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HOW EFFECTIVE ARE PEDAGOGICAL AGENTS FOR LEARNING? A META-ANALYTIC REVIEW

NOAH L. SCHROEDER
OLUSOLA O. ADESOPE
RACHEL BAROUCH GILBERT
Washington State University

ABSTRACT

Research on the use of software programs and tools such as pedagogical agents has peaked over the last decade. Pedagogical agents are on-screen characters that facilitate instruction. This meta-analysis examined the effect of using pedagogical agents on learning by reviewing 43 studies involving 3,088 participants. Analysis of the results indicated that pedagogical agents produced a small but significant effect on learning. The overall mean effect size was moderated by the contextual and methodological features of the studies. The findings revealed that the use of pedagogical agents were more beneficial for K-12 students than post-secondary students. Pedagogical agents that communicated with students using on-screen text facilitated learning more effectively than agents that communicated using narration. The findings of this study have implications for advancing theory and practice, as well as highlighting productive future directions for research.

INTRODUCTION

Innovative educational technology tools have great promise for improving learning, yet they are often not utilized to their full potential (Moreno, Mayer, Spires, & Lester, 2001). For example, Moreno et al. (2001) suggested that it is common for these tools to inadvertently take the role of books, conveying large

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amounts of textual information. Attempts to utilize more of technology's capabilities have led researchers to investigate instructional software tools such as pedagogical agents (Figure 1) and intelligent tutoring systems. Pedagogical agents are on-screen characters that facilitate instruction to the learner (Adcock & Van Eck, 2005; Choi & Clark, 2006; Craig, Gholson, & Driscoll, 2002; Gulz, 2004; Johnson, Rickel, & Lester, 2000; Moreno, 2005; Veletsianos & Miller, 2008). Pedagogical agents can be as simple as static characters which respond through visual stimuli, such as text on the screen, to as complex as life-like three-dimensional characters which can provide visual signaling through gestures and body language, as well as auditory cues through narration. Intelligent tutoring systems have a knowledge base and are able to provide adaptive feedback to the learner based on their prior knowledge. By definition pedagogical agents are not artificially intelligent, but they can potentially be combined with intelligent tutoring systems. Pedagogical agents, if combined with intelligent tutoring systems, could provide customized, responsive classes and curricula to individual students. For example, an intelligent tutoring system which utilizes a conversational agent (AutoTutor) has produced improvements in learning scores of almost one letter grade (Graesser, Chipman, Haynes, & Olney, 2005).

Moreno's (2005) review of the literature noted that numerous researchers have investigated the effects of pedagogical agents on learning. Moreover, multiple names for such effects exist, such as "the *persona effect* (Lester, Towns, & Fitzgerald, 1999), *personal agent effect* (Moreno et al., 2001), or *embodied agent effect*" (Atkinson, 2002, p. 508). Research on the effects of pedagogical agents on learning has produced mixed results. For example, Moreno's (2005) and Mayer's (2005b) reviews suggested that pedagogical agents may be beneficial for learning, while Heidig and Clarebout's (2011) review found that pedagogical agent studies generally haven't provided statistically significant differences for learning outcomes. However, researchers have observed that the mixed results within pedagogical agent research are warranted considering the different features of agents, varying learner characteristics, and the contextual features of research (Heidig & Clarebout, 2011). Hence, this meta-analysis examined a broad range of participants, agent features, and contextual as well as methodological features of the primary studies to more carefully understand the varying conditions under which pedagogical agents can either enhance or inhibit learning.

THEORETICAL BACKGROUND AND LITERATURE REVIEW

Pedagogical agent research has been driven by contemporary educational and multimedia theories, with a strong foundation grounded in traditional psychological theories of human cognition. Before synthesizing pedagogical agent studies, we review the literature guiding the design and implementation of pedagogical agents for learning.

Figure 1. A pedagogical agent learning environment used in Lusk and Atkinson (2007, p. 754).

The Presence Principle

Mayer, Dow, and Mayer (2003a) succinctly defined the presence principle by stating "people do not learn better when an agent is physically present on the screen. Although the agent's voice is important for improving learning, the agent's physical image is not" (p. 811). This claim was further substantiated by Moreno et al.'s (2001) study, which found that "the agents' visual presence did not provide any cognitive or motivational advantage" (p. 209). Rather, Mayer et al. delineated that the agent's image is merely a seductive detail, something which is ignored or is distracting.

Moreno (2005) suggested that learners may begin to ignore the pedagogical agent over time. However, Louwerse, Graesser, McNamara, and Lu's (2008) eye-tracking study found that participants spent 56% of their time looking at the agent, even though the agent comprised only about one fourth of the screen. These findings suggest that a pedagogical agent is not ignored by the learner, and may provide a source of distraction during the learning task. However, van Mulken, André, and Muller (1998) suggested that while agents may be distracting, they can also provide a motivational benefit. Moreno concluded that if the motivation is greater than the distracting effects, learning may be facilitated.

In sum, the evidence surrounding the effect of pedagogical agents in multimedia learning environments is conflicting (Domagk, 2010). While some experimental pedagogical agent studies have found that a pedagogical agent's presence facilitates learning (e.g., Dunsworth & Atkinson, 2007), others found no significant effect (e.g., Mayer et al., 2003a; Moreno et al., 2001).

Social Agency Theory

Moreno et al. (2001) argued that "students learn a computer-based lesson more deeply when it is presented in a social agency environment than when it is presented as a text and graphics source" (p. 209). Social agency theory suggests "that social cues in a multimedia message can prime the social conversation schema in learners" (Louwerse, Graesser, Lu, & Mitchell, 2005; Mayer, Sobko, & Mautone, 2003b, p. 419). As such, researchers have suggested that once the learner realizes a social interaction is taking place, they feel as though they must employ human-human social interaction rules (Mayer et al., 2003b) because they see the computer as a social partner (Louwerse et al., 2005). These interactions include selecting information, organizing it, and integrating it with prior knowledge (Mayer et al., 2003b). However, researchers have suggested that continually adding social cues to a multimedia environment does not necessarily equate to more social agency (Louwerse et al., 2005).

Proponents of pedagogical agents have argued that by anthropomorphizing the computer system, or making it more human-like, students may be more motivated to learn (Kim & Ryu, 2003). For example, multimedia research has found that a standard, human voice will facilitate learning more than a non-standard voice (Atkinson, Mayer, & Merrill, 2005; Mayer, 2005b; Mayer et al., 2003b). Specifically working with pedagogical agents, Kim, Baylor, and Shen (2007) found that learners saw the agents as social models, expecting their agent to have a personality. Similarly, eye-tracking research with pedagogical agents indicated that people perceived agents as conversational partners (Louwerse et al., 2008). Veletsianos, Miller, and Doering (2009, p. 174) summarized that, ". . . interaction between humans and computers is expected to approximate social interactions between humans and humans." This claim implies that people may become engaged in the conversation with the agent similar to a learner-teacher interaction, or even learner-learner interaction. In sum, since the student perceives the interaction of the computer as social and begins the "*sense making process*" (Atkinson et al., 2005, p. 119), or the process of deeper understanding, then this may increase the possibility of transfer (Atkinson et al., 2005).

Cognitive Load Theory and the Split-Attention and Modality Principles of Multimedia Learning

Researchers have suggested that human cognition is centralized around the long-term memory (Kirschner, Sweller, & Clark, 2006; Sweller, 2005). Cognitive load theory addresses the individual's cognitive ability to receive new information and integrate it into the long-term memory due to working memory limitations.

