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How pedagogical agents communicate with students: A two-phase systematic review

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ABSTRACT

Technological advancements have improved the capabilities of pedagogical agents to communicate with students. However, an increased use of pedagogical agents in learning environments calls for a deeper understanding of student–agent communication to assess the effectiveness of pedagogical agents in learning. This study is a two-phase systematic review of scientific papers on pedagogical agent communication research published between 2010 and 2020, including review papers and original research papers. In the first phase, this study analyses literature reviews and meta-analyses to find the status and research gaps. The findings indicate that pedagogical agents' characteristics and impact on learning have been reviewed, but pedagogical agent communication and its relation to learning have not. In the second phase, the empirical studies of pedagogical agent communication are reviewed and classified into three categories that describe how pedagogical agent communication facilitates students' learning through (1) students' intrapersonal communication processes, (2) interpersonal communication between students and a pedagogical agent, and (3) by facilitating learning in a group. The findings show that pedagogical agent communication can enhance learning through intrapersonal communication of motivation, self-regulation, self-efficacy, and metacognition. At the interpersonal level, pedagogical agents aim to scaffold learning by giving feedback, prompts, and hints from learning processes and learning results. Pedagogical agents also support learning in a group by facilitating discussions and directing students' collaboration. Despite rapid technological advancements, pedagogical agents are not on the level to communicate fluently and human-like, which is likely to reduce their effectiveness and usability in learning. The review concludes that pedagogical agents' communication needs to be developed toward adaptive, adequate, relational, and logical communication, which requires a multidisciplinary theoretical approach, the use of artificial intelligence, affective computing, and psychometric assessments. Recommendations for future research addressing the gaps identified in this systematic review are discussed.

1. Introduction

In recent decades, learning technologies have become an integral part of classrooms, and it is forecast that in the future teachers

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will collaborate even more closely with digital teachers (Edwards & Edwards, 2017). Already, learning technologies have facilitated a significant transformation in education, changing it from learning in classrooms toward more personalized ways of learning (e.g., Pane, Steiner, Baird, & Hamilton, 2015; Xie, Chu, Hwang, & Wang, 2019). The continued development of learning technologies is likely to further change the role of teachers, and it is foreseeable that teachers will coteach with agents and individualize learning by designing, supporting, and supervising learning with technology (Edwards, Edwards, Spence, & Lin, 2018). One way of personalizing teaching is to embed pedagogical agents (PAs) in learning environments (Schroeder, Adesope, & Gilbert, 2013). PAs are lifelike characters that facilitate learning and guide students in digital learning environments (Clarebout & Heidig, 2012). The research on PAs has been typically driven by questions on technical features (Heidig & Clarebout, 2011) and PAs' anthropomorphic characteristics (Gnewuch, Morana, & Maedche, 2017), but relational and affective dimensions of learning are rising topics in PA research (Lawson et al., 2021). However, despite the fact that PAs have been studied actively, their effectiveness in enhancing students' learning remains debated (Schroeder & Gotch, 2015).

The research literature shows that PAs enhance the learning experience socially and cognitively (Kim & Baylor, 2016) and offer personalized and timely teaching, guidance, and mentoring (Bowman, 2012), which, however, underlines the importance of gaining more knowledge of the communication between students and PAs. Schroeder, Romine, and Craig (2017) have called for novel, theory-driven measures to study how PAs are perceived, and Edwards and Edwards (2017) have suggested borrowing insights from the communication field, *human–machine communication* (HMC), to understand students' learning with PAs. Relational and instructional communication practices such as immediacy, credibility, confirmation, motivation, and learning occur in communication regardless of the other interlocutor not being a human (Edwards & Edwards, 2017). Advanced technologies, such as artificial intelligence and natural language processing, can help generate better communication with agents and development of human-like features, such as emotions (Guzman, 2020). In the future, HMC research should focus on relational dynamics and relationships with machines, how people understand machines as communicators, and the blurred ontological boundaries between humans and machines (Guzman & Lewis, 2020). These are also topical in student–agent communication (SAC) as students increasingly communicate with technology. However, first, the state of the art in PA communication needs to be explored.

In this study, we investigate the status of research on how PAs communicate with students in digital learning environments. Edwards et al. (2018) stated that due to advancements in technology, students are not only communicating *through* technology, but *with* technology. Even if artificial intelligence and natural language processing enhance PAs' communication capabilities, some scholars have questioned PAs' ability to have a reciprocal conversation with a student (Kopp & Krämer, 2021). Particularly, as the expectations of the systems' communication capabilities are often unrealistic and they are evaluated as more advanced than they are (Luger & Sellen, 2016, May), which can lead to disappointment toward PAs.

To find out the state of art and to better understand the opportunities and limits of PAs' communication, this study conducts a two-phase systematic literature review on the core literature and analyses the research across communication, education, and technology disciplines. PAs have been the focus of research in all of these three disciplines, which have investigated PAs' purpose and impact in learning, their improved abilities to communicate with humans, and technological features.

The aim of this review is to map out the status of the research on PAs' communication with students and to understand how such communication facilitates learning in digital environments. To achieve this goal, this study intends to answer the following research questions (RQs):

RQ1. What is the status of research on PA communication?

RQ2. What roles and communication actions have been identified in PA communication?

RQ3. What theories have been applied to the study of PA communication?

RQ4. How does PA communication facilitate students' learning?

By answering these research questions, this study contributes to the body of knowledge on HMC and particularly on PA communication research by offering a holistic and interdisciplinary understanding of the status of research (theory) on the topic and, thereby, of the applicability and practice of HMC in PA communication.

2. Theoretical background

2.1. Pedagogical agents in education

Teaching is fundamentally social and understanding teachers' and students' interpersonal and group communication processes is essential (Goodnow, 1992). Traditionally, instructional communication research has focused on teachers' behavior that impacts affective and cognitive learning (Myers, 2010), such as teachers' message behavior and relational skills that foster motivation and learning (Edwards et al., 2018). Natural language processing and speech recognition technology have improved agents' capabilities to simulate interpersonal conversations (Kim & Baylor, 2016), which has made it possible to incorporate instructional communication aspects such as credibility, immediacy, clarity, and humor into the PA's communication (Edwards et al., 2018). After all, PAs have been developed to help learning through social interaction as they provide learning material (Kim, Baylor, & PALS Group, 2006; Veletsianos & Russell, 2014) and demonstrate, model to, or interact with students via text, voice, or both, depending on the technology used (Edwards & Edwards, 2017).

Since the late 1990s, PAs' different features and attributes in a learning context have been studied, for instance gestures (e.g., Davis, 2018; Kappagantula, Adamo-Villani, Wu, & Popescu, 2019), recognition of facial expressions (e.g., Baylor & Kim, 2009), voice and voice quality (e.g., Baylor, Ryu, & Shen, 2003; Chiou, Schroeder, & Craig, 2020; Edwards, Edwards, Stoll, Lin, & Massey, 2019), appearance (e.g., Baylor & Ryu, 2003; Domagk, 2010; Veletsianos, 2010), gender (e.g., Makransky, Wismer, & Mayer, 2019; Ozogul,

Johnson, Atkinson, & Reisslein, 2013; Schroeder & Adesope, 2015), roles (e.g., Baylor & Kim, 2003; Baylor & Kim, 2005; Kim & Baylor, 2016), and communication qualities such as politeness (Wang et al., 2008) and offering feedback (Lin, Atkinson, Christopherson, Joseph, & Harrison, 2013). Research has been conducted on PAs' characteristics, and only a few studies have focused on PAs' communication with students despite the potential use of PAs in classrooms.

Meanwhile, PAs have evolved from being merely guiding agents to being social learning companions (Kim & Baylor, 2016). Yet, research shows contradictory results for how PAs foster learning, and adding a PA in learning does not directly produce better learning outcomes (Schroeder et al., 2017). PAs rarely offer emotional support and empathy, which are essential features of a good teacher (Johnson & Lester, 2018). However, research is heading toward more relational and communicative aspects. Edwards and Edwards (2018) have suggested that because new technologies combine human and machine intelligence to support learning, traditional learning and its outcomes should be re-evaluated. Also, researchers have suggested reconsidering PAs' roles and tasks from the social support perspective instead of limiting it to the most efficient ways to convey information (Richards & Dignum, 2019). Relational aspects and communication have gained more interest lately, and research concurs that perhaps the most promising research direction is improving PAs' communication capabilities (Johnson & Lester, 2018; Kim & Baylor, 2016).

2.2. Computers are social actors

As research gradually expands to make PAs more human-like, the *computers are social actors (CASA) paradigm* (Nass & Moon, 2000) has become a widely used theoretical framework for studying HMC. The CASA paradigm suggests that people perceive computers in an anthropomorphic way and communicate with them as if they were humans, especially when social cues have been embedded. Many studies have relied on the CASA paradigm and assumed that students respond to machines as they would respond to humans in real life (Edwards & Edwards, 2018).

