (Baylor, 2011; Caballé *et al*., 2014; Gulz, 2005; Johnson, DiDonato, & Reisslein, 2013; Johnson, Ozogul, DiDonato, & Reisslein, 2013; Kim & Baylor, 2006; Lester *et al*., 1997; Mitrovic & Suraweera, 2000; Ryokai, Vaucelle, & Cassell, 2003; Veletsianos, 2009; Woo, 2009). Empirical research has demonstrated that people tend to respond to computer personalities as they would respond to other humans (Moon & Nass, 1996; Reeves & Nass, 1996). Commonly referred to as the persona effect, the positive influence of an APA is assumed to stem from social cues and interactions instantiated by the agent (Atkinson, 2002; Baylor & Kim, 2005; Johnson, Rickel, & Lester, 2000; Kim & Baylor, 2006; Kim, Baylor, & Shen, 2007; Lester *et al*., 1997; Moundridou & Virvou, 2002).

Compared with signalling using arrows, APA signalling using hand gestures and head gaze may be uniquely positioned to influence visual attention allocation and learning. Whereas arrow signalling is an artificial and relatively unfamiliar method of directing attention, students are very accustomed to deictic hand gestures, which prompt gaze directions. Gestures are ubiquitous in human communication and instruction (Hostetter & Alibali, 2008, 2010; Roth, 2001). A recent meta-analysis of 63 studies revealed that speech with gestures significantly improves listener's understanding compared with speech alone, with a moderate effect size (Hostetter, 2011). Studies indicate that producing gestures during encoding can improve recall (e.g., Cook, Yip, & Goldin-Meadow, 2010). Mayer and DaPra (2012) showed that a fully embodied APA, which used gestures, facial expressions and eye gaze, produced better learning outcomes than the same APA without such embodied actions. The authors suggest that when an APA uses such human-like movements, learners may more easily perceive it as social agent, thus adopting a social stance in which they feel more obligated to expend efforts to learn.

A few studies (Choi & Clark, 2006; De Koning & Tabbers, 2013; Johnson, Ozogul, Moreno, *et al*., 2013; Moreno *et al*., 2010; Van Mulken, Andre, & Muller, 1998) compared visual signalling delivered by an abstract arrow with visual signalling delivered by an APA. The results from a series of studies demonstrated that visual signalling delivered by an APA was significantly more effective than either an arrow providing identical signalling or a control condition without such signalling (Johnson, Ozogul, Moreno, *et al*., 2013; Moreno *et al*., 2010). De Koning and Tabbers (2013) also showed that animations, which included gestures of a disembodied hand, led to better retention and transfer, compared with an arrow providing identical signalling.

Although some results seem to suggest positive learning benefits of APAs, the research is commonly criticized for experimental designs that do not include adequate control conditions to establish unique benefits of APAs (Clark & Choi, 2005; Heidig & Clarebout, 2011). Specifically, in order to identify potential unique persona effects (related to the agent *per se*), instructional effects (related to the instructional techniques *per se*) and additive effects (related to both agent and instructional techniques), an experiment must make use of a 2 (instructional technique: with or without) × 2 (agent: with or without) design. Without a control (non-APA) condition that offers identical pedagogical support, it is not possible to conclude that differences between an APA condition and a non-APA condition are due to the agent *per se* (Dehn & van Mulken, 2000). Thus, the fundamental understanding of APA signalling requires a 2 (visual signalling, no visual signalling) × 2 (visual APA presence, no visual APA presence) design in order to clearly identify the individual contributions of visual (arrow) signalling, APA presence and APA visual signalling (i.e., gesturing).

Moderating effects of prior knowledge

In their reconsideration of CLT, Schnotz and Kürschner (2007) maintain that reducing the difficulty of a learning task does not necessarily lead to better learning for all learners. Instructional assistance can play an enabling function, reducing a complex task's difficulty to a manageable level for learners with low expertise. When an instructional technique assists learners to perform a task that would otherwise require great cognitive effort, it is said to have a facilitating function (cf. Schnotz & Rasch, 2005). However, if instructional help is offered to students with high expertise, the task may be made too simple, resulting in negative consequences, in that learning is inhibited because learners are no longer in their zone of proximal development (Vygotsky, 1978). Similarly, Koedinger and Aleven (2007) suggest that instructional designers are faced with an 'assistance dilemma', in which they must make decisions about when to provide additional information and when to withhold this supplementary help.

Commonly referred to as the expertise–reversal effect, several studies have shown that instructional techniques that promote learning for students with low prior knowledge (LPK) are often not effective for learners with more existing knowledge of the domain (for review, see Kalyuga, Ayres, Chandler, & Sweller, 2003). For example, Kalyuga, Chandler, and Sweller (2000) found that low expertise learners benefited more from diagrams with additional auditory explanations than from diagrams alone. When these same learners gained expertise in the domain, they learned more from diagrams only than from diagrams and auditory explanations. The authors concluded that, with additional knowledge of the domain, the auditory explanations became redundant to the diagrams and inhibited the learning process.

It is possible that learners' domain knowledge may play a particularly influential role when MERs are present. Prior studies have suggested that experts can better disregard irrelevant information in visual representations, focusing instead on conceptually relevant elements (Canham & Hegarty, 2010; Jarodzka, Scheiter, Gerjets, & van Gog, 2010; Koedinger & Anderson, 1990; Kozma & Russell, 1997). Therefore, signalling techniques aimed at directing attention to relevant information may be necessary for learners with LPK of the domain, and may be unnecessary or even detrimental to learners with high prior knowledge (HPK). For HPK students, visual signals may be superfluous and distracting from the basic instructional elements. Given the prior evidence supporting the expertise reversal effect and expertise differences in visual attention, one of the goals of the current experiment was to examine whether the effects of APAs and/or visual signalling are moderated by learners' prior knowledge.

Research questions and hypotheses

Research question 1: what is the impact of visual signalling?