Cognitive load theorists have designated three types of cognitive load: germane, intrinsic and extraneous (Paas, Renkl, & Sweller, 2003; Sweller, 2005, 2010). Germane cognitive load can be thought of as "effective cognitive load" (Paas, Renkl, & Sweller, 2003; Paas & Van Merrënboer, 1994; Sweller, 2005, p. 27) which is the result of schemas being constructed and new information being acquired (Sweller, 2005). Intrinsic cognitive load is due to the inherent complexity of the material being learned (Paas et al., 2003; Sweller, 2005). Intrinsic cognitive load can either be low or high depending on the material being learned and its interaction with prior knowledge (Sweller, 2005, 2010). Thus, intrinsic cognitive load may vary for each individual. Finally, Sweller (2005, 2010) suggested that extraneous cognitive load is caused by poor instructional design, and thus is the cognitive load that is not related to the actual material to be learned, but rather its presentation to the learner.

Cognitive load theory has direct implications for pedagogical agent design due to the agent's appearance on the screen, as well as the visual and auditory cues the agent may utilize. It has been argued that the agent's presence, gestures, appearance, or voice could make the display too rich to easily process, and thus cause extraneous cognitive load (Clark & Choi, 2007). However, Sweller (2005) suggested that when familiar information is presented to the working memory it does not affect the working memory's capacity. Thus, it is plausible that the cognitive load imposed by a pedagogical agent may decrease over time as long as its salient features such as gestures, movements, voice, and facial expressions remain consistent. Hence, while pedagogical agents may at first cause extraneous cognitive load due to an unfamiliar voice, movement, or appearance, as the learner is continually exposed to the agent, the cognitive load caused by the agent becomes germane and the pedagogy they facilitate may become more effective. Moreno (2005) supported this notion, suggesting that over time learners may begin to process the agent's image to a lesser degree.

Research surrounding the split-attention principle has suggested that materials presented to learners should not be in a format which makes them split their attention between two or more different sources of information; rather, the information should be integrated (Ayers & Sweller, 2005). Theoretically, this principle presents an issue in pedagogical agent research because of the agent's presence on the screen. Louwerse et al.'s (2008) eye-tracking study found that even when pedagogical agents only make up around one-fourth of the display, they still commanded the majority of the learner's visual attention, and more so than chance alone would dictate.

Interestingly, Moreno (2005) noted that eight pedagogical agent studies have failed to replicate results that align with the split-attention principle. Rather, Moreno hypothesized that students may begin to ignore the agent, or process the image to a lesser degree as they become more familiar with it being on the screen. Considering Moreno's claim, the results from Louwerse et al.'s (2008) eye tracking study, then relating the data to cognitive load theory, the element of distraction seems to be minimized. While Louwerse et al.'s findings clearly suggest that pedagogical agents maintain student attention, cognitive load theory suggests that after the initial viewing the student's memory recognizes the agent, and thus its processing requires no working memory resources. In sum, findings suggest that learners do split their attention between the agent and the learning material (Louwerse et al., 2008). However, pedagogical agent research has not reflected the split-attention principles deleterious effects on learning (Moreno, 2005).

Another principle explained by cognitive load theory is the modality principle. The modality principle states that working memory capacity can be expanded in certain situations by presenting some information visually and other information through auditory means (Low & Sweller, 2005). This principle aligns well with Mayer's (2005a) description of the "sensory-modality approach" (p. 34) to the dual channel assumption, in which he describes that learners take in new information through their eyes and their ears separately.

Ginns' (2005) meta-analysis found a moderate to large effect size in support of the modality principle. These findings are further supported by Moreno's (2005) review, which noted that the modality principle has been supported by six experiments involving pedagogical agents. However, the obvious contradiction between principles still remains: can pedagogical agents support the modality principle without creating a split-attention effect?

Research Questions

Over the past 2 decades, pedagogical agents have been studied for their effectiveness in facilitating learning. Researchers have found mixed results of the effects of pedagogical agents on learning outcomes (Domagk, 2010). A narrative review of the literature revealed that most pedagogical agent studies have found no significant differences in learning outcomes (Heidig & Clarebout, 2011). Hence, the purpose of this study was to conduct a meta-analysis to reconcile the mixed results. Meta-analyses are useful for systematically reviewing the body of literature and resolving variable findings through moderator analyses. Additionally, the use of meta-analysis affords the reporting of effect sizes and examination of the magnitude of the effect sizes under varying contextual and methodological conditions. Specifically, the meta-analysis addresses the following research questions:

1. Do pedagogical agents enhance learning when compared with non-agent systems?
2. How are the effects of learning with pedagogical agents moderated by the modality of communication, the agent's form, the type of voice used, and the level of animation the agent embodies?
3. How do the effect sizes of learning with pedagogical agents vary by subject domain, educational level, prior domain knowledge, the study setting, and the pacing of the learning system?

METHODOLOGY

The meta-analytical approach used in this study was based on the general procedures for synthesizing research outlined by Cooper and Hedges (2009). The meta-analysis was conducted in three phases. Phase I was the initial search for literature, Phase II was the secondary literature search and data coding, while Phase III was the analysis of the data and discussion of the results.

After defining the problem and the research questions, the inclusion criteria were determined to locate studies that examine the use of pedagogical agents for learning. In order to be included in the meta-analysis, each study had to meet the following inclusion criteria:

a) contrast the learning benefits of a pedagogical agent to a non-pedagogical agent learning system (no agent present at any point);
b) measure cognitive learning outcomes such as retention, transfer, or free recall;
c) report sufficient data to allow an estimation of standardized mean difference effect size;
d) publicly available (through databases, journals or library archives);
e) reported in English language; and
f) the agent played a role in instruction: for example, if an agent provided instructions or information to the learner, then it was considered playing a role in instruction; however, one agent was merely present on the screen as a seductive detail and did not provide instruction nor any process related to instruction, and as such, was not included in this analysis (Rickenberg & Reeves, 2000).

Phase I—Literature Search

In order to locate the studies needed for this meta-analysis, online database searches were conducted with the key terms "pedagogical agent*" OR "conversational agent*."[1] These terms were chosen based on keywords provided by the

[1] The asterisk in the search terms was used to capture studies which used a term including the word "agent." For example, studies with key terms "agent," "agents," and "agentic" were all captured with the search.

authors of published pedagogical agent studies. Electronic databases searched were: Academic Search Premier, Citeseer, ERIC, IEEE Xplore, PsycARTICLES, PsycBOOKS, PsycCRITIQUES, PsycINFO, and Web of Science. Additionally, we searched the 2011 meeting of the American Educational Research Association online repository, and the references of recent review articles were manually searched (e.g., Gulz, 2004; Kim & Ryu, 2003; Moreno, 2005). This exhaustive search of literature produced 576 research abstracts.

The articles' online titles and abstracts were examined to see if they met the required inclusion criteria. In cases where it was impossible to determine the eligibility of articles for inclusion or exclusion by reading the abstracts, full-text copies of such articles were obtained and the methodology and results sections of the articles were examined. If the study's eligibility was still in question it was retained to be examined in Phase II.

Phase II—Secondary Literature Search and Data Coding

The second phase began with 103 sources that passed the first selection phase. The full text copies of these 103 sources were then obtained and examined to see if they met all the inclusion criteria. Those that met the inclusion criteria were then entered into the coding form.

The coding form was developed specifically for this meta-analysis using IBM® SPSS® Statistics software (version 18). The form contained nine major categories of variables: (a) study authors and year, (b) contextual features of the study, (c) research design, (d) sampling strategy, (e) characteristics of participants, (f) recruitment methods, (g) data collection, (h) data analysis, and (i) results.

Descriptive statistics were used to calculate the effect sizes. If the descriptive statistics were not available, then other statistics, such as the t or F statistics, were used to calculate the effect sizes. If multiple versions of the same study appeared in the search, the journal publication was coded and other versions were utilized to create a more accurate coding form. We used Hedges' g, a weighted mean effect size that allows for correction of small samples.

