The Influence of a Pedagogical Agent on Learners’ Cognitive Load

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ABSTRACT
According to cognitive load theorists, the incorporation of extraneous features, such as pedagogical agents, into the learning environment can introduce extraneous cognitive load and thus interfere with learning outcome scores. In this study, the influence of a pedagogical agent’s presence in an instructional video was compared to a video that did not contain a pedagogical agent. The results indicated no significant differences on a multiple choice learning outcome measure or on a perceived mental effort measure that was rated both after the instructional sequence and after completion of the post-test. In addition, no significant differences were found between groups in relation to their training efficiency or instructional efficiency. Accordingly, the position that the mere appearance of a pedagogical agent in the learning environment increases the cognitive load imposed by a learning task should be re-examined.

Keywords
Pedagogical agent, Virtual human, Cognitive load, Mental effort

Introduction
Virtual characters continue to appear in a multitude of computer-based learning environments. One type of virtual character, the pedagogical agent, continues to be a focus of recent research. The term pedagogical agent refers to a wide range of virtual characters, but they always have a visual presence in the learning environment and their purpose is to help students learn the material (Moreno, 2005; Park, 2015; Yung & Paas, 2015).

While pedagogical agent research has been ongoing for approximately 20 years, researchers have continued to question the efficacy of a pedagogical agent’s ability to facilitate the learning process. While Heidig and Clarebout’s (2011) systematic review found that pedagogical agents often led to no significant differences between groups on learning outcomes, Schroeder, Adesope, and Gilbert’s (2013) meta-analysis found that pedagogical agents can lead to small positive effects on learning outcomes. Despite these findings, the author concurs with Heidig and Clarebout (2011) in that “the question of whether pedagogical agents generally facilitate the learning process is too broad” (p. 30). However, it is important to note that this statement could apply to nearly any type of technology-based learning tool. As such, it continues to be important to examine what types of outcomes various pedagogical agents can influence in the learning environment.

Proponents of pedagogical agents have argued that agents can enhance the social aspects of the multimedia learning environment, thus causing the learner to be more cognitively engaged with the learning materials (Atkinson, Mayer, & Merrill, 2005; Mayer & DaPra, 2012; Mayer, Sobko, & Mautone, 2003). Similarly, researchers have found evidence that the pedagogical agent’s design can influence learning outcomes and learners’ perceptions (Domagk, 2010; Veletsianos, 2007). However, we still do not have definitive guidance as to what features pedagogical agents should have and there are many possible agent implementations yet to be thoroughly investigated.

As with many other technological innovations, the use of pedagogical agents is somewhat controversial. Arguments against their use are typically grounded in cognitive load theory. For instance, Clark and Chi (2007) argued that pedagogical agents may overload a learner’s working memory capacity. This notion is echoed in Wouters, Paas, and van Merrienboer’s (2008) review, which concluded that agents must be designed carefully to avoid overloading the working memory capacity. Similarly, van Mulken, André, and Müller (1998) argued that a pedagogical agent may cause distraction to the learner during the learning process.

Another issue that deserves further attention in the realm of multimedia learning is the pacing of instruction. Most pedagogical agent research has been conducted in learner-paced environments, where the instruction is broken into pre-determined instructional segments (Schroeder, Adesope, & Gilbert, 2013). However, developing this sort of program often requires computer programming skills and time that many instructors do not have. Accordingly, many instructors will host videos on services like YouTube. A YouTube video shares qualities of both learner-paced and system-paced instructional sequences. For instance, the learner can pause and fast-forward – qualities that are similar to a learner-paced environment. However, the instructional sequence is not
segmented and does not pause and wait for learners to click to continue – qualities that are similar to a system-paced instructional sequence. Since some principles of multimedia learning can have differential, or even inverse effects in differently paced environments (Ginns, 2005), it is important to clarify the type of pacing being used. Schroeder and Adesope (2013, 2015) have identified the pacing that occurs in these types of videos as learner-attenuated system-paced (LASP) learning environments. Despite the fact that LASP learning environments are very common in educational settings, limited work exists examining how multimedia learning principles influence learning or perceptive outcomes when learning with pedagogical agents in these environments. To the author’s knowledge, only two studies have examined the use of pedagogical agents in a LASP learning environment (Schroeder & Adesope, 2013, 2015), and neither considered the impact on learners’ cognitive load.

