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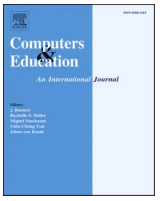

Pedagogical agents communicating and scaffolding students' learning: High school teachers' and students' perspectives☆

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ABSTRACT

Pedagogical agents (PAs) communicate verbally and non-verbally with students in digital and virtual reality/augmented reality learning environments. PAs have been shown to be beneficial for learning, and generative artificial intelligence, such as large language models, can improve PAs' communication abilities significantly. K-12 education is underrepresented in learning technology research and teachers' and students' insights have not been considered when developing PA communication. The current study addresses this research gap by conducting and analyzing semi-structured, in-depth interviews with eleven high school teachers and sixteen high school students about their expectations for PAs' communication capabilities. The interviewees identified relational and task-related communication capabilities that a PA should perform to communicate effectively with students and scaffold their learning. PA communication that is simultaneously affirmative and relational can induce immediacy, foster the relationship and engagement with a PA, and support students' learning management. Additionally, the teachers and students described the activities and technological aspects that should be considered when designing conversational PAs. The study showed that teachers and students applied human-to-human communication scripts when outlining their desired PA communication characteristics. The study offers novel insights and recommendations to researchers and developers on the communicational, pedagogical, and technological aspects that must be considered when designing communicative PAs that scaffold students' learning, and discusses the contributions on human–machine communication in education.

1. Introduction

Advancements in conversational technology's abilities to communicate have challenged us to reconceptualize interpersonal communication to include nonhuman communicators. According to the computers are social actors (CASA) paradigm (Nass et al., 1994; Nass & Moon, 2000), people tend to apply the same social scripts to both computers and humans. Technology has transformed from solely a transferring medium to a communication partner (Gunkel, 2012), and it can act in social roles, for example, as a teacher (Siegle et al., 2023; Spence, 2019). Increasingly, these technologies, such as pedagogical agents (PAs), have gained affective (Wang

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et al., 2023b) and conversational features (Lin et al., 2020), and researchers have called for novel research to describe, explain, and predict effective instructional communication practices with machines (Edwards & Edwards, 2018; Sikström et al., 2022).

Communication is a scripted process (Edwards et al., 2019), and teachers' communication has an essential impact on students' learning (Andersen et al., 1981; Khan et al., 2017). Thus, it is vital to understand which instructional communication characteristics should be applied in PA communication. Human–machine communication (HMC) research can provide opportunities to understand new types of communication with digital interlocutors (Guzman & Lewis, 2020; Hepp et al., 2024; Spence, 2019) and students' perceptions of agents' characteristics, message behavior, and relational skills (Edwards et al., 2018). Research on PAs' communication abilities is timely given the rapid advancements in generative artificial intelligence (AI) and large language models (LLMs) that offer possibilities for improving PA communication and interactions in unprecedented ways (Ali et al., 2024; Kasneci et al., 2023; Siegle et al., 2023).

In this study, PAs are defined as conversational learning technology that communicates with students using spoken language (e.g., an AI conversational agent), in written language (e.g., a chatbot), or non-verbally (e.g., a 3D character that employs gestures and expressions). PAs can act in different roles, such as a teacher or tutor, peer, or assistant, and they can exist in digital or virtual reality/augmented reality (VR/AR) environments or be embodied in nature (e.g., social robots). PA communication should be adaptive, adequate, relational, and logical (Sikström et al., 2022) but developing effective PA communication is a demonstrably complex process, and researchers acknowledge that it is still unclear how to develop effective communication with digital teachers (Alrajhi, 2024; Kim et al., 2021). Scholars have suggested using a multidisciplinary research approach to engineer robust conversational systems (Gunkel, 2012) and conducting studies with different learners in various instructional contexts (Jeon et al., 2023; Myers et al., 2016). It is surprising how rarely teachers' and students' insights have been considered during the development of learning technologies (Durall Gazulla et al., 2023), despite the positive impact of involving end users in the process has on the system's success (Bano & Zowghi, 2015; Vasconcelos et al., 2024). Several reviews over twenty years have shown that PAs are beneficial for learning (Castro-Alonso et al., 2021; Dai et al., 2022; Davis, 2018; Shroeder et al., 2013; Siegle et al., 2023), and the conditions under which PAs can be effective and appropriate are becoming clearer with time.

Yet, researchers have identified a gap on PA use by K–12 students and suggested to explore it as PAs have been shown to be more beneficial for younger pupils compared to postsecondary students (Schroeder & Adesope, 2014; Schroeder et al., 2013). This study addresses the research gap by exploring Finnish high school (general upper secondary education) teachers' and students' expectations of the essential communicational and technological features that should be implemented to ensure PA communication's success. Specifically, this study explores perceptions to respond to the following two research questions:

1. Which instructional communication capabilities should a PA possess?
2. Which technological aspects are necessary for a PA to effectively scaffold students' learning?