To maintain statistical independence, each individual participant's score was only considered once during the analysis. For example, Craig, Gholson, and Driscoll (2002) utilized three groups of participants in experiment one (agent with gesture, agent only, and no agent groups). The agent only group's scores were averaged with the agent with gestures group scores, and then compared to the no agent group. While we acknowledge that learners may perceive and interact with the two agent groups differently, we feel as though this method allowed for the most informed analysis of the agent groups while also ensuring that the no agent group's participants were not considered twice. Furthermore, where possible, comparisons were made between similar groups to determine if the agent's image affected learning. For example, in Atkinson's (2002) study, the text only group was compared to the text and agent group rather than the voice and agent group. Doing so allows the most accurate comparison possible to isolate only the effect of the agent's image, rather than other features of the software.

Data were coded by two independent researchers. The first researcher coded all the studies. The second coder is an experienced meta-analyst and randomly selected and coded approximately 25% of the included studies, producing a Cohen's kappa inter-rater reliability of .95. When differences were found between coded variables, the researchers discussed the issue until a common resolution was found. In some cases, researchers requested clarification from primary authors regarding variables that could not be explicitly coded.

Phase III—Data Analysis

Data were analyzed using Comprehensive Meta-Analysis version 2.2.048 (Borenstein, Hedges, Higgins, & Rothstein, 2008) and IBM® SPSS® Statistics software (version 18). The *Q* statistic was used to determine heterogeneity amid the sampled study properties. Borenstein, Hedges, Higgins, and Rothstein (2009) made the important distinction that the *Q* statistic and *p*-value is utilized for testing the null hypothesis, and should not be used to estimate the true variance. In other words, if there is a significant *p* value that is very low, for example $p < .001$, it does not indicate greater heterogeneity than a *p* value of $p < .049$. If the *p* value delineates that the *Q* statistic is statistically significant ($p < .05$), it indicates that heterogeneity exists (Borenstein et al., 2009; Lipsey & Wilson, 2001) and moderator analysis is needed (Lipsey & Wilson, 2001). Moderator analysis allowed for the determination of how different features of pedagogical agents benefited or inhibited learning. Finally, the I^2 statistic shows the variation that is not due to chance, but rather the heterogeneity of the sample (Higgins, Thompson, Deeks, & Altman, 2003). Higgins et al. suggested that a low I^2 value indicates that the variance is insignificant, while increasing I^2 values indicate heterogeneity. Higgins et al. delineated that a value of 25% represents a low I^2 statistic, 50% represents a medium I^2 statistic, and 75% represents a high I^2 statistic.

Methodological Outcomes

The first inclusion phase retained 103 qualified articles for further examination, of which 28 were coded in phase two after meeting all the selection criteria. These 28 articles produced 43 studies across 3,088 participants. Some articles allowed for the extraction of more than one study by including more than one experiment, or utilizing an experimental design where more than one agent group and more than one control group were present.

One study (Cheng, Chen, Huang, Weng, Chen, & Lin, 2009) yielded an unbiased mean effect size of $g = 2.94$ and was determined to be an outlier ($Z > 3.0$). The effect size was not deleted from the analysis because a reexamination of the study did not indicate any methodological flaws. As such, it was adjusted to a lower value ($g = 1.00$) which was slightly greater than the next-largest effect size ($g = .87$) as suggested by Tabachnick and Fidell (2007).

RESULTS

Research Question 1: *Do pedagogical agents enhance learning when compared with non-agent systems?*

Table 1 shows that the overall effect of learning with pedagogical agents was small but statistically significant ($g = .19$, $p < .001$). The Q statistic showed that the overall sample was heterogeneous, Q (42) = 73.62, $p < .05$. The I^2 statistic of 42.95 indicated that the variability among the effect sizes was greater than that expected from sampling error. As such, moderator analysis was conducted to examine the effects of learning with pedagogical agents under varying conditions. The outcomes of each study, methodological features of each study, and contextual features of each study can be found in Appendices A, B, and C, respectively.

Research Question 2: *How are the effects of learning with pedagogical agents moderated by the modality of communication, the agent's form, the type of voice used, and the level of animation the agent embodies?*

Table 2 shows the statistically significant difference found between groups for the modality of communication ($Q = 14.53$, $p < .05$). Pedagogical agents which communicated through on-screen text produced a moderate effect size of $g = .51$ ($p < .05$). Studies in which the pedagogical agents provided narration produced a small but statistically significant mean effect size ($g = .12$, $p < .05$). These findings contradict the modality principle of multimedia learning (Ginns, 2005; Low & Sweller, 2005; Mayer, 2005c; Moreno, 2005); however, studies which utilized agents communicating through on-screen text ($k = 8$) comprised only 12% of the participants in the analysis. Noteworthy is that the confidence interval does not

Table 1. Overall Effect Size of Pedagogical Agent Learning Systems

	Effect size and 95% confidence interval						Heterogeneity	
Model	*N*	*k*	*g*	SE	Lower limit	Upper limit	*Q*-value	I^2
Overall	3,088	43	0.19*	0.04	0.12	0.27	73.62*	42.95

*$p < .05$.

Table 2. Effect Sizes of Pedagogical Agent Features

	Effect size and 95% confidence interval						Heterogeneity	
	N	*k*	*g*	SE	Lower limit	Upper limit	*Q*-value	*p*
Modality effect								
Text	384	8	0.51*	0.10	0.31	0.72	11.26	0.13
Narration	2,427	32	0.12*	0.04	0.04	0.21	47.49	0.03
Voice or text combined	141	2	0.48*	0.19	0.11	0.86	0.34	0.56
Not reported	136	1	0.16	0.20	–0.23	0.56	0.00	1.00
Between levels (Qa)							14.53	< .001
Agent form								
Humanoid	1,755	23	0.20*	0.05	0.09	0.30	40.62	0.01
Non-humanoid	785	14	0.28*	0.07	0.14	0.42	21.73	0.06
Actual human	165	3	0.23	0.17	–0.10	0.56	0.06	0.97
Mix	136	1	0.16	0.20	–0.23	0.56	0.00	1.00
Not reported	247	2	0.13	0.13	–0.39	0.13	3.65	0.06
Between levels (Qa)							7.55	0.11
Voice type								
Human	1,179	12	0.12	0.07	–0.01	0.25	11.77	0.38
Computer-edited	157	1	0.13	0.16	–0.18	0.44	0.00	1.00
Computer generated	399	9	0.14	0.1	–0.05	0.34	3.42	0.91
No voice	384	9	0.51*	0.1	0.31	0.72	11.26	0.13
Not reported	969	13	0.16*	0.07	0.03	0.30	35.77	< .001
Between levels (Qa)							11.39	0.02
Animation effect								
Animated	2,445	32	0.15*	0.04	0.06	0.24	43.19	0.07
Static	78	2	0.00	0.22	–0.44	0.43	0.95	0.33
Mixed agent types	329	4	0.24*	0.12	0.01	0.48	2.62	0.45
Not explicitly reported	236	5	0.59*	0.13	0.33	0.85	16.12	< .001
Between levels (Qa)							10.73	0.01

*$p < .05$.

cross with that of the studies which utilized narration. As such, one must question whether the effect size is a derivation of the low participant numbers or whether pedagogical agents are truly more effective when they communicate through text rather than through audio narration. In sum, would the moderate effect size obtained for agents that communicate with text be robust across a large sample of studies?

The pedagogical agent's form (e.g., humanoid, non-humanoid, actual human, and mixed agent form) did not produce significant differences between groups ($Q = 7.55$, $p > .05$). However, Table 2 shows a statistically significant effect size of $g = .20$ ($p < .05$) was obtained for humanoid pedagogical agents, and $g = .28$ ($p < .05$) was obtained for non-humanoid pedagogical agents. Actual humans on the screen, both humanoid and non-humanoid agents on the screen, or studies that did not report the agent type did not yield significant effect sizes. As such, these findings suggest that fully anthropomorphizing the agents to appear as human-like may not be necessary to create the illusion and benefits of a social interaction.