Following the positive results of prior research on the effect of visual signalling in multiple representations, we hypothesized that the two visual signalling conditions – arrow signalling and APA signalling – would lead to better learning and learning perceptions than the control condition without visual signalling. It was assumed that the visual signalling techniques would reduce extraneous load associated with the selection phase of the CTML, thus freeing cognitive resources for germane process related to organization and integration of incoming information. Additionally, we assumed that visual signalling techniques make explicit the inter-representational relations, thus supporting the mental integration of multiple representations. Given the prior results indicating that APA signalling benefited learning, but arrow signalling did not (Johnson, Ozogul, Moreno, *et al*., 2013), we considered the possibility that only APA signalling would be successful in this capacity.

Research question 2: what is the impact of APA?

Conflicting hypotheses can be formulated for the impact of the visual presence of the APA. On the one hand, the persona effect suggests that the mere visual presence of the APA improves learning and learning perceptions via the social interactions instantiated by the APA. That is, the visual presence of the APA as it narrates the instructional text without providing any visual signalling (i.e., the APA is not pointing to relevant areas in the multiple representations) imparts social cues that make the learning more authentic, interesting and credible, and thus more effective. In contrast, from a cognitive load perspective, the visual presence of the APA may increase the extraneous cognitive load by adding a visual display component that distracts the learner from the relevant areas of the multiple representations (Craig *et al*., 2002; Moreno, 2005). In effect, the visual presence of the APA may guide the visual attention of the learner away from the relevant equations and engineering diagrams, thus interfering with the selection process.

Research question 3: how does learner prior knowledge moderate the effects of visual signalling and APA?

Commonly referred to as the expertise reversal effect, prior research has revealed that instructional manipulations that assist LPK learners are often not beneficial to, and can even hinder, learners with high levels of existing knowledge of the domain (Kalyuga *et al.*, 2003). Thus, we expected that prior knowledge would moderate the impact of visual signalling and APA. Specifically, we hypothesized that learning and learner perceptions would be positively impacted by visual signalling and APA presence for LPK students, but these factors may not benefit learning and perceptions for the HPK students, and, in fact, may lead to lower post-test scores and learner ratings for these learners.

Method

Experimental design

We sought to identify the fundamental effects of APA signalling with MERs through a 2 (visual signalling: signalling or no signalling) × 2 (visual APA presence: with agent or without agent) design; both factors were between subjects. Participants were randomly assigned to one of the four resulting experimental conditions: visual signalling with APA presence, visual signalling without APA presence, no visual signalling with APA presence and no visual signalling without APA presence. Dependent variables included post-test scores and participant ratings of the computer-based learning environment and ratings of cognitive load. Students participated in the experiment during a regular class session at their school.

Participants

Participants were a total of 250 middle school students from a public school in the Southwestern USA: 124 females and 126 males. The mean age was 12.5 years (standard deviation = 0.67 years). One hundred seventeen (46.8%) of the students reported Hispanic as their ethnicity, 62 (24.8%) students reported they were Caucasian, 39 students (15.6%) reported they were African American, 21 students (8.4%) reported being of other ethnicities, six (2.4%) reported they were Native American and five (2.0%) reported their ethnicity as Asian American. There were 64 participants in the visual signalling with APA condition (APA + S), 60 participants in the visual signalling without APA condition (S), 65 participants in the no visual signalling with APA condition (APA) and 61 participants in the no visual signalling without APA condition (C).

Materials and apparatus

Computerized materials

All participants interacted with a computer-based learning environment comprised of the following phases: (1) a demographic questionnaire requesting students to report their gender, age and ethnicity; (2) an introduction to the objectives of the instructional program; (3) an instructional session that provided a brief conceptual overview of a single-resistor electrical circuit; (4) a simulation session; and (5) a program rating questionnaire.

All experimental conditions included a brief, identical introduction to the objectives of the instructional program (Phase 2). Additionally, in all experimental conditions, an instruction session (Phase 3) presented identical narrated explanations and calculations using Ohm's law equation as well as identical depictive representations. The simulation session (Phase 4) presented a circuit diagram depicting the electric circuit and a Cartesian graph that plotted voltage as a function of the current in the electric circuit (see Figure 1). Equations that specified the given resistance and current values were integrated within the electric circuit diagram. Directly to the left of the electric circuit diagram, the appropriate sequence of equation calculation steps necessary for calculating voltage using Ohm's law was displayed. In summary, the simulation session presented MERs: spoken narration, mathematical equations, schematic circuit diagram and a Cartesian graph relating system quantities.

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 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