However, empirical research (Edwards, Edwards, Spence, & Westerman, 2016) has shown that humans who communicate with an agent do so expecting lower social presence and liking but experiencing greater uncertainty. People's conversations with agents differ from those with humans and, with agents, people use less rich vocabulary but more profanity (Hill, Ford, & Farreras, 2015). Importantly, HMC points out the ontological difference between a human and technology (Guzman, 2020), raising the fundamental question of what kind of a process communication between humans and technology is after all (Guzman, 2018). To respond to that question, one important research aspect is how people engage and communicate with technology (Guzman et al., 2020). In the educational context, communication between students and technology, the role of PAs (Kim & Baylor, 2016), and relational functionalities are the research areas that should be focused on (Johnson & Lester, 2018). Another important research area is how different

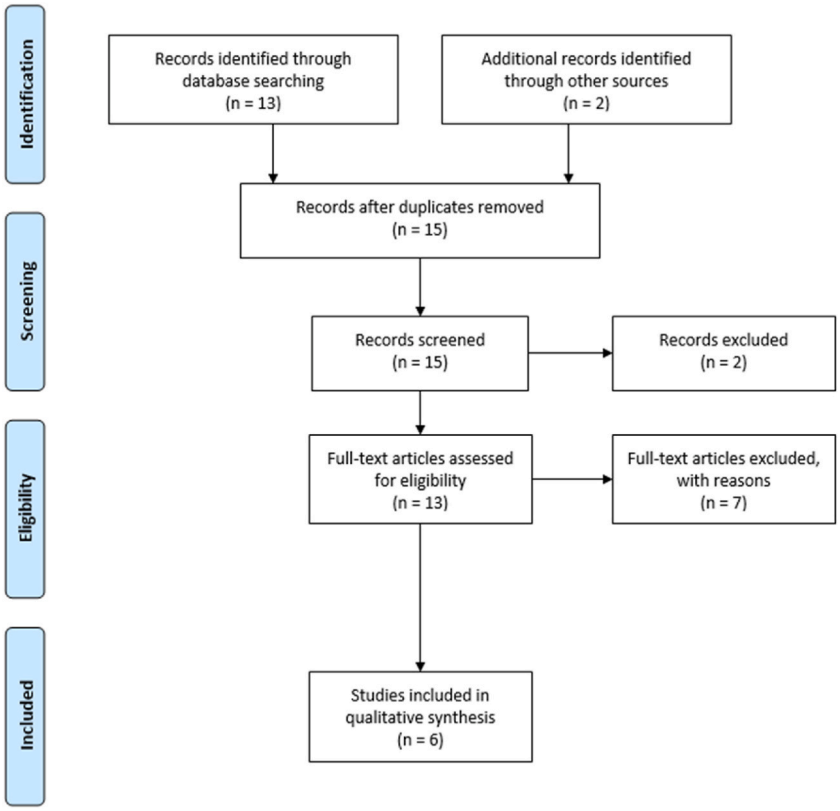

Fig. 1. Umbrella review PRISMA chart.

dimensions, such as agents' social intelligence, voice features, communication style, non-verbal communication, appearance, and quality of performance impact their perceived trustworthiness (Rheu, Shin, Peng, & Huh-Yoo, 2021). Nonetheless, the use of affective technologies that build and maintain relationships requires further research of how relationships should be formed and monitored in human–technology settings (Walker & Ogan, 2016). It appears evident that a cumulative, systematic knowledge on PA communication is needed to better address the future of SAC research and development.

3. Research approach

3.1. Data collection procedure

A two-phase systematic literature review was conducted in education, communication, and technology disciplines to investigate the body of research on how PAs communicate with students in digital learning environments. In the first phase, reviews and meta-analysis were searched and reviewed, and in the second phase empirical studies were searched and reviewed, which approach allowed the extraction of in-depth information for qualitative analysis.

The two-phase systematic literature review followed the analytical protocol of the PRISMA guidelines (Moher, Liberati, Tetzlaff, Altman, & Prisma Group, 2009). In phase one and phase two, the same search string was used in the following scientific databases for peer-reviewed articles: Scopus, ScienceDirect, SAGE Publications, Wiley, Taylor & Francis, ProQuest, and EBSCO. Due to the rapid development of technology, the article search was limited to full-length, peer-reviewed papers on education, communication, and technology published in English between 2010 and 2020. To understand the interrelation of these domains, the search was conducted with three domain-specific strings: "dialog" OR "conversation" OR "interaction" OR "discussion" (communication) AND "pedagogical agent" OR "conversational agent" OR "communicative agent" OR "communicative AI" OR "intelligent agent" OR "intelligent personal assistants" (technology) AND "learning outcome" OR "learning result" OR "academic achievement" (education).

In the first phase, an umbrella review, also known as a "review of reviews" (Grant & Booth, 2009), produced 13 reviews and meta-analyses from the databases and two reviews from additional sources (see Fig. 1). Altogether, six reviews and meta-analyses published in the highest-quality journals according to the SCImago Journal Rank (see Saarela & Kärkkäinen, 2020) and the number of citations were then included in the umbrella review.

In phase two, the same procedure was used to collect empirical studies on PA communication, resulting in 710 articles. In addition, the reference section of the recent meta-analyses (Castro-Alonso, Wong, Adesope, & Paas, 2021) was searched, from which five additional articles were added to the literature review. After discarding duplicates, 683 articles were included in the sample (see

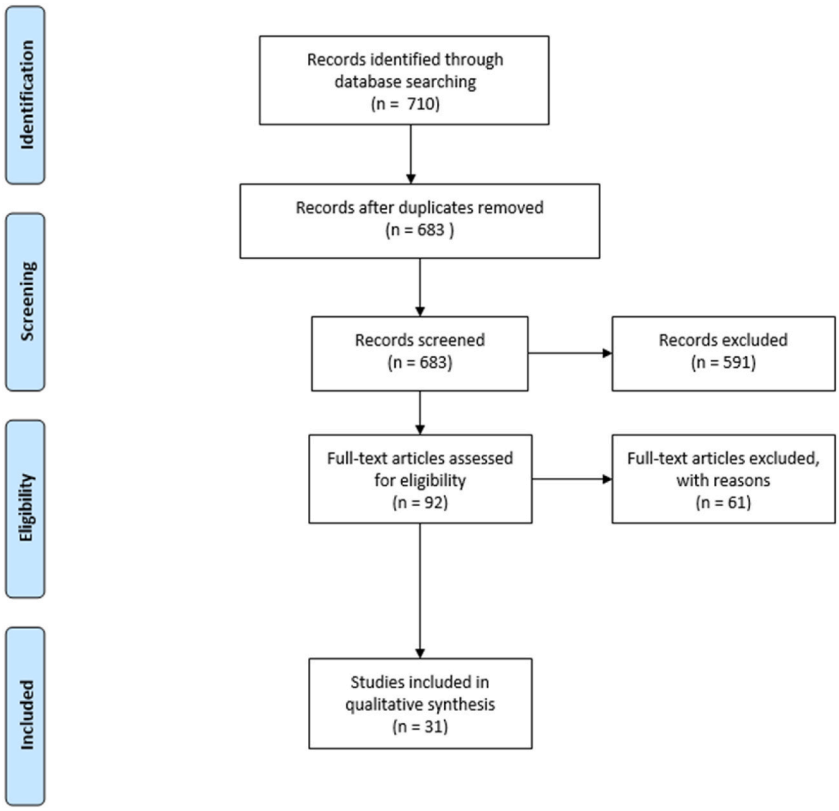

Fig. 2. Primary study review PRISMA chart.

Fig. 2).

After a detailed reading of the study abstracts and discarding the articles that did not entirely focus on this study's topic, 92 articles were eligible for the full text reviews. The set of articles were screened based on the following inclusion criteria: (1) the focus is on students' intrapersonal communication processes or interpersonal communication between students and the PA, (2) PAs' task-related or relational communication, and (3) PAs' communication that facilitates students' learning in a group. The articles in the final sample had to have at least one of these criteria, but many papers had more than one. In the end, 31 articles that discussed empirical investigations of PA communication were chosen, read thoroughly, and screened once more for their relevance to our research questions.

3.2. Data analysis procedures

First, in the umbrella review, the identified reviews and meta-analyses main findings that revealed the status and gaps in PA communication research were documented for the analyses. Second, in the primary study review, the analysis was conducted using a thematic analysis approach (Braun & Clarke, 2006). After familiarizing with the data, a close reading of each empirical study was performed by one of the researchers to extract key information related to this study's research questions. Notes were taken and then discussed with the research team. Later these were combined into three categories: (1) PAs' roles and communication actions, meaning which roles PAs have and how they communicate with students; (2) theories that were identified from the empirical studies theoretical background, discussion, or conclusion; and (3) the main findings on how PAs' communication facilitates learning.

4. Findings

4.1. Umbrella review: research findings on Student–Agent communication

The umbrella review was designed to establish the status of research on PA communication with students (RQ1) and thereby set the starting point for the primary study review (Table 1). The results revealed that PAs and their effect on learning have been under scrutiny; however, the research results are inconsistent and somewhat contradictory. Three paper reviews showed that PAs had only a slight impact on learning. PA research was depicted as overly complex, and PAs' effect on students' motivation and learning was questionable (Heidig & Clarebout, 2011). In an earlier review, PAs were found to have had only a small but positive effect on learning, and the researchers assumed that students preferred PAs possibly because they felt engaged when interacting with them (Schroeder et al., 2013). The recent meta-analysis (Castro-Alonso et al., 2021) reached the same conclusion: that learning with PAs was only slightly more effective than learning without them. Based on prior studies, PAs' impact on learning is broad and, despite the vagueness of the research results, PAs have been perceived as more beneficial than distracting.

Given the complexity of the PA research, the researchers have suggested redirecting the focus of studies on the conditions under which PAs foster learners' motivation and learning (Heidig & Clarebout, 2011). PAs' impact on learners was found not to be straightforward, and PAs reduced or caused extraneous cognitive load, depending on the situation (Schroeder & Adesope, 2014). Also, PAs could have a significant impact on motivation but, in contrast, had a relatively minor impact on knowledge retention and knowledge transfer (Guo & Goh, 2015). These reviews state that PAs seem to have an ability to motivate students, but such findings were unclear and need to be further investigated.

PAs have been embedded in learning environments to facilitate learning through communication, and PAs' interaction has benefited students, as students who have interacted with PAs have achieved higher cognitive performance compared to students who did not (Schroeder et al., 2013). The researchers assumed that interacting with PAs made students feel engaged, which consequently fostered learning (Schroeder et al., 2013). The researchers also indicated that students liked learning with PAs more than without them, which supports the assumption that students perceive PAs' interaction as social (Schroeder & Adesope, 2014). PAs communicate verbally and non-verbally, such as by gesturing, which was shown to be beneficial to students' knowledge transfer and retention (Davis, 2018). PAs' appearance also appears to play a role, and agents' appearances induced cognitive load differentially: humanoid agents reduced cognitive load and character agents increased cognitive load (Davis, 2018).