The purpose of this study is to explore the influence of a pedagogical agent on learners’ cognitive load in a LASP learning environment. In the next section, perceived cognitive load, pedagogical agents, and the efficiency of instructional sequences are discussed in relation to their theoretical underpinnings and connected with recent research.

**Literature review**

**Cognitive load theory**

According to theorists, human cognition relies on three essential and interacting components: the working memory, the long-term memory, and organizational structures called schema (Paas & Sweller, 2014; Sweller, 2005). In Paas and Sweller’s (2014) view, the long-term memory acts as an information repository or archive. This archive is organized by structures called schema, which are essentially series of interconnected mental models (Sweller, 2005). However, neither of these structures process new information. New information is processed through the working memory, which can only handle a finite amount of information at once (Paas & Sweller, 2014; Sweller, 2005). While a limited processor sounds like it would interfere with learning, Paas and Sweller (2014) suggested that the limitations actually make it possible for us to process all the information around us in our daily lives.

Cognitive load theorists have described three types of cognitive load a learner may experience during a learning task. These are known as intrinsic cognitive load, extraneous cognitive load, and germane cognitive load. Intrinsic cognitive load is caused by the level of complication of the learning material itself, which means that it varies for each individual learner (Kalyuga, 2011; Paas & Sweller, 2014; Sweller, 2005, 2010). The more complex the information is, and the more pieces or chunks of information that must be processed at one time in order to understand the content, the more intrinsic cognitive load the material causes (Sweller, 2010). However, poorly designed instructional sequences can also cause learners to exert more mental effort to learn the material than should have been required, from processes such as complicated visual searches for salient information or content which is presented physically distant from relevant images (Kalyuga, 2011; Paas & Sweller, 2014; Sweller, 2005, 2010). Theorists have termed the mental effort required for these tasks as being due to extraneous cognitive load. Finally, germane cognitive load is due to the mental effort required to actually integrate the new information into meaningful knowledge structures for that learner (Kalyuga, 2011; Paas & Sweller, 2014; Sweller, 2005, 2010). For a visual representation of how the above concepts may interact during a learning task see Paas, Tuovinen, Tabbers, and Van Gerven (2003, see Figure 1).

For many years researchers have created measures to examine what features within educational environments may cause intrinsic, extraneous, or germane cognitive load. However, many attempts to create such instruments have been criticized, and scholars have posited it may not be possible to measure each type of cognitive load individually (Kirschner, Ayers, & Chandler, 2011; Sweller, 2010). However, the mental effort scale (Paas, 1992) has been used for decades without many objections (Kirschner et al., 2011).

Paas’s (1992) mental effort scale is a one-item measure of perceived mental effort and it has been broadly used as an indication of the cognitive load a learner experienced. The measure has also been used to calculate how efficient an instructional condition is (see Paas & van Merriënboer, 1993). However, Paas et al. (2003) noted that researchers had not been using the measure of cognitive load in the efficiency calculation as it was initially intended. Paas and van Merriënboer (1993) intended for mental effort to be measured after the problem solving phase of the research study, which leads to a calculation known as instructional efficiency. Paas et al. (2003) found that many researchers were instead using standardized scores of mental effort ratings measured after the instructional sequence, but before problem solving. This calculation, while nearly identical mathematically, leads to a different outcome Paas et al. (2003) classified as training efficiency. While the nuance between the two types
of efficiency seems minor – stemming from when mental effort was measured – it impacts the interpretation of the results. While instructional efficiency refers to the mental effort required to solve the problems, training efficiency refers to the mental effort required to learn the material from the intervention. Fundamentally these are similar, yet different measures. Until recently, neither efficiency measure had been considered in relation to pedagogical agent research.