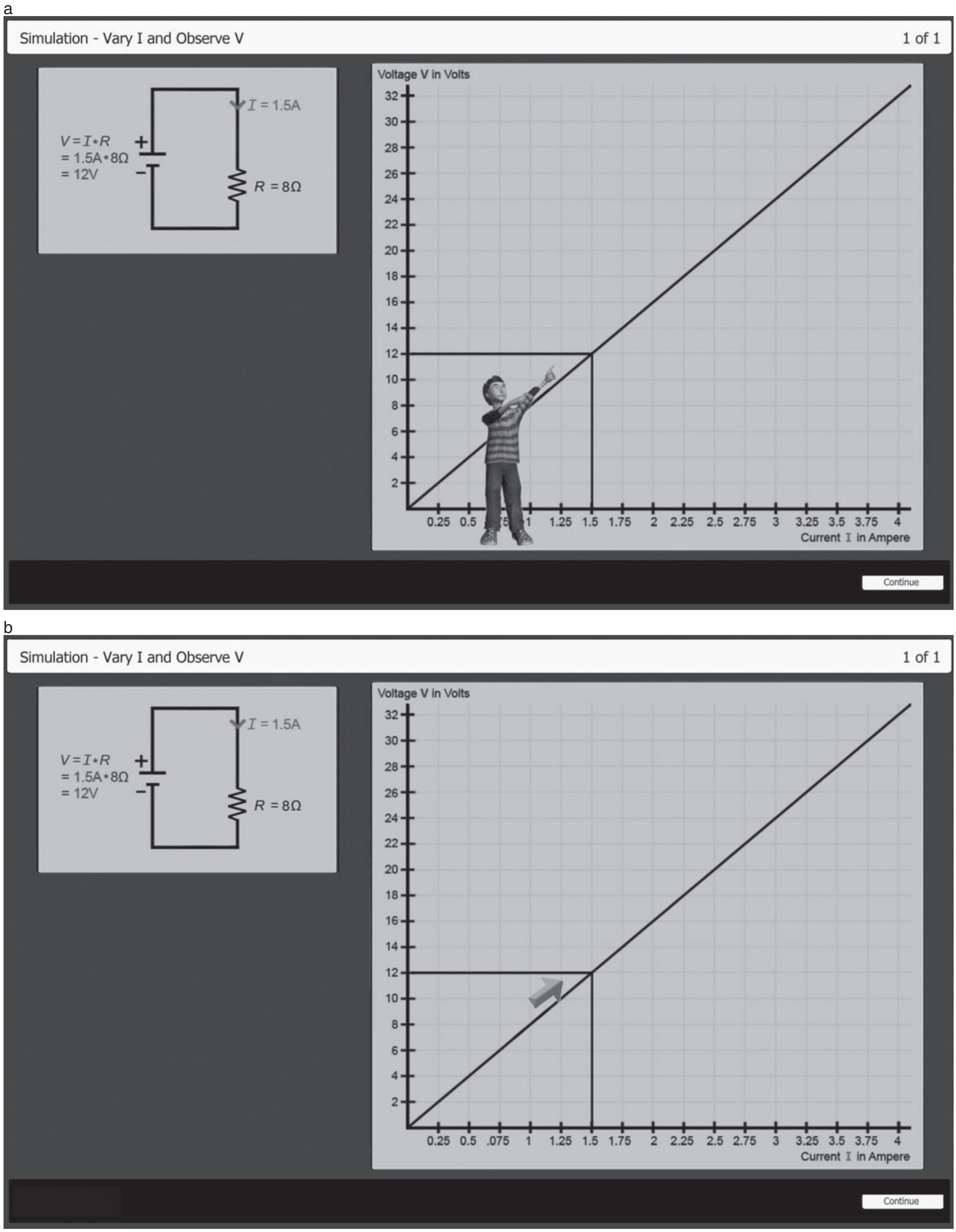

Figure 1 Sample Screen Shots of Multi-Representation Display Screen with Ohm's Law Equation Calculations, a Circuit Diagram and a Cartesian Graph of Voltage as a Function of Current Used in the Simulation Session. (a) Animated Pedagogical Agent Signalling Condition; (b) Arrow Signalling Condition

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 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 Ohm's law equation and the given circuit.

The versions differed only during the simulation session (Phase 4): In the visual signalling with APA (APA + S) condition, an APA appeared on the screen to dynamically signal to the visual element of the multiple representations in the display screen that corresponded to the current passage in the narrated explanation. The APA pointed to the visual element through deictic gestures, for example, pointing with arms and fingers, and directed head and eye gaze towards these elements, as illustrated in Figure 1a. The APA was a young male, approximately of the same age as the student participants, and was dressed casually, similar 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 three-dimensional computer agent created with Autodesk 3D Studio Max 5 (Autodesk, Inc., San Rafael, CA, USA), a software for building, animating and rendering three-dimensional models and characters. The narration voice files were applied to the APA using the VENTRILOQUIST (Digimation, Inc., Lake Mary, FL, USA) 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. All of 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 that were imported into Adobe After Effects CS2 (Adobe Systems, Inc., San Jose, CA, USA) to be layered onto the static image of the multiple representation screen.

In the visual signalling without APA (S) condition, a single arrow was used to provide identical dynamic signalling as in the APA + S condition. For instance, in the example in Figure 1, when the narration introduces the given circuit with the given resistance value, the agent 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 signalling in the different representations.

The no visual signalling with APA (APA) condition did not include any visual signalling, but displayed the visual image of the APA in the lower left corner of the display so as not to obstruct any instructional materials. The APA in this condition was only animated to provide the basic mouth and facial expressions correlated to the narrated speech (i.e., lip-synch) as well as random animated eyebrow and hand movements that are common for APAs that are not specifically pointing in any particular direction. The control condition (C) did not include any visual signalling and did not present a visual representation of the APA.

The last step of the computer-based learning environment presented an 18-item Likert-like survey instrument, including ten items asking participants to rate their learning perceptions concerning the program (e.g., 'I would recommend this program to other students') and eight items related to cognitive load. Each item in the instrument was rated on a 5-point scale ranging from 0 (*strongly disagree*) to 4 (*strongly agree*). The learning perceptions 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; Ozogul, Johnson, Moreno, & Reisslein, 2012; Reisslein, Moreno, & Ozogul, 2010). The construct validity of the revised survey was assessed with the judgment of subject matter experts in electrical engineering instruction and education research.

The learning perceptions questionnaire was assessed through a factor analysis using principal axis estimation, with all ten items from the learning perceptions questionnaire. Results demonstrated that two factors accounted for 60.4% of the variance. Extraction of these two factors was based on an eigenvalue threshold of one. The two identified factors related to (1) evaluations of liking of the program (seven items, such as 'I enjoyed learning with the program' and 'I liked the graphics in the program', with factor loadings ranging from 0.42 to 0.80) and (2) evaluations of the helpfulness of the graphics for understanding electric circuits (three items, such as 'The graphics made the lesson easier to understand' and 'The graphics in the program helped me to learn', with factor loadings ranging from 0.73 to 0.80). The internal reliability of the 'program liking' rating scale was 0.89 and internal reliability of the 'graphics understanding' rating scale was 0.87.