To sum up, the umbrella review confirmed the continued interest in studying the effects of using a PA for learning. However, the communication between students and PAs was not discussed in these six reviews, albeit that research shows that the learning situation

Table 1
Summary of the main results of the umbrella review.

Authors	Results
Heidig and Clarebout (2011)	Pedagogical agents' effectiveness on student's motivation and learning is not evident.
Schroeder, N. L., Adesope, O. O., & Gilbert, R. B. (2013)	Pedagogical agents have a small but significant effect on learning. Agents are more beneficial in K-12 education than in post-secondary studies and on-screen text is more effective than spoken language.
Schroeder, N. L., & Adesope, O. O. (2014)	Students may like studying with pedagogical agents better than without them and agents can motivate students under certain conditions.
Guo, Y. R., & Goh, D. H. L. (2015)	PAs have a significant impact on motivation but a relatively minor impact on knowledge retention and knowledge transfer.
Davis, R. O. (2018)	Pedagogical agents' gesturing is beneficial for learning and perception of the students.
Castro-Alonso, J. C., Wong, R. M., Adesope, O. O., & Paas, F. (2021)	Agents' characteristics, including nonverbal communication, motion, and voice do not moderate effectiveness. Agents help learning through multimedia, and different types of agents can be helpful.

in which PAs operate affects learning. Nonetheless, the same conclusions cannot be assumed in terms of learning unless we first map out related empirical research findings on PA communication. The results of the umbrella review corroborate the need for a specific review that considers PAs' instructional communication. In the next section, the results of the analysis of the empirical studies present PAs' communication impact on learning in the light of theories, the roles of PAs, and their communication actions.

4.2. Review of primary empirical studies

The thematic analysis of the research papers aimed to find out what elements have been studied empirically addressing the question of how PAs interact with students and how this interaction facilitates learning (Table 2). Specifically, phase two of the analysis focused on extracting information regarding PAs' roles and communication actions (RQ2), the identified and main utilized theories (RQ3), and how PAs' communication facilitates and impacts learning (RQ4). These themes are presented in the following sections, and the way they are related to each other is discussed in the Discussion section.

Table 2
Summary of agent's communicative actions and main findings.

Study	Communicative action	Main findings
McLaren et al., 2011a,b	Feedback, hints	Politeness affected low knowledge learners but not high knowledge learners.
McLaren et al., 2011a,b	Feedback, hints	Students benefited equally from polite and direct feedback and hints.
Behrend and Thompson (2012)	Feedback, normative/directive	Learner's control over the feedback style decreased significantly self-efficacy.
Veletsianos (2012)	Message, on-task/non-task	On-task messages were effective, but impersonal. Non-task messages were memorable but distracting and could cause uncanny-valley effect.
Lin et al. (2013)	Feedback, elaborate/simple	Students who received elaborate feedback scored significantly higher in learning results.
Okita & Schwartz, 2013	Feedback/recursive	Recursive feedback fostered the ability to solve new problems compared to direct feedback from competitive agents.
van der Meij (2013)	Instruct, motivational/ cognitive	Agents (motivational and motivational/control) led to higher scores on students' self-efficacy beliefs.
Chen and Chen (2014)	Facilitation, competitive peer learning	Agent's competitiveness could increase motivation and learning outcome.
D' Mello et al. (2014)	Facilitation, incorrect/ contradictory statements	Agent's incorrect or/and contradictory claims induced higher transfer.
Trevors, Duffy, and Azevedo (2014)	Scaffolding, feedback, prompts	Agent's prompts and feedback reduced ineffective learning activities but did not improve deeper level tactics.
Duffy and Azevedo (2015)	Scaffolding, feedback, prompts	Agents' prompts and feedback fostered self-regulative strategies.
Guo and Goh (2016)	Feedback, affective/neutral	Affective feedback benefited students' motivation, enjoyment, perceived usefulness and behavioral intention, but not learning outcome.
Tegos, Demetriadis, Papadopoulos, and Weinberger (2016)	Feedback, direct/undirect	Direct feedback to collaborate was more effective for knowledge acquisition and explicit reasoning.
Burgoon et al. (2016)	Support, guidance	Positive interactions increased perceived connectedness, feelings of being understood/receptivity, and dependability.
Tegos and Demetriadis (2017)	Scaffolding	Interventions improved individual's and group's learning outcomes.
Dinçer and Doğanay (2017)	Guiding	Agent's interaction had positive effects on learners' motivation, academic success and cognitive load.
Chen et al. (2018)	Feedback, emotional	Students preferred emotional feedback and disliked performance feedback. The combination of dialog and emotion was the most liked.
Yılmaz, Olpak, and Yılmaz (2018)	Support, metacognitive	Students who received metacognitive support scored significantly higher in self-regulation skills than control group.
Harley et al. (2017)	Scaffolding, prompts, feedback	Agent's prompts and feedback helped students to set collaboratively better learning goals.
Mohammadhasani et al. (2018)	Support, cognitive and emotional	Support benefited ADHD students' math learning.
Nielen et al. (2018)	Guidance, motivation	Guidance supported students with a genetic predisposition to attention problems learning.
Kautzmann & Jaques, 2019	Prompts, metacognitive	Metacognitive instruction led to greater improvement in metacognitive monitoring.
Fountoukidou et al. (2019)	Instructions	Agent's instructions led to increased self-efficacy, task performance, and task performance skills.
Yilmaz and Yilmaz (2019)	Support, metacognitive	Significant impact on motivation and metacognitive awareness and group processes.
Tärning and Silvervarg (2019)	Feedback	Agent's low self-efficacy feedback benefited both high and low self-efficacy students.
Daradoumis and Arguedas (2020)	Feedback, affective	Agent's affective feedback enhanced students' self-reflection.
Silvervarg et al. (2020)	Feedback, critical constructive	Agents positively affected students' responses to feedback and mitigated neglecting the feedback.
Lin et al. (2020)	Instruction, conversational/ formal	Agent's conversational style to instruct increased students' mental effort.
Song and Kim (2020)	Scaffolding, dialog	Agent's scaffolding enhanced learners' self-regulated learning skills.
Tan et al. (2020)	Message, loss-framed/gain-framed	Loss-frame messages were more engaging, motivating and prompted higher germane load. Gain-framed messages induced promotion focus learners' motivation.
Yilmaz and Yilmaz (2020)	Scaffolding, metacognitive support	Metacognitive support fostered students' attitudes towards collaborative learning but did not foster self-regulated learning skills.

4.2.1. Pedagogical agents' identified roles and communication actions

In the empirical studies, PAs were shown to have many communication roles, such as teacher, peer, mentor, and facilitator. PAs communicate with students through written or spoken language, but some PAs used both text messages and spoken language. Most of the reviewed PAs used only text messages, which were displayed in chats or speech bubbles, but some PAs used text-to-speech converters to turn text messages into audio messages. The PA's voice was often a computer voice, but in some cases a pre-recorded human voice was used as the PA's voice.

Several studies (see, e.g., Burgoon et al., 2016; Fountoukidou, Ham, Matzat, & Midden, 2019; Nielen et al., 2018; Song & Kim, 2020; Tegos & Demetriadis, 2017) show that PAs in digital learning environments scaffold, guide, instruct, and motivate individual learners, and that PAs also facilitate student collaboration and peer learning in groups. PAs' messages were task or non-task related, and PAs communicated with students by offering feedback, task-related messages, prompts, and hints to help the students to complete the learning task (Harley, Taub, Azevedo, & Bouchet, 2017; Lin et al., 2013; Veletsianos, 2012). PAs also communicated (see, e.g., Daradoumis & Arguedas, 2020; Kautzmann & Jaques, 2019; Tärning & Silvervarg, 2019) with students in a way that was supposed to support students' self-efficacy, self-regulation, motivation, and metacognition.

Often PAs gave feedback, which was given from the learning performance or the learning process and feedback and feedback styles, such as conversational, affective, elaborate, and polite, have been empirically studied. PAs' affective feedback was shown to have enhanced students' self-reflection and conceptual acquisition (Daradoumis & Arguedas, 2020). Students benefited equally from polite and direct feedback and hints (McLaren et al., 2011b), but when students were able to choose the feedback style, they preferred the PAs' emotional feedback over the feedback based on their learning performance (Chen, Chou, Tseng, & Su, 2018). Students who received elaborate feedback scored significantly higher in learning outcomes than students who received simple feedback (Lin et al., 2013); however, the politeness effect worked for low knowledge students but not for high knowledge students (McLaren et al., 2011a, b). A conversational feedback style to instruct increased students' mental effort and their interest in the learning material; however, without the PA, the material was perceived as easier to read (Lin, Ginns, Wang, & Zhang, 2020).

The preliminary evidence showed that students benefited from collaboration with a PA, particularly when the PA's feedback was timely and direct and students had a possibility to try the task again (Harley et al., 2017). Also, the students' personal attributes influenced how they received feedback. Students with dominant achievement goals or, in other words, highly motivated students, utilized the PA's prompts and feedback for their learning better than other students did (Duffy & Azevedo, 2015). One specific way to obtain feedback is recursive feedback from teachable PAs, which occurs when the teacher monitors how students use what has been taught. Students taught PAs (Okita & Schwartz, 2013) governing rules and received recursive feedback when the PA applied the learned rules in a game with a competitive agent. Students who received recursive feedback performed more competently in solving problems. Teachable PAs can be useful in many ways, such as in mitigating the resistance of lower-performing students to critical constructive feedback (Silvervarg, Wolf, Blair, Haake, & Gulz, 2020).