The type of voice used by the pedagogical agents (Table 2) produced significant differences between groups ($Q = 11.39$, $p < .05$). The no voice condition, or the condition where agents provided on-screen text instead of narration, produced a statistically significant effect ($g = .51$, $p < .05$). No significant effect sizes were obtained from human pre-recorded voices, computer-edited voices, or computer generated voices. These findings must be interpreted with caution, as 13 studies did not report the type of voice the pedagogical agents embodied. Moreover, few studies delineated whether the agent utilized a male or female voice, or whether the voice was dominant (e.g., "You must now click on the hint button") or passive (e.g., "You may find it easier to progress by looking at a hint"). Further research should be conducted to investigate whether or not Mayer's (2005b) claim about the type of voice used influencing learning can be extended to pedagogical agent research.

Table 2 also shows statistically significant differences were found between groups when examining the agent's level of animation ($Q = 10.73$, $p < .05$). Animated pedagogical agents produced a small but statistically significant effect ($g = .15$, $p < .05$). Conversely, the two studies that investigated static pedagogical agents neither produced a positive nor negative effect on learning ($g = .00$). Although cognitive load theory predicts that animated pedagogical agents would impose extraneous cognitive load on learners, thus inhibiting learning, animated pedagogical agent studies produced a higher effect size than studies which utilized static pedagogical agents. These findings are plausible as Sweller (2005) claims that after the information is integrated into the long-term memory, it requires no cognitive resources when the learner is re-exposed to it.

Animated pedagogical agents may be more engaging to the learner because they are more "human-like" (Dehn & van Mulken, 2000, p. 2), but their ability to signal the learner's attention to the relevant information (as in Choi & Clark, 2006; Mayer et al., 2003a) may be critical. A meta-analysis investigating the effects of gestures in human communication found a moderate effect, indicating that the act of gesturing is beneficial to communication (Hostetter, 2011). Thus, in the reporting of future work, researchers should more thoroughly describe what animations the agents embody (i.e., signaling, non-signaling gesturing, or facial expressions) as the research examined did not provide sufficient details to draw this conclusion.

Research Question 3: *How do the effect sizes of learning with pedagogical agents vary by subject domain, educational level, prior domain knowledge, the study setting, and the pacing of the learning system?*

Three domains of learning material were examined for differences between groups, mathematics, science, and humanities (Table 3). Statistically significant differences between groups were found ($Q = 7.70$, $p < .05$), with the highest effect size ($g = .28$, $p < .05$) produced from studies which used agents to learn science materials ($k = 19$). Similarly, studies that investigated the use of agents in mathematics ($k = 8$) produced an effect size of $g = .27$, $p < .05$, while studies which utilized learning materials from the humanities ($k = 16$) did not yield a significant effect size ($g = .06$, $p > 05$).

Pedagogical agents' ability to demonstrate or model tasks may have facilitated higher performance in science and mathematics compared to other domains, although none of the agents investigated truly embodied these abilities to the fullest extent possible. For example, none of the agents examined truly demonstrated or modeled any significant scientific method; rather, some agents incorporated various methods of signaling the learner's attention to certain parts of the screen. For example, the agent could point to part of the diagram on the screen as it becomes relevant to instruction, as in Moreno, Reislein, and Ozogul (2010). Regardless, these abilities coupled with the inherently abstract nature of science may also be attributed to the learning performance observed with the use of pedagogical agents in learning scientific materials. Perhaps pedagogical agents were able to motivate the learners to work at a level higher than normal? Or did agents engage the students by taking abstract scientific and mathematical constructs and demonstrating them in a fashion which the students were able to visualize what they could not from other resources? There is a need for rigorous studies that will provide insight into the participant's experiences with the system as well as more specific feedback to guide future agent design.

Table 3 also shows that significant differences were found between different educational levels of learners ($Q = 22.54$, $p < .05$). Studies with participants in grades four through seven produced a moderate statistically significant effect size of $g = .56$ ($p < .05$). Results from Table 3 also show that agent studies with post-secondary students produced a low effect size of $g = .12$ ($p < .05$). However,

Table 3. Effect Sizes of the Contextual Features of Pedagogical Agent Learning

	Effect size and 95% confidence interval						Heterogeneity	
	N	*k*	*g*	SE	Lower limit	Upper limit	*Q*-value	*p*
Domain								
Math	462	8	0.27*	0.10	0.08	0.46	4.96	0.67
Science	1,247	19	0.28*	0.06	0.17	0.40	36.67	0.01
Humanities	1,379	16	0.06	0.06	–0.05	0.18	24.29	0.06
Between levels (Q_B)							7.70	0.02
Educational level								
Grades 4-7	348	5	0.56*	0.11	0.34	0.78	3.26	0.51
Post-secondary	2,642	37	0.12*	0.04	0.04	0.20	47.81	0.09
Other (combined grades)	98	1	0.86*	0.23	0.42	1.31	0.00	1.00
Between levels (Q_B)							22.54	< .001
Prior knowledge								
Low	965	6	0.01	0.08	–0.15	0.14	20.78	< .001
Medium	258	5	0.31*	0.13	0.06	0.57	5.19	0.27
High	48	1	0.33	0.29	–0.24	0.89	0.00	1.09
Mixed	134	2	0.45*	0.20	0.07	0.84	2.19	0.14
Not reported	1,683	29	0.24*	0.05	0.14	0.34	34.91	0.17
Between levels (Q_B)							10.54	0.03
Setting								
Classroom	274	4	0.68*	0.13	0.43	0.92	5.00	0.17
Laboratory	1,673	25	0.16*	0.05	0.06	0.27	37.89	0.04
Other	30	1	0.01	0.36	–0.68	0.71	0.00	1.00
Not reported	1,111	13	0.12	0.06	–0.01	0.24	13.78	0.31
Between levels (Q_B)							16.94	< .001
Pacing								
Learner-paced	2,255	33	0.22*	0.05	0.13	0.31	51.28	0.02
System-paced	88	1	–0.02	0.22	–0.46	0.43	0.00	1.00
Not reported	745	9	0.13	0.08	–0.02	0.27	20.24	0.01
Between levels (Q_B)							2.09	0.35

*$p < .05$.

these differences must be interpreted with caution due to the small number of studies which investigated K-12 students ($k = 6$).

K-12 students performed noticeably better when interacting with a pedagogical agent than post-secondary students (Table 3). We speculate that K-12 students may derive more motivational benefits from pedagogical agents, and may be more impacted by the effects of a perceived social interaction. Are K-12 students more likely to feel as though a pedagogical agent is initiating a social interaction than a post-secondary student? Future research may explore this question. Another plausible rationale is that a novelty effect may exist more for the K-12 participants than post-secondary participants; hence the higher scores for the K-12 group. Longitudinal research is needed to understand if these improvements in learning performance will be sustained over time.

The prior knowledge levels of the participants, as shown in Table 3, produced significant differences between groups ($Q = 40.54$, $p < .05$). The use of pedagogical agents with moderate prior knowledge participants produced an effect size of $g = .31$ ($p < .05$). Since the use of pedagogical agents with learners of low prior knowledge did not produce a statistically significant effect size ($g = -0.01$, $p > .05$), we question if the agents made learning the material more difficult for these participants. However, these results must be interpreted with caution as 29 studies did not report the prior knowledge level of the participants.

Table 3 shows that significant differences were found depending upon the setting in which the study took place ($Q = 16.94$, $p < .05$). Laboratory studies yielded a low effect size of $g = .16$ ($p < .05$). Interestingly, only four studies evaluated pedagogical agent software in a classroom setting, yet these studies yielded the highest effect size ($g = .68$, $p < .05$). One plausible rationale could be a novelty effect, where the agents brought the participants a "new" experience which they found particularly engaging, thus they performed better. Alternatively, being in the classroom setting may have increased the motivation to work with the agents as these classroom-based studies may contribute to performance assessment for the participants; hence, they are encouraged to perform to the best of their ability. One must note, however, that these differences must be interpreted with caution as only four studies took place within a classroom.