The cognitive load questionnaire was also assessed using factor analysis with principal axis estimation, using an eigenvalue threshold of one. Results indicated that two factors accounted for 61.8% of the variance: (1) evaluations of the difficulty of the program (six items, such as 'It was difficult to learn from this program' and 'The topics that were covered in the lesson were difficult', with factor loadings from 0.68 to 0.85) and (2) evaluations of the germane processing of the program (two items, 'I concentrated a lot during learning' and 'I paid a lot of attention to this lesson', with factor loadings 0.74 and 0.84, respectively). The internal reliability of the 'difficulty' rating scale was 0.89 and internal reliability of the 'germane load' rating scale was 0.82. A 'program liking' ratings score, a 'graphics understanding' ratings score, a 'perceived difficulty' score and a 'perceived germane load' score were computed by averaging the ratings from the respective questions that loaded on these factors. We note that the development of instruments for measuring the different types of cognitive load is an ongoing effort (see, e.g., Leppink, Paas, Van der Vleuten, Gog, & Van Merrienboer, 2013) and thus the results for the different cognitive load types should be interpreted cautiously.

The computer-based learning module used in the study was developed using ADOBE FLASH CS4 (Adobe Systems, Inc., San Jose, CA, USA) 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 screen size of 1680 × 1050 pixels, and headphones.

Paper and pencil materials

Paper and pencil materials included a pre-test and a post-test on electric circuit analysis. The pre-test consisted of 12 items that assessed students' domain-relevant prior knowledge (with internal reliability of $\alpha = 0.69$). Items on the pre-test included conceptual knowledge questions about electric circuits, questions requiring identification of diagrammatic electric circuit elements, as well as algebra and graph reading problems and single-resistor electric circuit problems to be solved with the symbolic approach using the Ohm's law equation. The post-test included 13 novel single-resistor electrical circuit problems to be solved both with the Ohm's law approach and with the graphical approach using the Cartesian graph (internal reliability: $\alpha = 0.78$). Two independent scorers, blind to condition, scored the pre-test and post-test (inter-rater reliability of 0.98). Both pre-test and post-test were designed and printed using the same colour and layout scheme as the computer program.

Procedure

During a regular class meeting at the participants' school, students were provided with a laptop, headphones and two closed envelopes, containing the paper-based pre-test and post-test. The participant identification number and the letter representing the appropriate condition for each student were written on both envelopes (envelopes were randomly distributed to students). The researcher first instructed students to open the pre-test envelope and begin working on the pre-test. Once students completed the pre-test, they returned the pre-test back to the envelope and the researcher assisted the students to start the respective version of the computer-based module by entering the combination of identification number and condition letter on the envelopes. 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 post-test envelope and complete the post-test. The researcher then collected all laptops, and pre-test and post-test envelopes.

Results

Prior knowledge: pre-test

An initial 2 (visual signalling: no signalling or signalling) × 2 (APA: with APA or without APA) analysis of variance was conducted on pre-test scores to make certain there were no existing differences in prior knowledge among the conditions. An alpha level of 0.05 was used for all statistical tests. The main effect for signalling was not significant, $F < 1$ and the main effect for agent presence was not significant, $F < 1$. There was also not a significant interaction between the two factors, $F < 1$. We conducted a parallel analysis on time on task. Results indicated no significant main effects of signalling, $F(1,246) = 2.63$, $p = 0.11$, or agent presence, $F(1,246) = 2.96$, $p = 0.09$, on students' total time on task. There also was not a significant interaction between the two factors on time on task, $F(1,246) = 2.92$, $p = 0.09$.

Because we expected that students' prior knowledge would moderate the effects of visual signalling and APA presence, we performed a median split using the pre-test scores to divide all participants into low and HPK groups (overall median = 4). Participants who scored at or below the median were categorized as LPK, and participants who scored above the median were categorized as a HPK. Using the median split approach, 127 students were identified as LPK and 123 were identified as HPK. In order to determine main effects of prior knowledge, visual signalling, and agent presence, as well as interactions between and among the three factors, we conducted a series of 2 (prior knowledge: LPK or HPK) × 2 (visual signalling: signalling or no signalling) × 2 (agent presence: with or without APA) univariate analyses of variance on each of the dependent variables. Each of the independent variables was between subjects. Descriptive statistics for each of the dependent variables, by each of the three factors, are displayed in Table 1. The following subsections describe results for the post-test measure (learning), the program ratings instrument and the cognitive load instrument.

Learning: post-test

As would be expected, results indicated a significant main effect of prior knowledge on students' post-test scores, $F(1,242) = 29.23$, $p < 0.001$. HPK students had significantly higher post-test scores than LPK students. There was also a significant main effect of visual signalling for the post-test measure, $F(1,242) = 18.05$, $p < 0.001$, $\eta^2_p = 0.07$. Overall, participants in the visual signalling conditions scored significantly higher on the post-test compared with the students in the no visual signalling conditions, Cohen's $d = 0.48$. However, there was also a significant interaction between prior knowledge and visual signalling factors, $F(1,242) = 8.49$, $p = 0.004$, $\eta^2_p = 0.03$. Follow-up pairwise comparisons indicated that LPK students had significantly higher post-test scores after learning with visual signalling, $t(125) = 4.04$, $p < 0.001$, $d = 0.72$, whereas post-test scores did not differ between signalling and no signalling conditions for the HPK students, $t(121) = 1.05$, $p = 0.29$. When no signalling was present, HPK students scored significantly higher on the post-test compared with the LPK students, $t(124) = 5.16$, $p < 0.001$, $d = 0.93$. When signalling was provided, however, the difference between HPK and LPK students' post-test scores was not statistically significant, $t(124) = 1.94$, $p = 0.055$, $d = 0.35$. See Figure 2 for an illustration of the interaction between visual signalling and prior knowledge.