**Previous research with pedagogical agents and cognitive load measures**

Few pedagogical agent researchers have examined the influence of virtual characters on learners’ cognitive load outcomes compared to non-agent conditions (see Schroeder & Adesope, 2014). Most that have examined cognitive load outcomes used measures such as perceived ease (Frechette & Moreno, 2010) or perceived difficulty (Atkinson, 2002; Moreno, Mayer, Spires, & Lester, 2001). Fewer yet have calculated the training efficiency or instructional efficiency of the intervention. The author is aware of only two studies in which researchers have examined some form of efficiency when learning with pedagogical agents compared to non-agent conditions.

Choi and Clark (2006) examined the cognitive efficiency of learning with a pedagogical agent compared to a non-agent condition. However, it is important to note that they used a different formula than Paas and van Merriënboer (1993). In one condition, learners worked with a pedagogical agent that signaled their attention to appropriate parts of the screen. In the control condition, the learners had the same learning environment, except arrows replaced the virtual character. Their results showed that there were no significant differences on the cognitive efficiency outcomes between the two groups.

More recently, Yung and Paas (2015) compared the use of a pedagogical agent to a non-agent condition when teaching students about certain aspects of the circulatory system. The agent used visual cues, such as pointing, to help guide the learners’ attention to relevant items on the screen. In their analysis, they examined instructional efficiency using Paas and van Merriënboer’s (1993) formula. Their analysis of the results indicated that learners in the pedagogical agent condition had a significantly better relationship between their self-reported mental effort and their performance scores, meaning that the environment that contained a pedagogical agent was more efficient than the non-agent condition (Yung & Paas, 2015).

As shown, limited research examines the efficiency of pedagogical agents, as well as their impact on cognitive load outcomes in general. Similar to findings around learning outcomes, research around the cognitive load implications of including a pedagogical agent in the learning environment has produced mixed results (Schroeder & Adesope, 2014). Thus, more work is needed to understand to what extent pedagogical agents influence cognitive load outcomes and the training and instructional efficiencies of an intervention.

**Research questions**

It is clear that more systematic research is needed to understand how, to what extent, and under what circumstances pedagogical agents can influence learning outcomes. Similarly, it is apparent that we know little about what the inclusion of a pedagogical agent means in relation to cognitive load outcomes, yet concerns about the introduction of extraneous cognitive load are a primary reason why agents are often cited as unimportant, or even potentially ineffective, in the learning environment.

Due to the aforementioned gaps in the extant literature, this study sought to examine the influence of a pedagogical agent in a LASP learning environment through the investigation of the following research questions:

- **RQ1** - How does the inclusion of a pedagogical agent influence learners’ cognitive outcomes compared to a non-agent condition?
- **RQ2** - How does the inclusion of a pedagogical agent influence learners’ self-reported mental effort compared to a non-agent condition?
- **RQ3** - How does the inclusion of a pedagogical agent influence learners’ training efficiency compared to a non-agent condition?
- **RQ4** - How does the inclusion of a pedagogical agent influence learners’ instructional efficiency compared to a non-agent condition?
Methods

Participants

The participants in this study were 75 pre-service teachers at a public university in the United States. Six participants’ scores were removed due to missing data. Hence, 69 participants’ scores were examined. The average age of the participants was 21 years old \((SD = 4.105)\) and 84% were female. The participants were low prior knowledge learners, with 92.8% reporting that they’d never received any formal instruction around multimedia learning theory. Furthermore, no participants scored any points on the pre-test \((M_{overall} = 0.00, SD_{overall} = 0.00)\). The participants were randomly assigned to either the control group \((n = 33)\) or the experimental group \((n = 36)\).

Computer-based materials and design

The learning materials for this study consisted of a 486 word narrative presented by a recorded human male voice. The narrative was a slightly expanded version of the narrative used in Schroeder and Adesope (2013, 2015). The background consisted of six slides designed to provide a low-verbal redundancy learning environment. In other words, the main ideas were summarized on each slide in typical bullet point design, but the text did not align verbatim with the spoken narration.
The pedagogical agent-based learning environment was created using a combination of Microsoft Powerpoint, Media Semantics Character Builder software by Media Semantics Inc. (see http://mediasemantics.com/), and Camtasia Studio 8 by TechSmith Corporation (https://www.techsmith.com/camtasia.html). In the control condition (Figure 1), learners viewed a LASP video that was essentially a voice-over Powerpoint presentation. In the experimental condition (Figure 2), the virtual human remained stationary in the lower-right hand corner of the screen. In order to reduce confounding variables, the agent did not move or gesture, however it did have its lips synchronized to the narrative to create the illusion of a more life-like character. The survey was implemented using Qualtrics, an online survey software. The LASP instructional video was hosted on YouTube and then embedded into the Qualtrics survey.