The pacing of the learning system (Table 3) did not yield significant differences between groups ($Q = 2.09$, $p > .05$). Across 33 studies, pedagogical agents were effective when presented as learner-paced instructional tool ($g = .22$, $p < .05$). Conversely, the only system-paced study in this meta-analysis produced a non-significant ($p > .05$) effect of $g = -.02$. There is a need for more system-paced agent studies to more carefully examine the comparison between learner and system-paced agents. However, researchers have described the self-pacing principle, which states that giving the learners control over the system "allows them to pause and better reflect on the new information in order to couple it to already existing cognitive structures" (van Merriënboer & Kester, 2005, p. 83).

Publication Bias

The file drawer problem (Rosenthal, 1979) is an ongoing issue in meta-analysis. Researchers have claimed that publication bias exists in peer-reviewed journals, as they often do not publish non-statistically significant results (Rosenthal, 1979), or they publish results which reported a relatively high effect size (Borenstein et al., 2009). Researchers have suggested that the validity of meta-analysis comes into question due to the file drawer problem, for it may skew findings toward a more positive mean effect size (Adesope & Nesbit, 2012).

We utilized Comprehensive Meta-Analysis (Borenstein et al., 2008) to compute three approaches to examine the impact of publication bias. First, a funnel plot was constructed and it delineated symmetry, suggesting that publication bias is absent (Borenstein et al., 2009; Song, Khan, Dinnes, & Sutton 2002).

Next, the "Classic fail-safe *N*" test was used to determine the number of studies with null effect needed to raise the p value above $\alpha = .05$. This test revealed that 264 more qualified studies were needed. Egger's linear regression test (Egger, Smith, Schneider, & Minder, 1997) further substantiated these results, delineating the absence of publication bias ($p = .22$). Since all three approaches were consistent in suggesting the absence of publication bias, one can infer that publication bias was not present at a level that would pose a threat to the validity of the findings of this meta-analysis.

DISCUSSION AND CONCLUSION

The findings of this meta-analysis have direct implications for both theory and practice. This section will delineate the theoretical and practical implications and conclude with a discussion of the limitations of this study as well as suggestions for future research.

Theoretical Implications

The presence principle was not supported by the findings of this research. While Mayer et al. (2003a) suggest that the agent's image is not necessary on the screen to generate the learning benefits derived from the agent's voice, this study found that compared to non-agent conditions (including voice-only comparisons), pedagogical agents produce a small effect of $g = .19$ ($p < .05$). These findings do not support the presence principle, but rather suggests that the pedagogical agent's image may be more beneficial to learning than the agent's voice alone.

Social agency theory is supported by the findings of this meta-analysis. The findings indicated that participants learned more from a system with a pedagogical agent than a system without an agent. One could infer from these findings that the participants felt as though they were engaged in a social interaction with the pedagogical agent. However, additional work is needed to investigate if this is truly the case or if other features of the system are creating the learning benefits observed.

The findings of this meta-analysis suggest that even if the agent does cause distraction (Moreno, 2005; van Mulken et al., 1998) or extraneous cognitive load (Clark & Choi, 2007), the agent may facilitate learning. However, research should be conducted to examine if, as cognitive load theory predicts, pedagogical agents do, at first, create extraneous cognitive load. Further work could be done to examine how the cognitive load caused by agents differs over time and in respect to different agent features such as voice, appearance, and gestures.

Mirroring Moreno's (2005) findings, the results of this meta-analysis did not find support for the split-attention principle. Thus, learning was not impeded by the agent's appearance on the screen. This may be due to the agent requiring no cognitive resources to understand after it is processed the first time (Sweller, 2005). However, it is also plausible to infer that the motivational benefits noted by Gulz (2004), van Mulken, André, and Muller (1998), and Moreno (2005) outweigh any distraction the agent may cause.

Although Ginns' (2005) meta-analysis of the modality effect suggested that providing some information visually and other information aurally is beneficial to understanding, the findings of this meta-analysis do not support this claim in respect to pedagogical agents. The findings suggest that agents which communicated through text rather than narration were more effective at facilitating learning (g = .51 and g = .12, respectively). Thus, it appears that pedagogical agents should communicate with the learner through text rather than narration in learner-paced environments. Future research should further investigate if differences exist between the educational level of the learners, the pacing of the system, or the domain of the learning materials. For an extensive discussion of the modality effect, see Ginns (2005).

Practical Implications

The results of this study provide many insights into the design and practical application of pedagogical agents. The findings of this meta-analysis suggest that pedagogical agent-based systems may be more effective than non-agent systems. Furthermore, pedagogical agents provided the largest benefits to students in K-12 education (specifically grades 4-7), with smaller benefits found for post-secondary students. The findings also suggest that pedagogical agents which communicated through text rather than narration, as well as embodied some form of animation, provided more learning benefits than agents which did not. Our results indicate that the degree to which the agent is anthropomorphized does not appear to have a large impact on learning outcomes. Finally, the findings suggest that pedagogical agents may facilitate learning most effectively when students are investigating scientific or mathematics learning materials.

Limitations

It is important to note that while this meta-analysis effectively synthesizes existing empirical research on pedagogical agents, the analysis also has inherent limitations. Flather, Farkouh, and Yusuf (1997) suggested that while small meta-analysis (which they defined as having less than 200 outcomes) must be interpreted with caution, they provide useful future directions for research. As such, this section will address the limitations of this study and delineate several productive research directions.

Agent Capabilities

Heidig and Clarebout (2011) noted that there has been a wide variety of pedagogical agents used in many contexts, and that these agents possessed variable features. One such distinction in the literature is the delineation between pedagogical and conversational agents. Veletsianos et al. (2009) suggested that pedagogical agents merely deliver an instructional message, while a conversational agent can answer student questions. However, for this study we have not made the distinction between the two agents because both can be used to foster learning. As such, we tried to emphasize the image of the agent as the primary variable under investigation rather than whether or not it was equipped with artificial intelligence. Further work should investigate the differences which arise when learning with either pedagogical or conversational agents.

Agent Features

Cognitive load theory predicts that extraneous cognitive load, which can potentially be caused by the agent's appearance, actions, movements, or communication, can impede learning (Sweller, 2005). Since social agency theory hinges on the illusion of a social interaction, it is plausible that pedagogical agents may benefit from the use of gestures. Gestures may allow the learner to perceive the agent as being more human-like, and may also allow for a better understanding of the information that the agent is trying to convey. As such, the degree and purpose of animation that pedagogical agents embody should be investigated comprehensively, including the evaluation of how the degree of animation influences learning (as in Baylor & Kim, 2009). Similarly, researchers have suggested that pedagogical agents are stereotyped by their appearance (Moreno, Person, Adcock, Eck, Jackson, & Marineau, 2002; Veletsianos, 2010). Thus, features such as contextually-relevant agents (e.g., Veletsianos, 2010) and agents which are dislikable in appearance (e.g., Domagk, 2010) should continue to be researched. Finally, the style of communication the agent uses may impact learning and warrants future investigation. For example, what happens if an agent communicates as a peer rather than an instructor? What happens when the agent provides off-task messages (e.g., Veletsianos, 2012)? While we acknowledge that these features may impact learning with pedagogical agents, we could not examine their moderating influence due to the limited research surrounding them.

Multiple Agent Systems

Very few studies examined the effect of a peer pedagogical agent (k = 3), thus this area is wide-open for future studies. Particularly interesting is the concept of a virtual class, led by a virtual teacher, where the learner is represented as an agent in the virtual classroom environment. Could pedagogical agents coupled with intelligent tutoring systems successfully replace peers in collaborative work in an online learning environment? While this notion potentially delves into the realms of virtual reality and artificial intelligence research, the scenario outlined above could offer an interesting approach to online learning environments. Research is needed to examine differential effects on learning performance, affective measures, and the student experience in these multi-agent systems.