Students' and PAs' affective interaction and emotional connection have gained attention among researchers in recent years. Preliminary research (Harley et al., 2017) showed that learners are willing to engage with a PA and that prompts and feedback helped to set learning subgoals that led to better learning results than did less collaborative learning. For instance, PAs' affective feedback was found to foster students' motivation to learn and increase their enjoyment, but affective feedback did not affect their learning outcomes (Guo & Goh, 2016). Positive interaction between a student and a PA had a positive effect on their relationship and increased the students' feeling of being understood and engaged, but also their dependence on PAs (Burgoon et al., 2016). PAs' supportive communication has been shown to help students with cognitive disabilities; for instance, cognitive and emotional support benefitted attention deficit hyperactivity disorder (ADHD) students' learning (Mohammadhasani, Fardanesh, Hatami, Mozayani, & Fabio, 2018) and increased the unintentional vocabulary learning of students who had a genetic predisposition to attention problems (Nielen et al., 2018).

PAs use different types of messages when communicating with students, which have a different impact on learning. In a study by Veletsianos (2012), messages were divided into on-task and non-task messages, and in a study by Tan, Liew, and Gan (2020), messages were loss- or gain-framed. Veletsianos (2012) delivered three versions of the same tutorial, the first of which included on-task messages; the second, non-task messages; and the third, on- and non-task messages. The students perceived the on-task messages as effective but impersonal and the off-task messages as distracting but memorable. The addition of non-task messages to the on-task tutorial at first increased learning, but the further addition of non-task messages hampered both the students' learning and perception of the PA's abilities to communicate. The PA's non-task messages can create a feeling of unease (uncanny valley) because the students were often skeptical toward the PA's humanlike behavior and non-task communication (Veletsianos, 2012). The students perceived (Tan et al., 2020) the loss-framed messages (emphasizing negative outcomes) as more engaging and motivating but producing higher germane load than the gain-framed (emphasizing positive outcomes) messages. However, the gain-framed messages were found to motivate promotion-oriented students. An interesting aspect in PA communication research is learners' control over the PAs' communication style. Contrary to the researchers' hypothesis (Behrend & Thompson, 2012), learners' opportunity to choose the feedback style between direct (what to do next) and normative (in relation to other students) decreased their self-efficacy.

4.2.2. Theories identified in pedagogical agent communication research

PA communication research is multidisciplinary in nature, and the review revealed that theories identified in the introduction, background, discussion, or conclusion sections of the empirical studies originated primarily from education, communication, and psychology disciplines (see Table 3). Studies often included more than one theory, but most of the cited theories were only referred to in the background of the studies. To outline the main theoretical foundations of the analyzed empirical studies, only those theories, which were used to construct theoretical models, inform research questions and designs, or interpret results are discussed in more

detail in the following.

The analysis shows that *computers as social actors (CASA) paradigm* (Nass, Steuer, & Tauber, 1994), which originated from the *media equation theory* (Reeves & Nass, 1996), is a common theoretical foundation for empirical studies on PA's communication assuming that theories of learning, communication, and psychology are generally applicable to SAC. Looking more closely to the theories used, the reviewed empirical studies are mostly grounded on educational theories (36 cited), specifically cognitive load theory (10), social cognitive theory (10) and self-regulated learning (8), which is a social cognitive theory related concept. Studies that focused on self-efficacy have been counted under social cognitive theory since self-efficacy is also a related concept to this theory. From the field of psychology (15 cited), social agency theory (5) was most often used, and from communication discipline (11 cited), media equation theory (3) was slightly more frequently used than politeness theory (2).

Self-regulated learning (Zimmerman, 2002) is a concept that is derived from social cognitive theory (Bandura, 1991) referring to a student's ability to plan out learning, adaptively apply learning strategies, and maintain focus and motivation to achieve academic goals. Researchers have used it to understand if PAs can help students to learn more independently, and what kind of support improves self-regulation. PAs' metacognitive support was found to support self-regulated learning (Yilmaz & Yilmaz, 2019), for instance by providing metacognitive prompts (Song & Kim, 2020). Overall, the use of self-regulated learning theory has contributed to advancing the knowledge of PAs' scaffolding effects on students' intrapersonal learning processes and the role of metacognition (Song & Kim, 2020), self-efficacy (Tärning & Silvervarg, 2019), and students' motivation, metacognitive awareness, and group processes (Yilmaz & Yilmaz, 2019).

Cognitive load theory is a theory of individuals' information processing and use of working memory. Applied to the context of learning, the theory suggests positive cognitive load based on intrinsic load (effort to learn) and on germane load (effort to store the knowledge), but the theory also suggests that dividing attention between different information sources and processing peripheral information while learning can induce (extraneous) cognitive load. When PAs' non-task comments, which would fall under this peripherical information processing, were studied, the empirical results showed a statistically significant relationship that lots of non-task comments harm learning and perceptions of the agent's ability to interact with learners (Veletsianos, 2012). PAs were found to have a positive effect on cognitive load (Dinçer & Doğanay, 2017), and when PAs' feedback styles and appearance were investigated, both of which can be a source of cognitive load, the results showed that appearance or elaborate feedback was not found to increase cognitive load (Lin et al., 2013). PAs that used a conversational style of presenting instructions increased mental effort, which is an indication of intrinsic cognitive load, but at the same time students were more interested in the learning material (Lin et al., 2020). Loss-framed messages, which emphasize negative outcomes, were perceived as producing more germane load than gain-framed

Table 3
Identified theories on education, psychology, and communication disciplines.

Discipline	Relevant studies
Education (36)	
Cognitive load theory (10)	Veletsianos, 2012; Lin et al., 2013; van der Meij, 2013; Guo & Goh, 2016; Dinçer & Doğanay, 2017; Harley et al., 2017; Mohammadhasani et al., 2018; Fountoukidou et al., 2019; Lin et al., 2020; Tan et al., 2020
Social cognitive theory (10)	Behrend & Thompson, 2012; van der Meij, 2013; Mohammadhasani et al., 2018; Fountoukidou et al., 2019; Kautzmann & Jaques, 2019; Tärning & Silvervarg, 2019; Yilmaz & Yilmaz, 2019; Song & Kim, 2020; Tan et al., 2020; Yilmaz & Yilmaz, 2020
Self-regulated learning (8)	Trevors et al., 2014; Duffy & Azevedo, 2015; Harley et al., 2017; Yılmaz et al., 2018; Kautzmann & Jaques, 2019; Yilmaz & Yilmaz, 2019; Song & Kim, 2020; Yilmaz & Yilmaz, 2020
Cognitive theory of multimedia learning (4)	McLaren et al., 2011a,b; Dinçer & Doğanay, 2017; Lin et al., 2020
Cognitive affective theory of learning with multimedia (1)	D' Mello et al. (2014)
Attribution theory (2)	van der Meij, 2013; Chen & Chen, 2014
Expectancy-value theory (1)	van der Meij (2013)
Psychology (15)	
Social agency theory (5)	McLaren et al., 2011a,b; Dinçer & Doğanay, 2017; Lin et al., 2013; Lin et al., 2020
Self-determination theory (2)	Behrend & Thompson, 2012; Lin et al., 2020
Cognitive dissonance theory (2)	Behrend & Thompson, 2012; D' Mello et al., 2014
Regulatory focus theory (1)	Tan et al. (2020)
Theory of mind (1)	Okita & Schwartz, 2013
Control theory (1)	Okita & Schwartz, 2013
Interruption theory (1)	D' Mello et al. (2014)
Achievement goal theory (1)	Duffy and Azevedo (2015)
Transactivity theory (1)	Tegos and Demetriadis (2017)
Communication (11)	
Media equitation theory (3)	McLaren et al., 2011a,b; Veletsianos, 2012
Politeness theory (2)	McLaren et al., 2011a,b
Expectancy violations theory (1)	Burgoon et al. (2016)
Message framing theory (1)	Tan et al. (2020)
Group theory (1)	Veletsianos (2012)
Conflict theory (1)	Veletsianos (2012)
Uncanny valley theory (1)	Veletsianos (2012)
Media naturalness theory (1)	Burgoon et al. (2016)
No specific theory used (4)	Tegos et al., 2016; Nielen et al., 2018; Daradoumis & Arguedas, 2020; Silvervarg et al., 2020

messages, which emphasize positive outcomes (Tan et al., 2020).

Social agency theory has also been used in these studies. This theory suggests that social cues can prime students' social schema and increase their willingness to engage in social interaction, which can further foster students' efforts to understand PAs' communication. Studies utilizing this theory have focused on investigating communication as a social cue, including PAs' verbal and non-verbal communication. For instance, PAs' formative versus conversational instructions resulting in that conversational style can positively affect students' learning outcomes, cognitive load, and intrinsic motivation (Lin et al., 2020). Similarly, elaborate feedback, which is richer with social cues, was found to be better in facilitating students' learning than simple feedback (Lin et al., 2013). Furthermore, adding social cues such as politeness was consistent with social agency theory, at least with low-knowledge students who engaged socially with an agent (McLaren et al., 2011a). However, this effect was not found in the following research, and low-prior-knowledge students did not benefit more from politeness than high-prior-knowledge students (McLaren et al., 2011b).

Other theories used are related to communication theories which focus on communication processes and factors influencing the quality of communication between different social actors and institutions, and communication between humans and technology. Media equation theory (3) and politeness theory (2) were the top two theories cited, albeit none of the communication theories referred empirically dominated the PA research field (see Table 3). According to these theories, the underlying expectation is that people tend to respond to technology as if it was a human, and for instance, PA's politeness has been shown to induce students' willingness to engage socially with an agent (McLaren et al., 2011a,b). However, non-task messages, which were found to foster learning and interaction from a communication point of view, were also recommended to be kept to a limited amount, because too many non-task messages can potentially distract and create a sense of unease (uncanny valley) among technology users (Veletsianos, 2012). From a communication perspective, PAs have been experienced as social and, according to expectancy violations theory, humans have expectations toward agents and interactions with them that can be violated by an agent affecting interaction and communication processes (Burgoon, 2016).