Qualitative methods, such as focus groups and interviews, seem particularly well suited for exploring how people experience digital devices and building new HMC knowledge (Guzman, 2023; Kim et al., 2020). Thus, the data was collected through semi-structured interviews in autumn 2022 and winter 2023. This study was confined to Finland, which is the leading country in digital learning (European Commission, 2020) and an early adopter of new learning technologies (Finnish National Agency for Education, 2022). The context was considered fruitful for exploring teachers' and students' insights regarding PAs, as technology acceptance is high, and both groups are likely to have some experience in using different technologies. The results extend HMC theory development to the instructional context by showing how teachers and students apply human communication behaviors when discussing their expectations and opinions on PAs' capabilities and opportunities for supporting students learning. In addition, the findings offer practical information that can be harnessed in technological development.

2. Literature review

2.1. Human–machine communication in the instructional context

In the future, teachers will increasingly design, monitor, and support students' learning and share teaching tasks using artificial agents (Edwards et al., 2018). Thus, it is essential to recognize new pedagogical communication practices and potentialities (LeFebvre & Keith, 2023), including how PAs can scaffold students' learning. Effective instructional communication enhances students' learning (Backlund, 2008), and developers know that mindful PA design can more intensively engage students in learning (Heidig & Clarebout, 2011). However, how and to what extent instructional communication behavior and practices apply to communication between a PA and a student is unclear. Teaching is fundamentally social (Goodnow, 1992), and teacher–student communication is interpersonal in nature, despite its educational origin (Wubbels et al., 2015). In the instructional communication literature, a teacher's communication has the following two dimensions: (1) relational, emphasizing the importance of the teacher–student relationship and mutual understanding, and (2) task-related, focusing on the teacher as the primary source of information (Frymier & Houser, 2000; Mottet & Beebe, 2006). Researchers argue that students respond to machines as they would to human teachers (Edwards & Edwards, 2018). As a result, immediacy, credibility, motivation, and learning can occur, even if one communicator is a machine or communication takes place in a simulated environment (Edwards & Edwards, 2017).

Increasingly, human and machine intelligence can be compiled, and "students and teachers are not only talking *through* machines, but also *to* them, and *within* technology" (Edwards & Edwards, 2018, p. 185). To develop effective AI systems, we must understand learner's goals and values, which requires perspectives from the social sciences and human learning (Sharples, 2023). Human

communication theories explain perceptions, information processing, and message behavior to provide relevant insights into HMC (Edwards et al., 2019; Westerman et al., 2020). Instructional communication research can contribute to HMC theory and practice because designing effective communication between a human and an agent demands an understanding of teachers' instructional practices (Edwards & Edwards, 2017). Thus, instructional variables can be used in HMC to establish positive communication in the educational context (Edwards & Craig, 2023), and in turn, HMC can provide theoretical venues and research methods for studying communicative AI and innovating new theoretical approaches (Guzman & Lewis, 2020; Richards et al., 2022). This is especially important because recent advancements in generative AI, particularly LLMs, improve significantly PAs' ability to communicate with students (Gill et al., 2024).

2.2. Pedagogical agent communication

PA communication should be adaptive, adequate, relational, and logical (Sikström et al., 2022), and advancements in technologies—namely generative AI, LLMs, and affective computing (AC) that interprets, and simulates human affects (Wang, Song, et al., 2022b; Pătruţ & Spatariu, 2016)—can improve PAs' abilities to adapt communication and perform natural emotional responses when communicating with students (Araujo and Bol, 2024; Kasneci et al., 2023). PAs that simulate affects enhance the student–technology relationship (Baylor, 2018). For example, affective PA increased students' positive emotions, improved intrinsic motivation, and facilitated learning performance (Wang et al., 2022a), and enthusiastic PA resulted in increased perceptions of positive emotions (Beege & Schneider, 2023).