Suggestions for Future Research

Systematic examination of the studies included in this meta-analysis indicated a lack of thorough reporting about the pedagogical agent systems used. This ambiguity can lead to misinformation and misinterpretation, as well as prevent replication of the studies. For example, two studies did not describe what the non-agent condition was comprised of, and further did not provide a picture of the learning environment from which one could infer such information. The APA Publications and Communications Board Working Group on Journal Article Reporting Standards (2008) suggested that authors provide "details of the interventions or experimental manipulations intended for each study condition, including control groups" (p. 844).

The APA Publications and Communications Board Working Group on Journal Article Reporting Standards (2008) also made recommendations specifying what authors should report, including information pertaining to the content of the intervention, the method of intervention, the treatment fidelity, the setting of the intervention, and the time span of the intervention. The type of voice used with the pedagogical agent system was not reported in 13 of the included studies. Twenty-nine studies did not report the learner's prior knowledge level. If the level of prior knowledge is not known, it is difficult to evaluate learning because any positive performance may be attributed to the participants already having the requisite prior knowledge. Thirteen studies did not report the setting in which the study took place. Reporting the study setting lends important contextual features for proper interpretation and allows for more accurate follow-up studies. Similarly, 23 studies did not report the treatment duration. If the intervention was only 3 minutes, the rationale for the outcomes may be vastly different than if the intervention was for a longer duration. It is important for educational researchers to be more thorough when reporting about the studies they performed so that the experiments can be replicated, and meaningful conclusions can be drawn.

The ambiguity surrounding the pedagogical agent field may be what has led to the use of such a wide range of control groups. The studies included in this analysis utilized at least nine different control conditions. As such, the outcome of these experiments deserves critical examination, particularly due to the possibility of confounding variables. Findings of this meta-analysis mirror Dehn and van Mulken's (2000) claim that "several of the existing studies defined the control and experimental conditions in such a way that they differed in more than just the dimension under investigation. Consequently, differences between the two conditions cannot be attributed exclusively to this dimension" (p. 18). To remedy the issue of confounds, Clark and Choi (2005) suggested the balanced separation principle, in which control groups that are as close as possible to the experimental groups be used. Researchers should keep these concepts in mind when conducting pedagogical agent studies in order to truly equate their findings to the pedagogical agents' interaction with the learner rather than other confounding variables. Further guidance for pedagogical agent experimentation is delineated by Heidig and Clarebout (2011).

Expand K-12 Experimentation

Moderate and high effect sizes were extracted from studies in which the participants were in grades four through seven ($g = .56$, $p < .05$) and a mix of K-12 students ($g = .86$, $p < .05$). Unfortunately, only five studies examined the use of pedagogical agents for students in grades four through seven and only one study's participants were a mixture of K-12 students. As such, research is particularly needed with students in grades K-3 and 9-12. This type of research could have a great impact on practice as currently at least 4 states in the United States require K-12 students to complete some sort of online coursework as a requirement for high school graduation (Kennedy & Archambault, 2012).

Summary

In sum, results of this meta-analysis showed that pedagogical agents were found to have a small, yet positive effect on learning ($g = .19$, $p < .05$). Many of the different features that pedagogical agents can embody provide differential effects, some of which do not align with commonly accepted principles of multimedia design. For example, this meta-analysis does not support the modality principle (Ginns, 2005; Low & Sweller, 2005; Mayer, 2005c; Moreno, 2005), as a higher effect size was extracted from pedagogical agent studies in which the agents communicated through on-screen text than studies in which the agents provided narration. However, the findings of this meta-analysis support social agency theory, with the use of pedagogical agent-based systems leading to higher cognitive performance than non-agent systems, presumably due to a feeling of social interaction between the learner and the agent. Researchers should continue to explore the multifaceted features of pedagogical agents and carefully examine the independent and interacting features of pedagogical agents for learning.

APPENDIX A: Outcomes of Each Study

Contrast	Author	Effect size (g)	Agent Mean	Agent *SD*	Agent *N*	Non-agent Mean	Non-agent *SD*	Non-agent *N*	Remarks about scores
Agent + agent with gestures vs no agent	Craig et al. (2002)	–0.07	3.14	1.72	90.00	3.26	1.71	45	Free Recall, Matching, Transfer, Multiple Choice
Text + agent vs text	Atkinson (2002)	–0.18	6.30	2.91	10.00	6.83	2.66	10	Near Transfer, Far Transfer, Performance on Practice Problems
Voice + agent vs voice	Atkinson (2002)	–0.04	7.77	2.67	10.00	7.87	1.74	10	Near Transfer, Far Transfer, Performance on Practice Problems
Voice + agent vs text or voice exp. 2	Atkinson (2002)	0.57*	7.71	3.57	25.00	5.63	3.61	50	Near Transfer, Far Transfer, Performance on Practice Problems
Mixed appearance agents vs no agent exp. 1	Domagk (2010)	–0.04	12.12	4.11	244.00	12.27	3.20	48	Retention, Transfer
Mixed appearance + mixed voice vs no agent exp. 2	Domagk (2010)	–0.23	11.51	4.28	139.00	12.48	3.54	35	Retention, Transfer
Mixed agent types vs no agent	Frechette & Moreno (2010)	0.19	8.73	3.04	68.00	8.14	3.08	18	Free Recall, Transfer, Comprehension
Mixed agent type + animated image vs voice only	Lusk & Atkinson (2007)	0.07	5.35	2.42	58.00	5.16	2.87	29	Near Transfer, Far Transfer, Performance on Practice Problems
Mixed agent type + static image vs voice only	Lusk & Atkinson (2007)	0.18	4.88	2.41	58.00	4.43	2.63	29	Near Transfer, Far Transfer, Performance on Practice Problems

APPENDIX A (Cont'd.)

Contrast	Author	Effect size (g)	Agent Mean	Agent *SD*	Agent *N*	Non-agent Mean	Non-agent *SD*	Non-agent *N*	Remarks about scores
Mixed prompt + agent vs no agent	Yung (2009)	0.34	10.05	4.36	53.00	8.58	3.61	13	Terminology Test, Comprehension Test
Male agent vs male voice	Louwerse et al. (2005)	0.14	0.55	0.20	32.00	0.52	0.21	32	Multiple Choice
Female agent vs female voice	Louwerse et al. (2005)	0.17	0.60	0.18	32.00	0.57	0.17	32	Multiple Choice
Agent vs no agent exp. 1	Moreno et al. (2001)	0.92*	21.78	3.54	20.00	17.96	4.51	24	Retention, Transfer
Agent vs no agent exp. 2	Moreno et al. (2001)	0.78*	14.57	5.49	24.00	10.70	4.24	24	Retention, Transfer
Agent + text vs text exp. 4	Moreno et al. (2001)	0.14	19.54	6.19	15.00	18.78	4.39	16	Retention, Transfer
Agent + voice vs voice exp. 4	Moreno et al. (2001)	–0.51	22.65	4.23	17.00	24.63	3.31	16	Retention, Transfer
Agent + text vs text exp. 5	Moreno et al. (2001)	0.29	18.64	5.31	19.00	17.15	4.61	21	Retention, Transfer
Agent + voice vs voice exp. 5	Moreno et al. (2001)	0.22	24.45	3.44	19.00	23.63	3.74	20	Retention, Transfer
Animated agent vs arrow + voice	Choi & Clark (2006)	0.10	25.25	6.47	32.00	24.60	6.13	42	Performance