Although there was not a significant main effect of agent presence, $F < 1$, there was a significant interaction between prior knowledge and agent presence, $F(1,242) = 15.46$, $p < 0.001$, $\eta^2_p = 0.06$. Follow-up pairwise comparisons indicated that HPK students had significantly higher post-test scores after learning without an APA, $t(121) = 3.11$, $p = 0.002$, $d = 0.56$, whereas LPK students had higher scores after learning with the APA, $t(125) = 2.19$, $p = 0.03$, $d = 0.39$. When an APA was present, there was not a significant difference between LPK and HPK students' post-test scores, $t(127) = 1.41$, $p = 0.16$. However, when no APA was used, HPK students had higher post-test scores than the LPK students, $t(119) = 5.80$, $p < 0.001$, $d = 1.05$. See Figure 3 for an illustration of the interaction between APA presence and prior knowledge.

Results further demonstrated a significant interaction between visual signalling and APA presence, $F(1,242) = 8.73$, $p = 8.73$, $\eta^2_p = 0.04$. Follow-up pairwise comparisons indicated that post-test scores were higher for the APA + S condition, compared with the APA condition, $t(127) = 5.87$, $p < 0.001$, $d = 1.04$, the S condition, $t(122) = 2.75$, $p = 0.007$, $d = 0.49$, and the C condition, $t(123) = 2.82$, $p = 0.006$, $d = 0.50$. There was not a significant difference between the S and C conditions, $t < 1$. There also was no significant difference between the APA and C conditions, $t(124) = 1.69$, $p = 0.09$. (See Figure 4 for an illustration of the interaction between visual signalling and APA presence.)

Table 1. Descriptive Statistics for Dependent Variables, by Agent Condition, Signalling Condition and Prior Knowledge Level

APA presence	Visual signalling	Prior knowledge (max = 12)	Post-test (max = 13)	Program liking (0–4)	Graphics understanding (0–4)	Perceived difficulty (0–4)	Perceived germane load (0–4)
No APA	No signalling (C)	LPK ($n = 29$)	7.31 (3.94)	2.41 (0.89)	2.58 (1.00)	2.49 (0.59)[o,p,q]	2.81 (1.07)
		HPK ($n = 32$)	11.62 (1.54)	2.61 (0.79)	3.01 (0.76)	1.46 (0.79)	2.83 (1.12)
		Total ($n = 61$)	9.57 (3.63)	2.52 (0.84)	2.80 (0.90)	1.95 (0.87)	2.82 (1.09)
	Signalling (S)	LPK ($n = 31$)	9.01 (3.18)	2.30 (1.01)	2.75 (0.99)	1.82 (1.02)	2.58 (1.00)
		HPK ($n = 29$)	10.76 (1.99)	2.59 (0.99)	3.04 (1.05)	1.53 (1.13)	2.74 (0.89)
		Total ($n = 61$)	9.85 (2.79)	2.44 (1.00)	2.89 (1.02)	1.68 (1.07)	2.66 (0.95)
	Total	LPK ($n = 60$)	8.19 (3.64)	2.36 (0.95)	2.67 (0.99)	2.15 (0.90)[m,n]	2.69 (1.03)
		HPK ($n = 61$)	11.21 (1.81)[e,g]	2.60 (0.89)	3.02 (0.91)[g]	1.49 (0.96)	2.79 (1.01)
		Total ($n = 121$)	9.71 (3.23)	2.48 (0.92)	2.85 (0.96)	1.82 (0.98)	2.74 (1.02)
APA	No signalling (APA)	LPK ($n = 36$)	8.13 (3.21)	2.62 (0.87)	2.90 (0.87)	1.84 (1.01)	2.76 (0.91)
		HPK ($n = 29$)	9.21 (1.99)	2.32 (0.96)	2.70 (0.83)	1.83 (0.89)	2.71 (1.07)
		Total ($n = 65$)	8.61 (2.76)	2.49 (0.91)	2.81 (0.85)	1.84 (0.95)	2.74 (0.98)
	Signalling (APA + S)	LPK ($n = 31$)	11.06 (1.75)	2.53 (0.82)	3.31 (0.59)	1.61 (0.78)	2.53 (0.89)
		HPK ($n = 33$)	10.94 (1.75)	2.61 (0.70)	2.88 (0.86)	1.41 (0.97)	2.83 (0.74)
		Total ($n = 64$)	11.00 (1.74)[h,i]	2.57 (0.75)	3.09 (0.76)	1.51 (0.88)	2.69 (0.82)
	Total	LPK ($n = 67$)	9.49 (3.01)[f]	2.58 (0.84)	3.09 (0.78)[f,j]	1.73 (0.91)	2.66 (0.90)
		HPK ($n = 62$)	10.13 (2.04)	2.47 (0.84)	2.80 (0.84)	1.60 (0.95)	2.77 (0.90)
		Total ($n = 129$)	9.79 (2.60)	2.53 (0.84)	2.95 (0.82)	1.67 (0.93)	2.71 (0.90)
Total	No signalling	LPK ($n = 65$)	7.76 (3.55)	2.53 (0.88)	2.76 (0.94)	2.13 (0.91)	2.78 (0.98)
		HPK ($n = 61$)	10.48 (2.13)[d]	2.47 (0.88)	2.86 (0.80)	1.63 (0.85)	2.77 (1.09)
		Total ($n = 126$)	9.08 (3.24)	2.50 (0.88)	2.81 (0.87)	1.89 (0.91)[l]	2.78 (1.03)
	Signalling	LPK ($n = 62$)	10.04 (2.75)[c]	2.42 (0.92)	3.03 (0.86)	1.72 (0.90)	2.56 (0.94)
		HPK ($n = 62$)	10.85 (1.85)	2.60 (0.84)	2.96 (0.95)	1.47 (1.04)	2.79 (0.81)
		Total ($n = 124$)	10.45 (2.37)[b]	2.51 (0.88)	2.99 (0.90)	1.59 (0.98)	2.67 (0.88)
	Total	LPK ($n = 127$)	8.87 (3.37)	2.47 (0.90)	2.89 (0.91)	1.93 (0.93)[k]	2.67 (0.96)
		HPK ($n = 123$)	10.67 (2.00)[a]	2.53 (0.86)	2.91 (0.88)	1.55 (0.95)	2.78 (0.95)