Supported by Social agency theory (Mayer, 2014; Moreno et al., 2001), research shows that PAs communicating with social cues are more likely to induce students' willingness to learn (Mayer et al., 2020; Sinatra et al., 2021). Other important social cues are related to non-verbal communication, such as PA's facial expressions and gestures (Baylor & Kim, 2009), and personalized communication style; all essential for learning (Moreno et al., 2001; Moreno & Mayer, 2004, 2007). Thus, researchers suggest that future AI systems in education should create social relationships with learners as these systems assess relationships and adaptively deploy interaction-fostering behaviors (Walker & Ogan, 2016). Students have found studying with PAs to be more interesting than studying without them (Lin et al., 2020). For example, students who received PA support displayed improved learning results and deployed more cognitive and metacognitive self-regulated learning strategies than did students without such support (Dever et al., 2022, 2024). The key factors for students when adopting PAs are perceived usefulness and ease of communication (Kim et al., 2020). Studies have shown that an adaptive and conversational communication style has many benefits, similar to the classroom context. For example, in a comparative study, students perceived relational agents more favorably than functional ones (Kim et al., 2021). A PA's conversational style increased students' mental effort, resulting in increased efforts to learn (Lin et al., 2020). When higher education students were divided into three groups—learning with an affective PA, a neutral PA, or a neutral voice narration—the results showed that affective PAs induced high levels of emotion in students, students perceived instructions efficiently, and students' knowledge transfer significantly improved (Ba et al., 2021). This evidence forces us to reconsider how teaching and learning are organized in classrooms, what the teachers' roles will be in the future, and how PAs will be implemented in classroom activities.

3. Research methods

We adopted a qualitative research method to collect and analyze teachers' and students' insights and expectations of PAs' desired communication capabilities and behaviors when scaffolding students' learning. We conducted in-depth semi-structured interviews with eleven high school teachers and five focus-group interviews with sixteen high school students (with three to four students per group) during the fall of 2022 and winter of 2023. After the eleventh teacher interviews failed to produce significant new information, we concluded that the data had reached a saturation point (Guest et al., 2006). The same was done with the student focus groups, and the saturation point was reached after five focus group interviews.

3.1. Participants

The high school teachers and students were recruited by using a mix of convenience and snowball sample methods (Noy, 2008; Tracy, 2019). One contact person from a high school identified subject teachers, who were interested and had some experience with technology. These participants were contacted by phone and all of them were later interviewed. Two teachers then recommended their colleagues from other schools, who were contacted and interviewed. Two of the student focus groups were formed based on the school principal's invitation, and three students were invited through personal contacts, after which they formed independently their own focus groups. Each participant was emailed an invitation to the study and signed an informed consent document before the interviews commenced. The interviews and focus groups were run on Zoom in the Finnish language by the first author, were all recorded and later transcribed. The interviews with teachers lasted on average 47 min, whereas the focus group interviews lasted an average of 58 min. Quotes were later translated into English and checked for language consistency by another researcher who was not involved in the data collection. Six female and five male teachers were interviewed, specializing in subjects of history, social studies, philosophy, psychology, mathematics, information technology, biology, geography, physics, and languages, including English, Swedish, Finnish, German, and French. Their work experience varied from one to thirty-one years, the median years of experience being twenty years. The student focus groups consisted of twelve female students and four male students who were between fifteen and eighteen years old.

3.2. Data analysis

The interview transcripts produced rich and versatile qualitative data, which were analyzed using the thematic analysis procedure (Braun & Clarke, 2006). The first author familiarized with the data and screened teachers' and students' interviews separately. The features that reflected their insights were systematically highlighted throughout the data, and the codes were generated during the screening process. Themes can be identified before the data collection or during or after the data analysis (Croucher & Cronn-Mills, 2014; Ryan & Bernard, 2003; Scharp & Sanders, 2019). Potential themes were reviewed, revised against the extant literature, and then discussed and refined with three other authors. Simultaneously, descriptive quotes illustrating the teachers' and students' insights into sub-themes were extracted.

4. Results

The data analysis revealed four major themes related to the characteristics and capabilities that teachers and students would like a future PA to possess: 1) *communication characteristics*, 2) *PAs' activities*, 3) *technological aspects*, and 4) *characteristics of students who would benefit from PAs' support* (see Table 1). This study's results are presented in the following four sections. The first section presents the teachers' and students' insights into how a PA should perform relational and task-related communication when interacting and communicating with students. The second section demonstrates the activities that PAs are expected to perform when scaffolding students' learning. The third section focuses on the technological aspects and requirements that a conversional PA needs to meaningfully communicate with students. In the fourth section, the characteristics of students who would benefit from a conversational PA are discussed.