Overall, it is clear from the analysis that the education field still dominates the theoretical foundations of empirical studies on PAs' communication, despite the fact that research points towards increasing our understanding of communication in human–machine interactions.

4.2.3. How pedagogical agents facilitate learning

The review of empirical studies showed how PA communication facilitates learning and identified four students' intrapersonal communication processes supported by PA communication: (1) self-regulation, (2) self-efficacy, (3) motivation, and (4) metacognition. Beside these, PAs communicate interpersonally with students and support students learning in a group.

First, self-regulated learning and students' self-regulation skills have become increasingly popular research topics for students' independent study in learning environments. Broadly, empirical studies show that PAs' communication has a positive effect on learners' motivation, academic success, and cognitive load (Dinçer & Doğanay, 2017), and prompts and feedback foster the use of self-regulated learning strategies (Duffy & Azevedo, 2015). The findings indicate that PAs' personally tailored questions in terms of goal setting, monitoring, and evaluation of learning benefit students (Song & Kim, 2020) and that PAs support students' self-regulated learning by helping them to set subgoals for their learning, which was particularly helpful when a PA and a student formed subgoals collaboratively (Harley et al., 2017). PAs' scaffolding for self-regulation has been seen to help reduce ineffective learning activities, although scaffolding did not induce deeper-level learning tactics (Trevors et al., 2014).

Second, PA communication affects students' self-efficacy, which is their belief that they can manage the learning task. Students who received instructions from a PA while learning reported higher self-efficacy, better task performance and task performance skills than others (Fountoukidou et al., 2019). Particularly, motivational and mixed instructions (motivational and cognitive) were found to be effective leading to higher self-efficacy beliefs (van der Meij, 2013).

Third, the studied PAs were embedded in digital learning environments, and PAs were found to help students' motivation to learn and perform, by, for example, adding competitive elements to a PA's characteristics (Chen & Chen, 2014). On the other hand, when a PA provided false or contradictory statements for students to decipher the scientifically correct answer, this element did not affect the student's learning, according to the students' self-reports (D'Mello, Lehman, Pekrun, & Graesser, 2014).

Fourth, PAs' communication can foster students' metacognition and use of metacognitive skills, as students who received metacognitive support from a PA scored significantly higher in self-regulation skills than the control group (Yılmaz et al., 2018). Similarly, students who received a PA's metacognitive instructions together with prompts and feedback, instead of only prompts and feedback, improved in monitoring their metacognitive knowledge (Kautzmann & Jaques, 2019).

In the context of computer-supported collaborative learning, PAs' metacognitive support has shown significant positive effects on students' motivation and awareness, but moreover, on group processes such as group cohesion and the group atmosphere (Yilmaz & Yilmaz, 2019). A subsequent study showed that a PA's communication improved students' attitudes toward collaborative online learning but did not improve their self-regulation skills (Yilmaz & Yilmaz, 2020). However, PAs' interventions in discussions and support for students to build prior knowledge and contribute to the course content improved learning outcomes (Tegos & Demetriadis, 2017). Similarly, the intervention improved the students' dyad performance and learning outcome; in particular, direct interventions fostered knowledge acquisition and explicit reasoning (Tegos et al., 2016).

5. Discussion

The aim of this study was to find out the status of research on PA communication and how it impacts students' learning. Only by understanding how current research is addressing this complex yet evolving phenomenon can we better plan and advance research

that can create an impact. The analysis of the empirical studies shows that PA communication can affect students' learning through (1) students' intrapersonal communication processes, (2) interpersonal communication between students and the PA, and (3) facilitating students' learning in a group. Below, the results are discussed to build an understanding of how PA communication facilitates learning by bridging the perspectives of communication, learning, and technology.

First, PAs' scaffolding, motivation, and support can initiate students' *intrapersonal* communication processes of metacognition, self-regulation, self-efficacy, and motivation. Intrapersonal communication comprises internal processes of communication including message interpretation, goal determination, and self-assurance (Shedletsky, 2017). These processes translate to SAC in the form of the student's interpretation of PAs' messages, self-regulated learning, and self-efficacy beliefs. In the classroom, teachers' instructional skills, such as immediacy, affinity-seeking, relational power, clarity, credibility, humor (Beebe & Mottet, 2009; Fei & Derakhshan, 2021), and effective ways of combining messages and relational communication (Allen, 2017), are known to be important when scaffolding students' intrapersonal communication processes. Nowadays, these abilities, embedded as PAs' features, are particularly needed when students are learning more independently in digital learning environments. However, it is notable that the distinction between intrapersonal communication and interpersonal communication is not straightforward, as PA interpersonal communication can help solve learning tasks and induce intrapersonal learning processes.

Second, at the *interpersonal* level, PAs scaffold learning by giving task-related messages, feedback, prompts, and hints during the learning process and from learning results. Adapting interpersonal communication is crucial for the quality of the teaching (Pennings et al., 2018), and instructional strategies, including feedback and prompts, can be intimidating, so teachers should mitigate their use (Brummernhenrich & Jucks, 2016). Learning is a socially engaging activity, and PAs can bring relational closeness to SAC, thus, PAs also should avoid intimidating language and, instead, be polite and sensitive. Social fidelity through personalized language, politeness, personality, and social memory, are promising ways to enhance closeness in the relationship between student and agent (Sinatra et al., 2021). Overall, the bulk of empirical studies show that PAs possess some interpersonal level capabilities that are relevant for pedagogical purposes, stressing the importance of instructional communication research in PA development.

Third, PA communication *scaffolds collaborative learning* by facilitating discussions and directing student collaboration. PAs improve learning in many ways, for example, by supporting group and individual performance, task and group awareness, and attitudes toward collaborative learning. In computer-supported collaborative learning (CSCL), PAs have been found to be useful, and in the future, the use of learning analytics and PAs could boost students' collaborative learning by pairing same-level students or, in turn, through peer learning with different-level students. This specific role of a PA has been found to play an important role in other domains, for instance in team collaboration in a working context (Laitinen, Laaksonen, & Koivula, 2021), indicating that PA can be a member of a team and foster group communication and collaboration. Opportunities for broader applicability across other research areas can be expected.

Showing affection is essential for communication and learning in real life and in digital learning environments. Students' experienced emotions can benefit learning, motivate, reduce intrinsic load, and widen the cognitive resources or help retrieve the information (Plass & Kalyuga, 2019). For a long time, there has been an aspiration for socially intelligent PAs (e.g., Wang et al., 2008). Modern technologies have made this aspiration more possible to become reality through speech emotion recognition (e.g., Zhang, Tao, Chuang, & Zhao, 2021), real-time emotion recognition (Harley, Bouchet, Hussain, Azevedo, & Calvo, 2015), AI that recognizes human emotions (Kaplan & Haenlein, 2019), and facial emotion recognition (e.g., Chowdary et al., 2021). These technologies could be used to detect students' affections to advance PA's anthropomorphic and adaptive communication. Adding affective elements should be considered, not least because students have been able to recognize the emotions of animated instructors (Lawson et al., 2021) which for researchers stress the significance of adding the elements that induce emotions in learning environments (Plass & Kalyuga, 2019). VR/AR environments could also be environments to pay attention to, since these environments with AI technology might be better suited to replicate anthropomorphic communication (Davis, Park, & Vincent, 2021).

Finally, this study pinpoints the central role of instructional communication in the research and development of PA. Usually, instructional communication is a process wherein meaning is created between students and teachers (Mottet, Richmond, & McCroskey, 2006). Researchers have suggested that PAs should have dialogues with students and deploy real teaching strategies (Dinçer & Doğanay, 2017), but SAC is not yet at the level of being a reciprocal communication process wherein meaning is mutually created. The PAs in this literature review were software-based, embedded in digital learning environments. Agents typically use pattern matching and string processing, but more advanced technologies enable agents to use complex knowledge-based models (Hussain et al., 2019), and emerging technologies will enable multiple agents with different strategies and communication styles at the same time (Lippert, Shubeck, Morgan, Hampton, & Graesser, 2019). Despite the advancements, effective, scalable, and robust dialog management techniques are still a challenge, but, for example, explainable AI could make a dialog management system more human-like as users can understand the rationale behind it (Brabra et al., 2021). However, at least for now, PAs are rather responsive to students' communication actions and cannot maintain a conversation, and, therefore, PA interaction cannot be called a reciprocal communication process.

5.1. Theoretical advancements in studying PA's communication in digital environments

The second contribution of this study is to learn more about the theoretical advancement in studying PAs' communication in digital learning environments. When looking at the empirical studies on the roles and communication actions of PAs and their impact on learning, it is possible to see a clear epistemological relationship in how the major theories have informed the research design and interpretation of the results and how these, in turn, support and validate existing theoretical assumptions as if they were on a two-way-influencing circle (see Fig. 3).

The choice of theoretical approaches clearly defines how the roles of PAs are designed. When looking at education and psychology theories, which have dominated research in this area and, respectively, address how learning is understood, what the PAs' roles are, and how students' feelings and thoughts have been seen to impact learning, it is possible to see a clear influence on what is studied concerning roles, communication actions, and learning outcomes. PAs have been designed to facilitate learning through communication, and social cognitive theory and self-regulated learning, in particular, have been used to study and explain students' independent learning in digital environments and which factors influence this learning. Social agency theory, for its part, has helped advance PA development and research concerning roles and communication actions from the perspective that social cues can evoke social schema leading to students' increased efforts to understand PAs' communication, which might lead to enhanced learning. On the other hand, cognitive load theory provides a theoretical lens, whereby through PAs' characteristics and actions that induce extraneous, intrinsic cognitive or germane load on learners' working memory have been examined.