Pre-test

The pre-test consisted of the same three free-response knowledge questions as in Schroeder and Adesope (2013, 2015). The questions were, “State six things you know about cognitive load theory,” “Describe the split-attention principle,” and “Describe the modality principle.” Scoring followed the same procedures as Schroeder and Adesope (2013, 2015), and there was a maximum score of 14 points available. For the first question regarding cognitive load theory, points were issued for correctly identifying (1 point) or describing (1 point) germane, intrinsic, or extraneous cognitive load, as well as the long-term memory, schema, or working memory (Schroeder & Adesope, 2013, 2015). The second and third questions were each worth one point, which was earned by correctly describing the principle in question (Schroeder & Adesope, 2013, 2015).

Post-tests

There were three post-tests involved in this study. The first measure was the mental effort rating scale developed by Paas (1992). In this case, the wording of the item was slightly modified to be more appropriate to having just completed viewing an instructional video. The item was stated as, “In studying the preceding video I invested” and was answered through a 9-point Likert scale ranging from very, very low mental effort through very, very high mental effort.

The second measure was a 30-item multiple choice test. The measure was very similar to the instrument used in Schroeder and Adesope (2013, 2015), and measured the major concepts presented in the narrative. In an effort to establish rudimentary validity evidence for the measure, it was reviewed by a faculty member familiar with the concepts presented in the script. The internal consistency reliability was found to be α = .75.

The final measure was Paas’s (1992) original mental effort instrument. The item was answered through a 9-point Likert scale ranging from very, very low mental effort through very, very high mental effort.

Procedure

The study took place in a classroom that contained one desktop computer for each student. Headphones were provided to the participants if necessary. Participation in the study was optional and learners were not compensated for participating. Overall, participating took approximately 30 minutes.

Participants first completed the demographic questions, followed by the pretest. After the pretest, they either watched an instructional video containing a pedagogical agent or one that did not, depending upon the experimental condition they were assigned to. After viewing the video, the participants answered the modified version of Paas’s (1992) mental effort scale, followed by the multiple choice measure, and then finally Paas’s (1992) original mental effort scale. The researcher was present throughout the duration of the data collection.

Results and discussion

In this section, the results of the study are addressed and discussed in relation to each research question and previous research.
RQ 1 – How does the inclusion of a pedagogical agent influence learners’ cognitive outcomes compared to a non-agent condition?

An independent t-test was conducted to examine if any differences existed between groups’ learning outcome scores. Levene’s test for equality of variances was significant $F = 4.520$ ($p = .037$), and thus equal variances were not assumed. The results of the independent t-test showed no significant differences between groups $t(66.14) = .021$ ($p = .983$). As shown in Table 1, the means of both groups were nearly identical.

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Table 1. Means and standard deviations of learning outcomes for each group

The finding of no significant differences between groups on learning outcomes is consistent with some other studies investigating the effectiveness of a pedagogical agent compared to a non-agent condition (Heidig & Clarebout, 2011). In this case, the result was somewhat expected due to the fact that the agent did not do anything to specifically facilitate the learning process. Rather, in order to minimize confounding variables, the pedagogical agent just stood next to the content and provided narration. Thus, these results show support of the “Persona Zero-Effect” (Miksatko, Kipp, & Kipp, 2010, p. 3) in that the pedagogical agent’s presence did not significantly influence learning outcomes.

RQ 2 – How does the inclusion of a pedagogical agent influence learners’ self-reported mental effort compared to a non-agent condition?