Note. Significant differences are set at the 0.05 level. APA = animated pedagogical agent; HPK = high prior knowledge; LPK = low prior knowledge.
[a]HPK > LPK. [b]Visual signalling > no visual signalling. [c]LPK: visual signalling > no visual signalling. [d]No visual signalling: HPK > LPK. [e]HPK: no APA > APA. [f]LPK: APA > no APA. [g]No APA: HPK > LPK. [h]APA + S > APA. [i]APA + S > S. [j]APA: LPK > HPK. [k]LPK > HPK. [l]No visual signalling > visual signalling. [m]No APA: LPK > HPK. [n]LPK: no APA > APA. [o]LPK: C condition > S condition. [p]LPK: C condition > APA + S condition. [q]C condition: LPK > HPK.

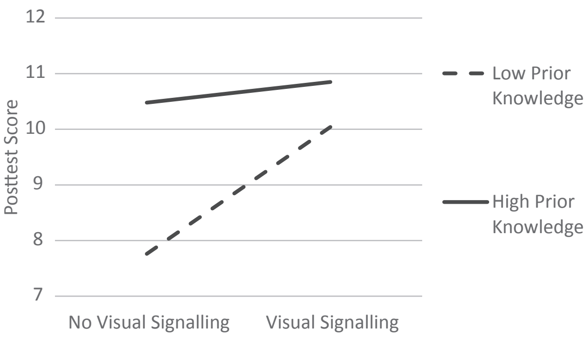

Figure 2 Post-test – Interaction between Prior Knowledge and Visual Signalling

The three-way interaction (prior knowledge × signalling × agent presence) was not statistically significant, $F(1,242) = 1.11$, $p = 0.29$.

Program ratings

For the 'program liking' rating scale items, there were no significant main effects for prior knowledge, visual

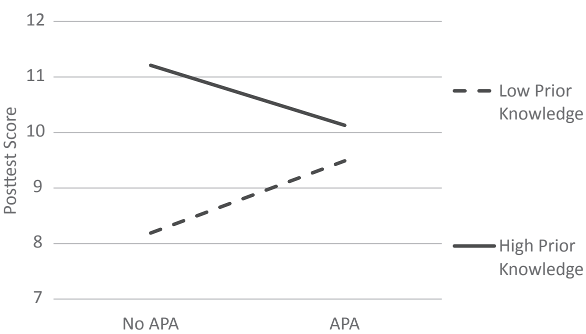

Figure 3 Post-test – Interaction between Prior Knowledge and Animated Pedagogical Agent (APA) Presence

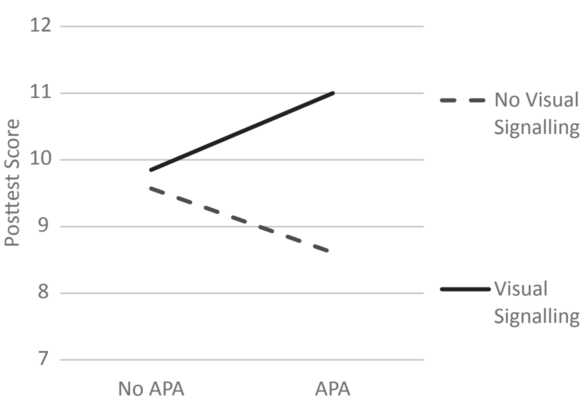

Figure 4 Post-test – Interaction between Visual Signalling and Animated Pedagogical Agent (APA) Presence

signalling or agent presence (all Fs < 1). There was also no significant interaction between agent presence and visual signalling, $F < 1$, between prior knowledge and agent presence, $F(1,242) = 2.44$, $p = 0.12$, or between prior knowledge and signalling, $F(1,242) = 1.08$, $p = 0.30$. The three-way interaction was also not statistically significant, $F < 1$.

For the 'graphics understanding' rating scale items, there was not a statistically significant main effect of prior knowledge or agent presence (Fs < 1), nor a statistically significant main effect of visual signalling, $F(1,242) = 3.18$, $p = 0.08$. The interaction between agent presence and visual signalling was also not significant, $F < 1$. However, there was a significant interaction revealed between prior knowledge and agent presence, $F(1,242) = 9.15$, $p = 0.003$, $\eta^2_p = 0.04$. Follow-up pairwise comparisons revealed that when an agent was present, LPK students rated the graphics as more understandable than HPK students, $t(127) = 2.06$, $p = 0.04$, $d = 0.36$. Conversely, when no agent was used, HPK students rated the graphics as more understandable than the LPK students, $t(119) = 2.06$, $p = 0.04$, $d = 0.38$. LPK students rated the APA conditions as more understandable, compared with conditions without APA, $t(125) = 2.69$, $p = 0.008$, $d = 0.47$, whereas HPK students' ratings of graphics understanding did not differ between APA and no APA conditions, $t(121) = 1.44$, $p = 0.15$. The interaction between prior knowledge and visual signalling and the three-way interaction were not statistically significant (both Fs < 1).

Cognitive load

Analyses of the six 'perceived difficulty' items indicated a significant main effect for prior knowledge, $F(1,242) = 11.07$, $p = 0.001$, $\eta^2_p = 0.04$. LPK students had higher perceived difficulty ratings than the HPK students. The analysis indicated a statistically significant main effect for visual signalling, $F(1,242) = 7.32$, $p = 0.007$, $\eta^2_p = 0.03$. Overall, students in the conditions without visual signalling rated the learning session more difficult than those in the conditions with visual signalling, $d = 0.31$. There was not a significant interaction between prior knowledge and visual signalling, $F(1,242) = 1.45$, $p = 0.23$.