Nonetheless, communication theories are limitedly used, despite the fact that communication plays a central role in education and in students' learning. Not much emphasis has been paid to social processes and how communication genre, patterns, and styles influence learning and SAC. According to the reviewed literature, PAs are treated as assistants rather than as teachers in learning situations. We argue that this may be because PAs' communication abilities and strategies in those empirical settings were not at the same level (in terms of capabilities and quality) as a teacher. The quality of PAs' communications is central to students benefiting from PAs' scaffolding and support. Despite the rapid development of conversational technologies, SAC still raises the fundamental question of how and to what extent instructional communication strategies are transferable to the communication between a student and an agent. However, it is known that instructional communication applies to digital contexts (Sellnow et al., 2015) and ease of communication increases students' likelihood to adopt agents in learning (Kim, Merrill, Xu, & Sellnow, 2020). So far, the main weight has been put on learning and psychology theories, but inconsistent results among different studies indicate that these theoretical approaches have not helped researchers in identifying best and effective practices to design PAs. Future research could leverage the potential of communication theories in describing, explaining, and predicting (Edwards & Edwards, 2017) SAC through the lenses of these technologies' communication skills.

As all the recent work suggests, PAs' interactions with students should simulate human-like relationships, and this means that PAs should recognize learners' emotions and respond to them to enhance SAC. This, however, requires research on new theories that recognize affective outcomes and their relationship to learning (Baylor, 2018). Recently, Schneider, Beege, Nebel, Schnaubert, and Rey (2021) have proposed the promising Cognitive-Affective-Social Theory of Learning in digital Environments (CASTLE) to study this phenomenon. The theory postulates that social cues trigger learners' social schemata, which can foster social (also parasocial), motivational, emotional, and metacognitive processes. Dynamic and even more interactive learning increases the richness of social cues, which is likely to activate social schema. Future research could consider taking a point of departure from CASTLE and exploring other scenarios and learning outcome factors.

A final implication informed by the qualitative analysis of the empirical studies relates to the fine line between balancing different technology affordances and features with their impact on students' learning. Depending on which theory was used, contrasting results in terms of learning effects (positive versus negative) were found. So, while one theory would suggest increasing certain features, for instance social cues, as a positive element for learning outcomes, another theory would suggest less features to reduce fatigue and cognitive load. Finding the right balance is hard but a necessary research effort. To address this balance question, we would suggest

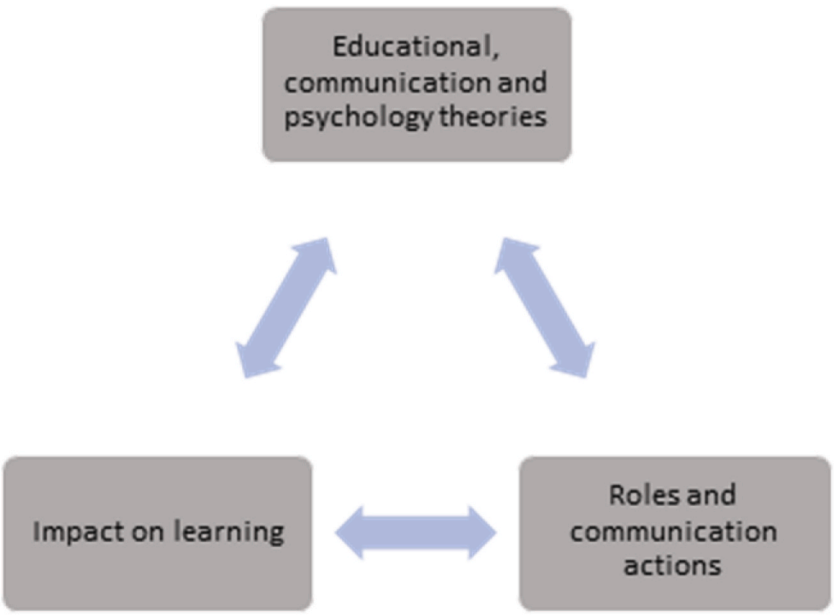

Fig. 3. Advancement of PA theory development.

increasing the involvement of end users, teachers, and students in the early phases of technological developments. Their insights could offer important value to develop user friendly conversational learning technology and should be part of the dialog between research and practice leading to the development of efficient products and helping researchers in advancing theory.

To sum up, the review shows a lot of untapped areas of research and confirmed the conclusion of Kopp and Krämer (2021) that PAs are not yet at the level of carrying on a "half-decent coherent conversation" (p. 1) with a human. Teaching and learning are inherently social and conveyed through communication, and the current technology cannot reproduce the complexity of human communication at a sufficient level. This review concludes that for effective SAC, communication needs to be as relational, adaptive, and adequate—therefore logical—as teachers' good quality instructional communication. However, this requires, in addition to rigorous theory-driven research, AI, affective computing, speech emotion, and facial expression recognition technology to detect and respond to students' emotions. Developing PA communication is important because, despite the shortcoming, students have perceived learning with PAs to be beneficial, and this inspires future research toward better SAC.

6. Conclusions and future directions

The umbrella review revealed a gap in early literature reviews concerning PA studies, which the second part of this study addressed by integrating scientific knowledge from three disciplines—education, technology, and communication—offering a systematic and holistic review. The study primarily contributes to synthetizing major findings on roles and communicative actions, major theoretical approaches, and the main findings of PA communication's impact on students' learning. This study contributes to making researchers aware of the current developments and sets an agenda for more relational, adaptive, adequate, and logical SAC research and development.

To bring PA communication to the level of carrying a reciprocal communication requires a multidisciplinary approach of applying different theoretical knowledge of learning, psychology, and instructional communication to studies on emergent technologies. Rigorous theory-driven study is needed to understand more deeply the communication between students and PAs, not only as interaction but as a reciprocal and effective communication process. Moreover, theory-based research should be used to test theoretical applicability and its heuristics in explaining SAC. This, in turn, will help understanding which theoretical variables do not apply and need to be reconsidered.

At first, we suggest that communication theories should be taken under scrutiny more intensively, as they might offer the needed extension to better understand PA communication. Such theories also address the need to shed light on relational aspects of SAC, such as students' trust and immediacy with a PA, which can enhance intrapersonal communication processes of self-regulated learning, self-efficacy, motivation, and metacognition. The second suggestion is to investigate PAs' supportive interpersonal communication and communication as a member of the group in VR/AR environments. Conversational technology is an area of interest in many fields, and the third suggestion would be to encourage collaboration with other disciplines that are interested in cross-sectorial benefits, for instance marketing and corporate communication. However, after all, the maturity of the technology sets the boundaries of how learning and communication theories are transferable to SAC, one of the challenges being that PA is at the same time communication partner (teacher/peer), computer system, and communication medium. Yet another challenge is that when developing natural language processing, minor languages often lack sufficiently large datasets that are required for reliable language processing development. Nonetheless, the future seems to be bright and, of the emerging new technologies, particularly promising are affective computing, speech emotion, and facial expression recognition, which can improve PAs' abilities to respond according to students' emotions. In addition, biometric research methods are an interesting measurement to confirm how students perceive PAs' communication, to free from a sole reliance on students' self-reported perceptions. We conclude that SAC should be developed in co-creation with instructional communication researchers and learning technology researchers, but most importantly with the end users, students, and teachers.

7. Limitations

This review, like all studies, has its limitations. PA communication is a multidisciplinary and multidimensional research subject pertaining mostly to education, communication, and technology. Knowing the complexity of this subject and its unexplored nature, we combined search strings from three domains to harvest all relevant articles. The scientific knowledge is scattered across these disciplines and identifying the common themes and terms from three different domains was often challenging. Thus, it is possible that some relevant articles outside these domains were unintentionally excluded. Another limit is that we focused only on English articles, so publications in other languages were not part of our sample. Since the search produced a lot of data, we had to set strict inclusion criteria which may have resulted in excluding some relevant work related to the phenomenon under scrutiny.

Credit author statement

Pieta Sikström: Conceptualization, methodology, analysis, investigation, data curation, writing- original draft, review, editing, visualization. Chiara Valentini: Supervision, methodology, writing- review, editingAnu Sivunen: Supervision, methodology, writing-review, editing. Tommi Kärkkäinen: Conceptualization, supervision, methodology, writing- review, editing.