As mentioned, the learners’ self-reported mental effort was measured at two separate points in time in order to differentiate training efficiency from instructional efficiency. To examine this research question, the raw scores of the mental effort measures themselves are examined.

In relation to the self-reported mental effort scores measured directly after watching the instructional video, the examination of the data indicated that it was not normally distributed. Squareroot, log, and reciprocal transformations failed to improve the normality of the distribution. Accordingly, non-parametric statistics were used to analyze the data. Despite the fact that the experimental group’s mean score reflects that learning from the instructional video required slightly less mental effort than the control group (Table 2), the results of a Mann-Whitney test revealed that there were no significant differences between the control group ($Mdn = 5.00$) and the experimental group’s ($Mdn = 5.00$) scores, $U = 541.50$, $z = -.656$, $p = .512$, $r = -.079$.

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Table 2. Means and standard deviations of perceived mental effort for each group immediately after the instructional video

Self-reported mental effort scores were also examined from when the learners finished the multiple choice test. Preliminary analysis of the data indicated that the data were normally distributed. Hence, an independent samples t-test was used to test for any significant differences between groups. Levene’s test showed equal variances could be assumed $F = .014$ ($p = .907$). Analysis of the results showed that while the experimental group reported a higher mean mental effort required to solve the problems (Table 3), this effect was not statistically significant ($t(67) = -1.404$, $p = .165$).

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Table 3. Means and standard deviations of perceived mental effort for each group immediately after problem solving

While at first glance non-significant results may seem unimportant, in this case they are actually quite enlightening. As previously mentioned, arguments against the incorporation of pedagogical agents generally hinge on the notion that pedagogical agents have the potential to increase the extraneous cognitive load present within the learning environment (Clark & Choi, 2007; van Mulken, André, and Müller, 1998; Wouters, Paas, &
van Merriënboer, 2008). Presumably, the concern is that the agent is a distraction from the learning materials (van Mulken, André, & Müller, 1998). In this study the agent was not designed to facilitate learning in any specific way through gesture, rather it was merely present throughout the video. Hence, if agents were a source of distraction to the extent some seem to imply, it is plausible this would have been reflected in the mental effort scores. It must be stated however, that the agent used in this study did not use gestures, move across the screen, or otherwise try and cause a distraction from the learning content. Thus, the results of this study show that the mere incorporation of a pedagogical agent may not necessarily increase the cognitive load imposed by a LASP learning environment, but the author reiterates Wouters et al.’s (2008) comment that agents should be carefully designed. In the future researchers should explore the impact of an agent that signals, gestures, or otherwise moves or interacts with the learner (i.e., the agent should do more than simply provide the narrative) to examine the impact on cognitive load outcomes. However, in such a study it would be important to minimize confounding variables between conditions.

RQ 3 – How does the inclusion of a pedagogical agent influence learners’ training efficiency compared to a non-agent condition?

First, the standardized scores were calculated from both the self-reported mental effort after watching the instructional video as well as the multiple choice test. The scores were then entered into Paas and van Merriënboer’s (1993) formula.

An independent samples t-test was used to compare the two groups’ scores (Table 4). Levene’s test showed that equal variances could be assumed (F = 2.91, p = .093). The results showed that there were no significant differences between groups (t(67) = -.331, p = .742).

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To the author’s knowledge, no other studies investigating pedagogical agents compared to non-agent conditions have calculated training efficiency, so it is difficult to draw many conclusions based on one study. However, since the differences between groups did not reach statistical significance, it is safe to say that the mere incorporation of a pedagogical agent into the LASP learning environment did not hinder nor benefit the learners’ training efficiency. Reconsidered, including a pedagogical agent may not necessarily make the content easier for the students to learn from a LASP instructional video. Thus, as advised by other scholars, pedagogical agents should be carefully designed (Veletsianos, Miller, & Doering, 2009; Wouters et al., 2008), yet more research needs to be conducted to examine how different features agents may possess, such as signaling to relevant information, influence the training efficiency.

RQ 4 – How does the inclusion of a pedagogical agent influence learners’ instructional efficiency compared to a non-agent condition?