Although there was not a statistically significant main effect for agent presence, $F(1,242) = 1.77$,

$p = 0.19$, results indicated a significant interaction between prior knowledge and agent presence, $F(1,242) = 5.79$, $p = 0.017$, $\eta^2_p = 0.02$. Follow-up pairwise comparisons indicated that when no agent was used, LPK students had higher difficulty ratings than HPK students, $t(119) = 3.88$, $p < 0.001$, $d = 0.71$. However, when an agent was present, difficulty ratings did not differ between LPK and HPK students, $t < 1$. LPK students rated the learning conditions without an APA as significantly more difficult (compared with the APA conditions), $t(125) = 2.57$, $p = 0.011$, $d = 0.47$, whereas difficulty ratings were not statistically significantly different between APA conditions and no APA conditions for the HPK students. There was not a statistically significant interaction between agent presence and visual signalling, $F < 1$.

The three-way interaction among all three factors was statistically significant, $F(1,242) = 3.98$, $p = 0.047$, $\eta^2_p = 0.02$. For students with LPK, difficulty ratings were significantly higher for the C condition compared with the S condition, $t(58) = 3.10$, $p = 0.003$, $d = 0.80$, and compared with the APA + S condition, $t(63) = 3.06$, $p = 0.003$, $d = 0.79$. For these same LPK students, no statistically significant difference was revealed between APA and APA + S conditions, $t(65) = 1.05$, $p = 0.30$, or between S and APA + S conditions, $t < 1$. For HPK students, whether an agent was present or not, difficulty ratings did not differ between signalling and no visual signalling conditions (ps > 0.05). Also, for these HPK students, regardless of whether visual signalling was provided, difficulty ratings were not statistically different between APA and no APA conditions (ps > 0.05).

In the C condition, LPK students rated the program significantly more difficult than the HPK students, $t(59) = 5.75$, $p < 0.001$, $d = 1.48$. Differences in difficulty ratings between LPK and HPK students were not statistically significant for the S condition, $t(58) = 1.06$, $p = 0.29$; the APA condition, $t < 1$; or the APA + S condition, $t < 1$.

Analysis of the two 'perceived germane load' rating items did not demonstrate significant main effects for any of the three factors (all Fs < 1). There was also not a significant interaction between prior knowledge and visual signalling, $F(1,242) = 1.05$, $p = 0.31$. None of the remaining interactions were significant either (all Fs < 1).

Discussion

Results indicate that visual signalling via the APA positively impacted learning and led to lower student perceptions of difficulty. The APA hand gestures to relevant information in diagrams, equations and Cartesian graphs may have facilitated learners in the first stage of multimedia learning, *selection*, and in the *integration* phase (Mayer, 2005). In order for students to successfully organize visual and verbal information and integrate that information together with prior knowledge, they must first select essential information from among the array of available information. The post-test results suggest that the selection processes were supported via the APA signalling and students therefore were able to apply more cognitive resources towards organization and integration cognitive processes. Perceived difficulty ratings suggest the assumption that visual signalling may have reduced extraneous load associated with search processes for relevant and corresponding information. We also suggested that visual signalling makes explicit the referential connections between the verbal information (i.e., narration) and the visual information (i.e., diagrams), thereby facilitating the germane mental integration process of external representations. Unfortunately, significant effects were not detected for the germane load ratings in this experiment. The interpretation of the main effect of visual signalling is best understood by consideration of the interactions between this factor and APA presence as well as learner prior knowledge.

Analyses from the experiment did not reveal significant main effects of the APA on any of the dependent variables. The visual presence of the agent did not positively or negatively impact learning and learner perceptions overall. Considering the results of this experiment, we do not advocate the persona effect (Lester *et al*., 1997) suggesting that APAs generally promote learning for all learners by instantiating a social interaction that increases motivation and learning (although this may be true for particular learners). Rather, we concur with Heidig and Clarebout (2011) that APA research should examine the conditions under which agents can promote learning and the conditions when APAs are not effective or potentially detrimental to learning.

The examination of the interaction between visual signalling and APA presence revealed two crucial results: (1) student learning was promoted by the APA signalling, but not by the arrow signalling, similar to earlier findings (De Koning & Tabbers, 2013; Johnson, Ozogul, Moreno, *et al*., 2013; Moreno *et al*., 2010) and (2) the APA had a beneficial impact on learning only when it provided visual signalling. We suggest that through the use of hand gestures, an APA may be uniquely positioned to make the function of signalling more apparent to students and to promote adherence to attention guidance. Young students, such as those in our study, have countless previous experiences with the deictic gestures used by their teachers to signify where visual attention should be directed (Roth, 2001). Therefore, the intentions behind a dynamic arrow that moves around a visual display may be more difficult to comprehend than the same signalling provided by an APA. This assumption is not fully supported by the difficulty ratings, although the ratings were descriptively lower in the APA signalling compared with the arrow signaling condition.

The lack of an overall persona effect in this study is in line with the majority of the limited empirical studies that utilize appropriate control (non-agent) conditions (for review, see Heidig & Clarebout, 2011). Moreover, results demonstrated that the APA + S condition led to better learning than the APA condition. The hand gestures used by the animated agent had a unique positive impact on student learning, whereas the mere presence of the APA did not. This implies that compared with the physical embodiment of an on-screen character and the motivational benefits it might produce, the type of instructional support provided by the APA is a more crucial element to consider in educational research and instructional design.