Agent + voice vs voice or text	Dunsworth & Atkinson (2007)	0.30	8.22	3.38	17.00	7.22	3.16	34	Retention, Near Transfer, Far Transfer, Heart Drawing
Agent vs no agent	Moundridou & Virvou (2002)	0.33	4.88	0.34	24.00	4.75	0.44	24	Performance
Agent vs no agent exp. 4	Mayer et al. (2003a)	0.19	6.60	3.28	20.00	5.95	3.52	19	Transfer
Agent vs text only	Hershey-Dirkin et al. (2005)	–0.14	12.30	2.60	29.00	12.70	3.20	29	Performance
Social agent vs voice only	Hershey-Dirkin et al. (2005)	0.40	13.30	2.40	29.00	12.40	2.00	29	Performance
Agent vs no agent	Theodoridou (2010)	–0.02	15.63	3.42	23.00	15.71	4.21	24	Immediate and Delayed Post-tests
Agent(s) vs no agent	Murray & Tenenbaum (2010)	0.86*	7.21	1.98	69.00	5.54	1.77	29	Test 2, from dissertation version of manuscript
Agents vs no agent	Kirk (2009)	0.13	25.71	12.80	82.00	24.05	12.46	75	Chemistry Achievement
Males using agent vs non-agent	Kizilkaya & Askar (2008)	0.26	6.76	1.44	34.00	6.31	2.02	29	Science Achievement
Females using agent vs non-agent	Kizilkaya & Askar (2008)	0.83*	8.09	1.67	35.00	6.63	1.84	27	Science Achievement
Agent vs non-agent	van Mulken et al. (1998)	0.01	23.96	16.00	15.00	23.79	0.50	15	Technical and Non-technical Comprehension and Recall (*t* tests)
Agents vs text (seductive graphic)	Park (2006)	0.47	5.55	1.14	31.00	4.88	1.38	16	Recall, Comprehension

APPENDIX A (Cont'd.)

Contrast	Author	Effect size (g)	Agent Mean	Agent *SD*	Agent *N*	Non-agent Mean	Non-agent *SD*	Non-agent *N*	Remarks about scores
Agents vs text (no seductive graphic)	Park (2006)	–0.09	5.23	1.14	31.00	5.33	1.15	15	Recall, Comprehension
Agent vs text or voice	Graesser et al. (2003)	0.14	0.47	0.20	40.00	0.44	0.21	77	Free Recall, Cued Recall, Cloze Recall
Mixed teaching type agent vs no agent	Baylor (2002)	0.16	13.34	4.13	104.00	12.66	4.05	32	Performance
Agent vs text	Adcock et al. (2006)	–0.36	2.50	0.54	59.00	2.67	0.41	71	Communications Skills
Text + voice + agent vs text only	Burgoon et al. (2000)	0.36	5.10	0.58	10.00	4.80	0.98	10	Understanding (Recall, Content Understanding)
Voice + text + animated agent vs text + voice	Burgoon et al. (2000)	–0.09	4.88	1.53	10.00	5.00	0.85	10	Understanding (Recall, Content Understanding)
Voice + animated agent vs human interaction	Burgoon et al. (2000)	0.13	5.18	0.57	10.00	5.08	0.90	10	Understanding (Recall, Content Understanding)
Student + student + agent and student + agent vs 2 students	Holmes (2007)	0.60*	8.02	2.00	45.00	6.81	2.00	24	$F(1, 68) = 5.56, p < .022$

Mixed animation vs no agent exp. 2	DaPra & Mayer (2011)	–0.02	6.59	3.98	59.00	6.65	3.45	29	Retention, Transfer
Agent vs no agent	Moundridou & Virvou (2001)	0.27	3.42	1.50	10.00	3.00	1.50	9	$t = .59$ ($p = .28$)
Male + female agent vs no agent	Plant et al. (2009)	0.46*	4.33	1.65	71.00	3.55	1.73	35	Math Test Scores
Agent vs no agent	Cheng et al. (2009)	0.99*	10.00	2.00	40.00	8.00	2.00	40	Number of Student Trials (Effect size reversed)
Overall		0.19*							

*Indicates $p < .05$.

APPENDIX B: Methodological Features of Studies

Contrast	Author	Modality	Agent form	Voice type	Animation level
Agent + agent with gestures vs no agent	Craig et al. (2002)	Narration	Humanoid	Not reported	Animated
Text + agent vs text	Atkinson (2002)	Text	Non-humanoid	No voice	Animated
Voice + agent vs voice	Atkinson (2002)	Narration	Non-humanoid	Human	Animated
Voice + agent vs text or voice exp. 2	Atkinson (2002)	Voice or text combined	Non-humanoid	Human	Animated
Mixed appearance agents vs no agent exp. 1	Domagk (2010)	Narration	Humanoid	Human	Animated
Mixed appearance + mixed voice vs no agent exp. 2	Domagk (2010)	Narration	Humanoid	Human	Animated
Mixed agent types vs no agent	Frechette & Moreno (2010)	Narration	Actual human	Human	Mix animated and static
Mixed agent type + animated image vs voice only	Lusk & Atkinson (2007)	Narration	Non-humanoid	Human	Mix animated and static
Mixed agent type + static image vs voice only	Lusk & Atkinson (2007)	Narration	Non-humanoid	Human	Mix animated and static

Mixed prompt + agent vs no agent	Yung (2009)	Voice or text combined	Humanoid	Not reported	Animated
Male agent vs male voice	Louwerse et al. (2005)	Narration	Humanoid	Computer generated	Animated
Female agent vs female voice	Louwerse et al. (2005)	Narration	Humanoid	Computer generated	Animated
Agent vs no agent exp. 1	Moreno et al. (2001)	Narration	Non-humanoid	Not reported	Unknown
Agent vs no agent exp. 2	Moreno et al. (2001)	Narration	Non-humanoid	Not reported	Unknown
Agent + text vs text exp. 4	Moreno et al. (2001)	Text	Non-humanoid	No voice	Unknown
Agent + voice vs voice exp. 4	Moreno et al. (2001)	Narration	Non-humanoid	Not reported	Unknown
Agent + text vs text exp. 5	Moreno et al. (2001)	Text	Actual human	No voice	Animated
Agent + voice vs voice exp. 5	Moreno et al. (2001)	Narration	Actual human	Human	Animated
Animated agent vs arrow + voice	Choi & Clark (2006)	Narration	Humanoid	Human	Animated
Agent + voice vs voice or text	Dunsworth & Atkinson (2007)	Narration	Humanoid	Human	Animated

APPENDIX B (Cont'd.)

Contrast	Author	Modality	Agent form	Voice type	Animation level
Agent vs no agent	Moundridou & Virvou (2002)	Narration	Humanoid	Computer generated	Animated
Agent vs no agent exp. 4	Mayer et al. (2003a)	Narration	Non-humanoid	Not reported	Animated
Agent vs text only	Hershey-Dirkin et al. (2005)	Narration	Humanoid	Computer generated	Static
Social agent vs voice only	Hershey-Dirkin et al. (2005)	Narration	Humanoid	Computer generated	Animated
Agents vs no agent	Theodoridou (2010)	Narration	Humanoid	Computer generated	Animated
Agent(s) vs no agent	Murray & Tenenbaum (2010)	Narration	Humanoid	Not reported	Animated
Agents vs no agent	Kirk (2009)	Narration	Non-humanoid	Computer edited	Animated
Males using agent vs non-agent	Kizilkaya & Askar (2008)	Text	Non-humanoid	No voice	Animated
Females using agent vs non-agent	Kizilkaya & Askar (2008)	Text	Non-humanoid	No voice	Animated

Agent vs non-agent	van Mulken et al. (1998)	Narration	Humanoid	Not reported	Animated
Agent vs text (seductive graphic)	Park (2006)	Narration	Humanoid	Not reported	Animated
Agents vs text (no seductive graphic)	Park (2006)	Narration	Humanoid	Not reported	Animated
Agent vs text or voice	Graesser et al. (2003)	Narration	Not specified	Not reported	Animated
Mixed teaching type agent vs no agent	Baylor (2002)	Not reported	Humanoid and non-humanoid	Not reported	Animated
Agent vs text	Adcock et al. (2006)	Narration	Not specified	Not reported	Animated
Text + voice + agent vs text only	Burgoon et al. (2000)	Narration	Humanoid	Computer generated	Static
Voice + text + animated agent vs text + voice	Burgoon et al. (2000)	Narration	Humanoid	Computer generated	Animated
Voice + animated agent vs human interaction	Burgoon et al. (2000)	Narration	Humanoid	Computer generated	Animated
Student + student + agent and student + agent vs 2 students	Holmes (2007)	Text	Humanoid	No voice	Mix animated and static

APPENDIX B (Cont'd.)