First, the standardized scores were calculated from both the self-reported mental effort after completing the multiple choice test as well as the multiple choice test itself. The scores were then entered into Paas and van Merriënboer’s (1993) formula.

An independent t-test was used to examine if differences existed between the two groups (Table 5). Levene’s test showed that equal variances could be assumed (F = .203, p = .654). The results showed that there were no significant differences between groups (t(67) = 1.041, p = .301).

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As mentioned, to the author’s knowledge only one study has examined the instructional efficiency of a pedagogical agent compared to a non-agent condition. The results of this study are contrary to Yung and Paas’s (2015) findings. Yung and Paas (2015) found that a pedagogical agent significantly improved the instructional
efficiency of the environment compared to the non-agent condition. Presumably, this is due to the difference in agent features between the studies. In this study, the agent was relatively static, while in Yung and Paas’s (2015) study the agent signaled the learner’s attention through gestures. Since the signaling principle and its benefits for learning and reducing extraneous cognitive load are relatively well established (Mayer & Fiorella, 2014), it should not be surprising that the signaling agent in Yung and Paas’s (2015) study had a more favorable instructional efficiency than the non-agent condition. A useful next step would be to conduct a study comparing a static agent to an agent that gestures to examine if the gestures used to signal content are what influence the instructional efficiency, or if the difference in results is attributable to some other difference between the studies.

Conclusion

This study marks a preliminary attempt to comprehensively examine the cognitive load implications of including a pedagogical agent into a LASP learning environment. The results of this study have implications for both theory and practice.

In relation to cognitive load theory, this study adds to the literature around training efficiency and instructional efficiency. As mentioned, these measures are rarely used in the context of pedagogical agents. The results of the study show that the incorporation of a relatively static agent did not significantly influence cognitive load outcomes, training efficiency, or instructional efficiency. Thus, an agent does not necessarily make the content easier to learn, nor make the problem solving process any more difficult. However, more work is needed to examine the different features pedagogical agents may possess, such as signaling, movement, and the ability to demonstrate tasks in order to examine if they have any influence on cognitive load outcomes or measures of efficiency.

For those considering implementing an agent, the results of this study indicate that the mere incorporation of an agent does not necessarily increase the cognitive load of a LASP learning environment. Hence, choosing to incorporate an agent will not necessarily impede student learning. Rather, evidence from recent reviews suggests that the incorporation of an agent will either not make a significant difference to learning outcomes (Heidig & Clarebout, 2011) or may even facilitate learning outcomes (Schroeder et al., 2013). In fact, Moreno (2005) stated that no studies had found that a pedagogical agent impeded learning compared to a non-agent condition. Despite these findings, the author reiterates calls for the thoughtful design of pedagogical agents (Wouters et al., 2008, Veletsianos et al., 2009). As Veletsianos et al. (2009) stated, “pedagogical agent integration in educational settings should be guided by the added-value opportunities that agents present for enhancing the social, pedagogical, and technological opportunities provided to learners” (p. 179). Hence, while we have not yet uncovered many specific features that help agents to be widely effective in different content domains, these features may become apparent if researchers continue to systematically investigate agents that add value to the learning environment rather than merely are present.

In closing, the findings of this study must be interpreted with the understanding of the inherent limitations of its design. First, the study used a type of pacing rarely examined in pedagogical agent research. Thus, a similar study should be conducted in a learner-paced environment to see if the results are transferrable. Similarly, the content of the learning sequence was conceptual in nature rather than procedural. Due to this, similar studies should be conducted with learning materials that require procedural knowledge to see if any significant differences are found. In addition, the instructional sequence was relatively short in duration. Future research should be conducted with learning materials that require a longer period of student interaction with the content and the pedagogical agent. Finally, this study did not examine the influence of a well-designed pedagogical agent meant to specifically facilitate learning in any meaningful way. In short, the agent was present, but did not gesture to important content or otherwise signal the learners’ attention. Being that increasing the pedagogical affordance of the learning environment is a key notion behind pedagogical agent implementation, it would be salient to examine the influence of a well-designed pedagogical agent compared to a static agent. This question was outside the scope of this study, but would provide important considerations for pedagogical agent researchers.

References