Prior knowledge interactions

Many of the interesting results from the experiment were revealed by examining the interactions between student prior knowledge and the treatment factors. As predicted on the basis of the previously identified expertise reversal effect (Kalyuga *et al*., 2003), students' existing domain knowledge moderated the impact of visual signalling and APA presence. LPK students had significantly higher post-test scores and graphic ratings and lower difficulty ratings after learning with the APA, whereas HPK students learned more from the conditions without the APA. In fact, in the APA conditions, LPK and HPK students had equivalent post-test scores and difficulty ratings. Similar outcomes were obtained by Choi and Clark (2006) and Johnson, Ozogul, Moreno, *et al*. (2013), although earlier studies did not reveal a detrimental impact of APA on HPK students. For the LPK students, the APA may offer motivational benefits by initiating a social interaction (i.e., persona effect), but HPK students may not need additional encouragement towards the learning task and thus, the APA may simply distract these learners, redirecting visual attention from the diagrams, equations and graphs towards the visual representation of the APA (Craig *et al*., 2002; Moreno, 2005). In this case, the HPK students are expending time and cognitive resources on unnecessary help, an effect referred to as negative facilitation (Schnotz & Kürschner, 2007).

As expected, prior knowledge also moderated the impact of the visual signalling. LPK students had higher post-test scores after learning with signalling conditions, whereas post-test scores did not differ between signalling and no signalling conditions for the HPK students. When signalling was available to students, post-test scores did not differ between low and HPK students. LPK students require the instructional guidance provided by the visual signalling, and benefit from the presumed reduction of extraneous load associated with search processes for relevant and corresponding information in visual representations. Unlike LPK students, the HPK students had sufficient existing domain-relevant knowledge (i.e., algebra and graph reading) to support the process of selection of relevant information and thus, visual signalling was not necessary. The equivalent performance of HPK students in signalling and no signalling conditions suggests that signalling did not produce a negative facilitation (Schnotz & Kürschner, 2007) for these students. However, as students become more knowledgeable in the domain, such signalling may become redundant and distract from learning processes.

Examination of the three-way interaction among the three factors indicated an interesting pattern of results for the difficulty ratings. When no visual signalling was provided to LPK students, difficulty ratings were higher for the non-APA conditions, compared with the APA conditions. However, when visual signalling was available, the difference between APA and non-APA conditions was not statistically significant for LPK students. Similarly, when the APA was not present, LPK students provided higher difficulty ratings for the no visual signalling conditions compared with the visual signalling conditions, but the difference between visual signalling and no visual signalling conditions disappeared when an APA was provided. Also, when signalling and APA are not used (i.e., the C condition), HPK students rated the program less difficult than the LPK students. When either visual signalling or APA was used (i.e., S or APA conditions) or both were utilized (i.e., APA + S condition), difficulty ratings did not differ between HPK and LPK students. This pattern of results suggests that LPK students' perceptions of the difficulty of the material may be positively impacted by either of the factors, but the two support mechanisms are not additive. That is, when one support technique is provided, the addition of the other does not lead to additional benefits to the perception of difficulty.

It should be noted that the pattern of results surrounding student perceptions does not precisely match the results for learning outcomes (i.e., post-test scores). For example, LPK students rated the no agent, no visual signalling condition significantly more difficult than the no agent, with visual signalling condition, although no difference was detected between these two conditions for the post-test measure. In such circumstances, the learning experience may seem easier, but effects are apparently not strong enough to increase actual learning outcomes. It is possible that LPK students experienced difficulty monitoring their own understanding of the material (Nietfeld & Schraw, 2002; Schraw & Nietfeld, 1998), given the instructional support of arrows. Additionally, with greater exposure (i.e. more frequent and lengthier learning experiences) to a learning environment with similar instructional support features, improved student perceptions of learning could ultimately lead to learning consequences as well, by promoting self-efficacy and persistence with the tasks. Thus, effects on perceptions of the learning environment and difficulty should also be taken into consideration in instructional design decisions.

Practical implications

Taken together, the results from our experiment indicate that the decision to implement support techniques, such as an APA or visual signaling, should depend on learner characteristics, such as prior knowledge. Specifically, the results suggest that LPK students should be provided with computer-based learning environments that include an APA that provides visual signalling to relevant information in given visual representations of the domain. On the other hand, HPK students do not experience learning benefits from the use of either an APA or visual signalling. Thus, learning environments for these students should exclude the use of either, because learning perceptions can be negatively influenced by these factors. In order to further tailor the learning experience to the development of learner expertise, embedded assessment techniques (Shute, Ventura, Bauer, & Zapata-Rivera, 2009) can be used and APA signalling can be removed when adequate knowledge representations develop. If the APA signalling continues to be used once a learner has sufficient knowledge to use the MERs on their own, the unnecessary support mechanism may eventually detract from learning (Schnotz & Kürschner, 2007).

Limitations and future directions

A primary limitation of our experiment is the lack of significant findings for the germane load measures. Because additional cognitive resources are available when extraneous load is reduced, it was expected that a converse pattern of results to the difficulty rating scale would be revealed for the germane load measure. Furthermore, our interpretation that the APA signalling supports the germane process of integrating information from narrations, diagrams and formulas could be supported with higher germane ratings in the APA signalling condition. In order to better assess differences among conditions and learner groups, the items may need to be refined further.

As is common in experimental educational psychology, the experiment is limited in its examination of a single population (middle school students), using one educational topic (electric circuits) in a specific geographic location (southwestern USA) in a particular educational setting (traditional classroom). Future research on APAs and visual signalling should investigate the issues using different student populations, various geographic sites, using a variety of educational contexts. Although we believe that the findings from the experiment would be applicable to a variety of science, technology, engineering and mathematics domains that use similar visual representations, future studies may also use different domains.

Although we assume that the visual signalling technique reduces search time for relevant information in the visual representations, eye-tracking research can be used to ascertain the cognitive benefits of signalling on visual attention (Ozcelik *et al*., 2009, 2010; Van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009). Additionally, the possible distractive effects of the visual representation of APA on HPK students can be identified using eye-tracking research.

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