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References

Allen, M. (2017). *The sage encyclopedia of communication research methods* (Vols. 1–4). Sage Publications, Inc.
Bandura, A. (1991). Social cognitive theory of self-regulation. *Organizational Behavior and Human Decision Processes, 50*(2), 248–287.
Baylor, A. L. (2018). *Three research directions for affective learning technologies*. International Society of the Learning Sciences, Inc.
Baylor, A., & Kim, Y. (2003). Validating pedagogical agent roles: Expert, motivator, and mentor. In *EdMedia+ Innovate learning* (pp. 463–466). Association for the Advancement of Computing in Education.
Baylor, A. L., & Kim, Y. (2005). Simulating instructional roles through pedagogical agents. *International Journal of Artificial Intelligence in Education, 15*(2), 95–115.
Baylor, A. L., & Kim, S. (2009). Designing nonverbal communication for pedagogical agents: When less is more. *Computers in Human Behavior, 25*(2), 450–457.
Baylor, A. L., & Ryu, J. (2003). The effects of image and animation in enhancing pedagogical agent persona. *Journal of Educational Computing Research, 28*(4), 373–394.
Baylor, A., Ryu, J., & Shen, E. (2003). The effects of pedagogical agent voice and animation on learning, motivation and perceived persona. In *EdMedia+ Innovate learning* (pp. 452–458). Association for the Advancement of Computing in Education.
Beebe, S. A., & Mottet, T. P. (2009). Students and teachers. In W. F. Eadie (Ed.), *21st century communication: A reference handbook* (pp. 349–357). Sage Publications, Inc.
Behrend, T. S., & Thompson, L. F. (2012). Using animated agents in learner-controlled training: The effects of design control. *International Journal of Training and Development, 16*(4), 263–283.
Bowman, C. D. (2012). Student use of animated pedagogical agents in a middle school science inquiry program. *British Journal of Educational Technology, 43*(3), 359–375.
Brabra, H., Báez, M., Benatallah, B., Gaaloul, W., Bouguelia, S., & Zamanirad, S. (2021). Dialogue management in conversational systems: A review of approaches, challenges, and opportunities. *IEEE Transactions on Cognitive and Developmental Systems, 1-1*, 1–15.
Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.
Brummernhenrich, B., & Jucks, R. (2016). He shouldn't have put it that way!" How face threats and mitigation strategies affect person perception in online tutoring. *Communication Education, 65*(3), 290–306.
Burgoon, J. K., Bonito, J. A., Lowry, P. B., Humpherys, S. L., Moody, G. D., Gaskin, J. E., et al. (2016). Application of expectancy violations theory to communication with and judgments about embodied agents during a decision-making task. *International Journal of Human-Computer Studies, 91*, 24–36.
Castro-Alonso, J. C., Wong, R. M., Adesope, O. O., & Paas, F. (2021). Effectiveness of multimedia pedagogical agents predicted by diverse theories: A meta-analysis. *Educational Psychology Review*, 1–127.
Chen, Z. H., & Chen, S. Y. (2014). When educational agents meet surrogate competition: Impacts of competitive educational agents on students' motivation and performance. *Computers & Education, 75*, 274–281.
Chen, Z. H., Chou, C. Y., Tseng, S. F., & Su, Y. C. (2018). Feedback of interface agents on student perception: Level, dialogue, and emotion. *Journal of Educational Technology & Society, 21*(1), 82–90.
Chiou, E. K., Schroeder, N. L., & Craig, S. D. (2020). How we trust, perceive, and learn from virtual humans: The influence of voice quality. *Computers & Education, 146*, Article 103756.
Chowdary, M. K, Nguyen, T. N, & Hemanth, D. J (2021). Deep learning-based facial emotion recognition for human–computer interaction applications. *Neural Computing & Applications*, 1–18.
Clarebout, G., & Heidig, S. (2012). Pedagogical agents. In Seel (Ed.), *Encyclopedia of the Sciences of learning*. Springer.
Daradoumis, T., & Arguedas, M. (2020). Cultivating students' reflective learning in metacognitive activities through an affective pedagogical agent. *Educational Technology & Society, 23*(2), 19–31.
Davis, R. O. (2018). The impact of pedagogical agent gesturing in multimedia learning environments: A meta-analysis. *Educational Research Review, 24*, 193–209.
Davis, R. O., Park, T., & Vincent, J. (2021). A systematic narrative review of agent persona on learning outcomes and design variables to enhance personification. *Journal of Research on Technology in Education, 53*(1), 89–106.
Dinçer, S., & Doğanay, A. (2017). The effects of multiple-pedagogical agents on learners' academic success, motivation, and cognitive load. *Computers & Education, 111*, 74–100.
D'Mello, S., Lehman, B., Pekrun, R., & Graesser, A. (2014). Confusion can be beneficial for learning. *Learning and Instruction, 29*, 153–170.
Domagk, S. (2010). Do pedagogical agents facilitate learner motivation and learning outcomes?: The role of the appeal of agent's appearance and voice. *Journal of Media Psychology: Theories, Methods, and Applications, 22*(2), 84.
Duffy, M. C., & Azevedo, R. (2015). Motivation matters: Interactions between achievement goals and agent scaffolding for self-regulated learning within an intelligent tutoring system. *Computers in Human Behavior, 52*, 338–348.
Edwards, A., & Edwards, C. (2017). The machines are coming: Future directions in instructional communication research. *Communication Education, 66*(4), 487–488.
Edwards, A., & Edwards, C. (2018). Human-machine communication in the classroom. In M. L. Houser, & A. M. Hosek (Eds.), *Handbook of instructional communication: Rhetorical and relational perspectives* (2nd ed., pp. 184–194). Taylor & Francis.
Edwards, C., Edwards, A., Spence, P. R., & Lin, X. (2018). I, teacher: Using artificial intelligence (AI) and social robots in communication and instruction. *Communication Education, 67*(4), 473–480.
Edwards, C., Edwards, A., Spence, P. R., & Westerman, D. (2016). Initial interaction expectations with robots: Testing the human-to-human interaction script. *Communication Studies, 67*(2), 227–238.
Edwards, C., Edwards, A., Stoll, B., Lin, X., & Massey, N. (2019). Evaluations of an artificial intelligence instructor's voice: Social Identity Theory in human-robot interactions. *Computers in Human Behavior, 90*, 357–362.
Fei, X., & Derakhshan, A. (2021). A conceptual review of positive teacher interpersonal communication behaviors in the instructional context. *Frontiers in Psychology, 12*, 26–23.
Fountoukidou, S., Ham, J., Matzat, U., & Midden, C. (2019). Effects of an artificial agent as a behavioral model on motivational and learning outcomes. *Computers in Human Behavior, 97*, 84–93.
Gnewuch, U., Morana, S., & Maedche, A. (2017, December). *Towards designing Cooperative and social conversational agents for Customer Service*. ICIS.
Goodnow, C. (1992). Strengthening the links between educational psychology and the study of social contexts. *Educational Psychologist, 27*(2), 177–196.
Grant, M. J., & Booth, A. (2009). A typology of reviews: An analysis of 14 review types and associated methodologies. *Health Information and Libraries Journal, 26*(2), 91–108.
Guo, Y. R., & Goh, D. H. L. (2015). Affect in embodied pedagogical agents: Meta-analytic review. *Journal of Educational Computing Research, 53*(1), 124–149.
Guo, Y. R., & Goh, D. H. L. (2016). Evaluation of affective embodied agents in an information literacy game. *Computers & Education, 103*, 59–75.
Guzman, A. L. (2018). What is human-machine communication, anyway. Human-Machine Communication. *Rethinking Communication, Technology, and Ourselves, 1–28*.
Guzman, A. L. (2020). Ontological boundaries between humans and computers and the implications for Human-Machine Communication. *Human-Machine Communication, 1*, 37–54.
Guzman, A. L., & Lewis, S. C. (2020). Artificial intelligence and communication: A human-machine communication research agenda. *New Media & Society, 22*(1), 70–86.