Contrast	Author	Modality	Agent form	Voice type	Animation level
Mixed animation vs no agent exp. 2	DaPra & Mayer (2011)	Narration	Humanoid	Human	Animated
Agent vs no agent	Moundridou & Virvou (2001)	Text	Non-humanoid	No voice	Animated
Male + female agent vs no agent	Plant et al. (2009)	Narration	Humanoid	Human	Animated
Agent vs no agent	Cheng et al. (2009)	Text	Humanoid	No voice	Unknown

APPENDIX C: Contextual Features of Studies

Contrast	Author	Domain	Educational level	Prior knowledge	Study setting	Pacing
Agent + agent with gestures vs no agent	Craig et al. (2002)	Science	Post-secondary	Low	Laboratory	Learner-paced
Text + agent vs text	Atkinson (2002)	Mathematics	Post-secondary	Medium*	Laboratory	Learner-paced
Voice + agent vs voice	Atkinson (2002)	Mathematics	Post-secondary	Medium*	Laboratory	Learner-paced
Voice + agent vs text or voice exp. 2	Atkinson (2002)	Mathematics	Post-secondary	Medium*	Laboratory	Learner-paced
Mixed appearance agents vs no agent exp. 1	Domagk (2010)	Humanities	Post-secondary	Low	Laboratory	Learner-paced
Mixed appearance + mixed voice vs no agent exp. 2	Domagk (2010)	Humanities	Post-secondary	Low	Laboratory	Learner-paced
Mixed agent types vs no agent	Frechette & Moreno (2010)	Science	Post-secondary	Mixed*	Laboratory	Not stated/Unclear
Mixed agent type + animated image vs voice only	Lusk & Atkinson (2007)	Mathematics	Post-secondary	Unknown	Laboratory	Learner-paced
Mixed agent type + static image vs voice only	Lusk & Atkinson (2007)	Mathematics	Post-secondary	Unknown	Laboratory	Learner-paced
Mixed prompt + agent vs no agent	Yung (2009)	Science	Post-secondary	Unknown	Not specified	Learner-paced

APPENDIX C (Cont'd.)

Contrast	Author	Domain	Educational level	Prior knowledge	Study setting	Pacing
Male agent vs male voice	Louwerse et al. (2005)	Humanities	Post-secondary	Unknown	Not specified	Not stated/Unclear
Female agent vs female voice	Louwerse et al. (2005)	Humanities	Post-secondary	Unknown	Not specified	Not stated/Unclear
Agent vs no agent exp. 1	Moreno et al. (2001)	Science	Post-secondary	Unknown	Laboratory	Learner-paced
Agent vs no agent exp. 2	Moreno et al. (2001)	Science	Grades 4-7	Mixed	Laboratory	Learner-paced
Agent + text vs text exp. 4	Moreno et al. (2001)	Science	Post-secondary	Unknown	Laboratory	Learner-paced
Agent + voice vs voice exp. 4	Moreno et al. (2001)	Science	Post-secondary	Unknown	Laboratory	Learner-paced
Agent + text vs text exp. 5	Moreno et al. (2001)	Science	Post-secondary	Unknown	Laboratory	Learner-paced
Agent + voice vs voice exp. 5	Moreno et al. (2001)	Science	Post-secondary	Unknown	Laboratory	Learner-paced
Animated agent vs arrow + voice	Choi & Clark (2006)	Humanities	Post-secondary	Medium*	Laboratory	Learner-paced
Agent + voice vs voice or text	Dunsworth & Atkinson (2007)	Science	Post-secondary	Unknown	Laboratory	Learner-paced
Agent vs no agent	Moundridou & Virvou (2002)	Mathematics	Post-secondary	High*	Not specified	Learner-paced
Agent vs no agent exp. 4	Mayer et al. (2003a)	Science	Post-secondary	Unknown	Laboratory	Learner-paced

Agent vs text only	Hershey-Dirkin et al. (2005)	Science	Post-secondary	Unknown	Not specified	Not stated/Unclear
Social agent vs voice only	Hershey-Dirkin et al. (2005)	Science	Post-secondary	Unknown	Not specified	Not stated/Unclear
Agent vs no agent	Theodoridou (2010)	Humanities	Post-secondary	Unknown	Laboratory	Learner-paced
Agent(s) vs no agent	Murray & Tenenbaum (2010)	Humanities	Other (combined grades)	Low*	Laboratory	Not stated/Unclear
Agent vs no agent	Kirk (2008)	Science	Post-secondary	Unknown	Not specified	Not stated/Unclear
Males using agent vs non-agent	Kizilkaya & Askar (2008)	Science	Grades 4-7	Unknown	Classroom	Learner-paced
Females using agent vs non-agent	Kizilkaya & Askar (2008)	Science	Grades 4-7	Unknown	Classroom	Learner-paced
Agent vs non-agent	van Mulken et al. (1998)	Humanities	Post-secondary	Unknown	Other	Not stated/Unclear
Agents vs text (seductive graphic)	Park (2006)	Humanities	Post-secondary	Unknown	Laboratory	Learner-paced
Agents vs text (no seductive graphic)	Park (2006)	Humanities	Post-secondary	Unknown	Laboratory	Learner-paced
Agent vs text or voice	Graesser et al. (2003)	Humanities	Post-secondary	Unknown	Not specified	Learner-paced
Mixed teaching type agent vs no agent	Baylor (2002)	Humanities	Post-secondary	Low	Not specified	Learner-paced

APPENDIX C (Cont'd.)

Contrast	Author	Domain	Educational level	Prior knowledge	Study setting	Pacing
Agent vs text	Adcock et al. (2006)	Humanities	Post-secondary	Low*	Not specified	Not stated/Unclear
Text + voice + agent vs text only	Burgoon et al. (2000)	Humanities	Post-secondary	Unknown	Laboratory	Learner-paced
Voice + text + animated agent vs text + voice	Burgoon et al. (2000)	Humanities	Post-secondary	Unknown	Laboratory	Learner-paced
Voice + animated agent vs human interaction	Burgoon et al. (2000)	Humanities	Post-secondary	Unknown	Laboratory	Learner-paced
Student + student + agent and student + agent vs 2 students	Holmes (2007)	Science	Grades 4-7	Medium*	Classroom	Learner-paced
Mixed animation vs no agent exp. 2	DaPra & Mayer (2011)	Science	Post-secondary	Unknown	Not specified	System-paced
Agent vs no agent	Moundridou & Virvou (2001)	Mathematics	Post-secondary	Unknown	Not specified	Learner-paced
Male + female agent vs no agent	Plant et al. (2009)	Mathematics	Grades 4-7	Unknown	Not specified	Learner-paced
Agent vs no agent	Cheng et al. (2009)	Science	Post-secondary	Unknown	Classroom	Learner-paced

*Indicates prior knowledge assigned by researchers.

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Direct reprint requests to:

Dr. Noah L. Schroeder
Department of Educational Leadership and Counseling Psychology
P.O. Box 642114
Washington State University
Pullman, WA 99164-1738
e-mail: noah.schroeder@wsu.edu