Harley, J. M., Bouchet, F., Hussain, M. S., Azevedo, R., & Calvo, R. (2015). A multi-componential analysis of emotions during complex learning with an intelligent multi-agent system. *Computers in Human Behavior, 48*, 615–625.
Harley, J. M., Taub, M., Azevedo, R., & Bouchet, F. (2017). Let's set up some subgoals: Understanding human-pedagogical agent collaborations and their implications for learning and prompt and feedback compliance. *IEEE Transactions on Learning Technologies, 11*(1), 54–66.
Heidig, S., & Clarebout, G. (2011). Do pedagogical agents make a difference to student motivation and learning? *Educational Research Review, 6*, 27–54.
Hill, J., Ford, W. R., & Farreras, I. G. (2015). Real conversations with artificial intelligence: A comparison between human–human online conversations and human–chatbot conversations. *Computers in Human Behavior, 49*, 245–250.
Hussain, S., Sianaki, O. A., & Ababneh, N. (2019, March). A survey on conversational agents/chatbots classification and design techniques. In *Workshops of the International Conference on advanced information Networking and applications* (pp. 946–956). *Cham*: Springer.
Johnson, W. L., & Lester, J. C. (2018). Pedagogical agents: Back to the future. *AI Magazine, 39*(2), 33–44.
Kaplan, A., & Haenlein, M. (2019). Siri, siri, in my hand: Who's the fairest in the land? On the interpretations, illustrations, and implications of artificial intelligence. *Business Horizons, 62*(1), 15–25.
Kappagantula, S. R. K., Adamo-Villani, N., Wu, M. L., & Popescu, V. (2019). Automatic deictic gestures for animated pedagogical agents. *IEEE Transactions on Learning Technologies, 13*(1), 1–13.
Kautzmann, T. R., & Jaques, P. A. (2019). Effects of adaptive training on metacognitive knowledge monitoring ability in computer-based learning. *Computers & Education, 129*, 92–105.
Kim, Y., & Baylor, A. L. (2016). Research based design of pedagogical agent roles: A review, progress, and recommendations. *International Journal of Artificial Intelligence in Education, 26*(1), 160–169.
Kim, Y., Baylor, A. L., & Pals Group. (2006). Pedagogical agents as learning companions: The role of agent competency and type of interaction. *Educational Technology Research & Development, 54*(3), 223–243.
Kim, J., Merrill, K., Xu, K., & Sellnow, D. D. (2020). My teacher is a machine: Understanding students' perceptions of AI teaching assistants in online education. *International Journal of Human-Computer Interaction, 36*(20), 1902–1911.
Kopp, S., & Krämer, N. (2021). Revisiting human-agent communication: The importance of joint co-construction and understanding mental states. *Frontiers in Psychology, 12*, 597.
Laitinen, K., Laaksonen, S. M., & Koivula, M. (2021). Slacking with the bot: Programmable social bot in virtual team interaction. *Journal of Computer-Mediated Communication, 26*(6), 343-36.
Lawson, A. P., Mayer, R. E., Adamo-Villani, N., Benes, B., Lei, X., & Cheng, J. (2021). Recognizing the emotional state of human and virtual instructors. *Computers in Human Behavior, 114*, Article 106554.
Lin, L., Atkinson, R. K., Christopherson, R. M., Joseph, S. S., & Harrison, C. J. (2013). Animated agents and learning: Does the type of verbal feedback they provide matter? *Computers & Education, 67*, 239–249.
Lin, L., Ginns, P., Wang, T., & Zhang, P. (2020). Using a pedagogical agent to deliver conversational style instruction: What benefits can you obtain? *Computers & Education, 143*, Article 103658.
Lippert, A., Shubeck, K., Morgan, B., Hampton, A., & Graesser, A. (2019). Multiple agent designs in conversational intelligent tutoring systems. *Technology, Knowledge and Learning*, 1–21.
Luger, E., & Sellen, A. (2016, May). Like having a really bad PA" the gulf between user expectation and experience of conversational agents. In *Proceedings of the 2016 CHI conference on human factors in computing systems* (pp. 5286–5297).
Makransky, G., Wismer, P., & Mayer, R. E. (2019). A gender matching effect in learning with pedagogical agents in an immersive virtual reality science simulation. *Journal of Computer Assisted Learning, 35*(3), 349–358.
van der Meij, H. (2013). Do pedagogical agents enhance software training? *Human-Computer Interaction, 28*(6), 518–547.
McLaren, B. M., DeLeeuw, K. E., & Mayer, R. E. (2011a). Polite web-based intelligent tutors: Can they improve learning in classrooms? *Computers & Education, 56*(3), 574–584.
McLaren, B. M, DeLeeuw, K. E, & Mayer, R. E (2011b). A politeness effect in learning with web-based intelligent tutors. *International Journal of Human-Computer Studies, 69*(1–2), 70–79.
Mohammadhasani, N., Fardanesh, H., Hatami, J., Mozayani, N., & Fabio, R. A. (2018). The pedagogical agent enhances mathematics learning in ADHD students. *Education and Information Technologies, 23*(6), 2299–2308.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & Prisma Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Annals of Internal Medicine, 151*(4), 264–269.
Mottet, T. P., Richmond, V. P., & McCroskey, J. C. (2006). Handbook of instructional communication. In *Rhetorical and relational perspectives*. Pearson Education Inc.
Myers, S. A. (2010). *Instructional communication: The emergence of a field* (pp. 149–159). The SAGE Handbook of Communication and Instruction.
Nass, C., & Moon, Y. (2000). Machines and mindlessness: Social responses to computers. *Journal of Social Issues, 56*, 81–103.
Nass, C., Steuer, J., & Tauber, E. R. (1994). Computers are social actors. In *Proceedings of the SIGCHI conference on human factors in computing systems* (pp. 72–78). ACM.
Nielen, T. M., Smith, G. G., Sikkema-de Jong, M. T., Drobisz, J., van Horne, B., & Bus, A. G. (2018). Digital guidance for susceptible readers: Effects on fifth graders' reading motivation and incidental vocabulary learning. *Journal of Educational Computing Research, 56*(1), 48–73.
Okita, S. Y., & Schwartz, D. L. (2013). Learning by teaching human pupils and teachable agents: The importance of recursive feedback. *The Journal of the Learning Sciences, 22*(3), 375–412.
Ozogul, G., Johnson, A. M., Atkinson, R. K., & Reisslein, M. (2013). Investigating the impact of pedagogical agent gender matching and learner choice on learning outcomes and perceptions. *Computers & Education, 67*, 36–50.
Pane, J. F., Steiner, E. D., Baird, M. D., & Hamilton, L. S. (2015). *Continued progress: Promising evidence on personalized learning*. Rand Corporation.
Pennings, H. J., Brekelmans, M., Sadler, P., Claessens, L. C., van der Want, A. C., & van Tartwijk, J. (2018). Interpersonal adaptation in teacher-student interaction. *Learning and Instruction, 55*, 41–57.
Plass, J. L., & Kalyuga, S. (2019). Four ways of considering emotion in cognitive load theory. *Educational Psychology Review, 31*(2), 339–359.
Reeves, B., & Nass, C. (1996). *Media equation: How people treat computers, television, and new media like real people and places*. Cambridge University Press.
Rheu, M., Shin, J. Y., Peng, W., & Huh-Yoo, J. (2021). Systematic review: Trust-building factors and implications for conversational agent design. *International Journal of Human-Computer Interaction, 37*(1), 81–96.
Richards, D., & Dignum, V. (2019). Supporting and challenging learners through pedagogical agents: Addressing ethical issues through designing for values. *British Journal of Educational Technology, 50*(6), 2885–2901.
Saarela, M., & Kärkkäinen, T. (2020). Can we automate expert-based journal rankings? Analysis of the Finnish publication indicator. *Journal of Informetrics, 14*(2), Article 101008.
Schneider, S., Beege, M., Nebel, S., Schnaubert, L., & Rey, G. D. (2021). The cognitive-affective-social theory of learning in digital environments (CASTLE). *Educational Psychology Review*, 1–38.
Schroeder, N. L., & Adesope, O. O. (2014). A systematic review of pedagogical agents' persona, motivation, and cognitive load implications for learners. *Journal of Research on Technology in Education, 46*(3), 229–251.
Schroeder, N. L., & Adesope, O. O. (2015). Impacts of pedagogical agent gender in an accessible learning environment. *Journal of Educational Technology & Society, 18*(4), 401–411.
Schroeder, N. L., Adesope, O. O., & Gilbert, R. B. (2013). How effective are pedagogical agents for learning? A meta-analytic review. *Journal of Educational Computing Research, 49*(1), 1–39.
Schroeder, N. L., & Gotch, C. M. (2015). Persisting issues in pedagogical agent research. *Journal of Educational Computing Research, 53*(2), 183–204.
Schroeder, N. L., Romine, W. L., & Craig, S. D. (2017). Measuring pedagogical agent persona and the influence of agent persona on learning. *Computers & Education, 109*, 176–186.

Sellnow, D. D., Limperos, A., Frisby, B. N., Sellnow, T. L., Spence, P. R., & Downs, E. (2015). Expanding the scope of instructional communication research: Looking beyond classroom contexts. *Communication Studies, 66*(4), 417–432.
Shedletsky, L. (2017). Intrapersonal communication. In M. Allen (Ed.), *The SAGE encyclopedia of communication research methods* (pp. 811–813). Sage Publications Inc.
Silvervarg, A., Wolf, R., Blair, K. P., Haake, M., & Gulz, A. (2020). How teachable agents influence students' responses to critical constructive feedback. *Journal of Research on Technology in Education, 53*(1), 67–88.
Sinatra, A. M., Pollard, K. A., Files, B. T., Oiknine, A. H., Ericson, M., & Khooshabeh, P. (2021). Social fidelity in virtual agents: Impacts on presence and learning. *Computers in Human Behavior, 114*, Article 106562.
Song, D., & Kim, D. (2020). Effects of self-regulation scaffolding on online participation and learning outcomes. *Journal of Research on Technology in Education*, 1–15.
Tan, S. M., Liew, T. W., & Gan, C. L. (2020). *Motivational virtual agent in e-learning: The roles of regulatory focus and message framing*. Information and Learning Sciences.
Tärning, B., & Silvervarg, A. (2019). I didn't understand, Í m really not very smart"—how design of a digital tutee's self-efficacy affects conversation and student behavior in a digital math game. *Education Sciences, 9*(3), 197.
Tegos, S., & Demetriadis, S. (2017). Conversational agents improve peer learning through building on prior knowledge. *Journal of Educational Technology & Society, 20*(1), 99–111.
Tegos, S., Demetriadis, S., Papadopoulos, P. M., & Weinberger, A. (2016). Conversational agents for academically productive talk: A comparison of directed and undirected agent interventions. *International Journal of Computer-Supported Collaborative Learning, 11*(4), 417–440.
Trevors, G., Duffy, M., & Azevedo, R. (2014). Note-taking within MetaTutor: Interactions between an intelligent tutoring system and prior knowledge on note-taking and learning. *Educational Technology Research & Development, 62*(5), 507–528.
Veletsianos, G. (2010). Contextually relevant pedagogical agents: Visual appearance, stereotypes, and first impressions and their impact on learning. *Computers & Education, 55*(2), 576–585.
Veletsianos, G. (2012). How do learners respond to pedagogical agents that deliver social-oriented non-task messages? Impact on student learning, perceptions, and experiences. *Computers in Human Behavior, 28*(1), 275–283.
Veletsianos, G., & Russell, G. (2014). Pedagogical agents. In M. Spector, D. Merrill, J. Elen, & M. J. Bishop (Eds.), *Handbook of research on educational communications and technology* (4th ed., pp. 759–769). Springer Academic.
Walker, E., & Ogan, A. (2016). We're in this together: Intentional design of social relationships with AIED systems. *International Journal of Artificial Intelligence in Education, 26*, 713–729.
Wang, N., Johnson, W. L., Mayer, R. E., Rizzo, P., Shaw, E., & Collins, H. (2008). The politeness effect: Pedagogical agents and learning outcomes. *International Journal of Human-Computer Studies, 66*(2), 98–112.
Xie, H., Chu, H. C., Hwang, G. J., & Wang, C. C. (2019). Trends and development in technology-enhanced adaptive/personalized learning: A systematic review of journal publications from 2007 to 2017. *Computers & Education, 140*, Article 103599.
Yılmaz, F. G., Olpak, Y. Z., & Yılmaz, R. (2018). The effect of the metacognitive support via pedagogical agent on self-regulation skills. *Journal of Educational Computing Research, 56*(2), 159–180.
Yilmaz, F. G. K., & Yilmaz, R. (2019). Impact of pedagogic agent-mediated metacognitive support towards increasing task and group awareness in CSCL. *Computers & Education, 134*, 1–14.
Yilmaz, R., & Yilmaz, F. G. K. (2020). *Examination of the effectiveness of the task and group awareness support system used for computer-supported collaborative learning* (pp. 1–26). Educational Technology Research and Development.
Zhang, S., Tao, X., Chuang, Y., & Zhao, X. (2021). Learning deep multimodal affective features for spontaneous speech emotion recognition. *Speech Communication, 127*, 73–81.
Zimmerman, B. J. (2002). Becoming a self-regulated learner: An overview. *Theory into practice, 41*(2), 64–70.