4.1. PAs' communication characteristics

The analysis shows that students and teachers think that PAs should primarily communicate like good teachers (i.e., in a positive and encouraging manner), because this kind of behavior induces enthusiasm and enhances students' motivation and engagement in their studies. PA communication must also be fluent and adaptive to make sense to students. As one student said, "So that a student can communicate with it, and it is not only one-way communication" (S5), and another teacher commented, "Conversational technology should be on the level of interacting meaningfully with students" (T2). Teachers and students believed that to experience support and closeness from a PA, it should be positive and express empathy for and interest in the student, which were also highlighted as teacher's most essential features. One teacher noted, "At some point, inducing feelings needs to come along when using a PA, and it can lead to attachment between a student and a machine" (T2). Teachers and students felt that for now, technology lacks the warmth of a teacher. The students and teachers liked meeting and communicating with one another, and informal chats were an important venue for supporting immediacy and building student–teacher relationships. As one teacher said, "I do not believe that a PA will reach the level where humans can communicate with each other" (T1). To effectively support a student, a PA should be able to detect a student's emotions and respond to them accordingly. One teacher said, "If technology could detect students' feelings and not just deliver the learning content" (T9). Teachers and students noted that adequate and affective communication can create a sense of immediacy between a student and a PA. As noted by one student, "A hint of humor or sarcasm would make a PA enjoyable. It would be funny if I had a little PA on my computer telling me things" (S7). This kind of *relational communication* creates an atmosphere in which students do not fear making mistakes and are encouraged to explore different venues for learning.

A PA's *task-related communication* can include prompts, hints, feedback, and questions which are communicative behaviors through which a PA interacts with a student. The students reported that balancing schoolwork, managing deadlines, and meeting other obligations in their lives caused stress, and they envisioned a PA as a learning companion helping them with their studies. One student noted, "I think a PA could give me ideas for developing and what could be improved if I had problems" (S3). However, these learning aids should be provided in a timely manner to avoid distracting students while they are focused on their studies. As commented by two students; "A PA should be fluent and not talk all the time so that a student can concentrate" (S4), and "Hints are good. It is easier if hints are given little by little if I do not understand. That way, it would not disrupt learning" (S3). The students underlined that PAs should deliver reminders in a friendly and polite way because demanding and unkind communication could add unnecessary stress. One student said, "If a PA would start reminding me that I have left some tasks unfinished, or I have not got good grades, I would tell it to shut up" (S4). The students said that timely feedback from a PA is valuable because it assists them in evaluating their learning progress. One teacher commented that, "Feedback should be encouraging, including questions about the student's feelings" (T3). Positive and encouraging feedback is particularly needed when a student faces difficulties, because failing at learning tasks negatively affects students' self-perceptions of themselves as learners. Additionally, a PA can provide supplementary information and learning materials that inspire students' interest in a given subject, particularly if they want to relate their learning to larger phenomena. One student said, "Students could also ask a PA questions, and it could explain the matter more in depth" (S14). However, the teachers and students were worried about misinformation and disinformation if a PA had unrestricted access to the internet. As one student commented, "I can't trust PA entirely, but it can offer a lot of help" (S6). In the case of contradiction wherein a PA would provide different information than did a teacher, the students said that they would believe their teacher.

Most importantly, the students and teachers said that for effective and reciprocal communication, a PA must be adaptive and adequate, and exhibit human-like behaviors to ensure engaging communication. As one student said, "If it feels like a PA answers like a human, it feels more reliable and credible. Then a PA's answer just did not appear from the internet" (S15). The students mentioned that if a PA fails to accommodate their needs and has frequent communication errors, it diminishes their trust and negatively impacts

Table 1
PAs' communication and technological characteristics.

Theme	Sub-theme	Sample quote
Communication characteristics	**Relational communication**	
	Empathetic	"PA needs to be empathetic, understanding, and flexible." (S7) "Inspiring, encouraging, and taking student's emotions into account." (T3)
	Adaptive	"PA should be adaptive, so that the conversation with a student is not one-sided." (S8) "It should adapt to a student's communication, just as teachers do." (T11)
	Encouraging	"It should be positive and encourage students when they study." (S1) "Most of all, students need encouraging, which however, can be offered by the PA." (T11)
	Motivating	"It could say something motivating to get started with the learning." (S5) "A PA could ask questions, communicate, and motivate students based on answers." (T10)
	Task-related communication	
	Feedback	"To provide feedback on learning, both when progress is being made and when it is not." (S6) "If a PA could give direct feedback, when certain criteria are met." (T6)
	Prompts and hints	"If you could get small hints that do not interfere with your own information seeking." (S4) "PA should not reveal the answer but rather provide hints that allow the student to find the answer on their own. (T10)
	Additional information	"It could increase interest if you could ask PA more specific questions related to the topic." (S16) "PA can serve as an additional source of information, helping a student to understand more comprehensively. (T9)
PA's activities	**Scaffolding learning process**	
	Helps concentrate	"PA should help you focus on studying, so you do not start fiddling with your phone." (S13) "Attentiveness detection would help a student in self-direction." (T9)
	Helps set goals	"Explaining the different methods what a student could use while learning." (S12) "Challenge a student to make independent decisions." (T2)
	Helps assess learning	"PAs could help develop ideas and help if there was a problem with a specific topic." (S3) "Automated assessment decreases teachers' assessment work." (T6)
	Personalizes tasks	"If you do not understand something, it could teach and simplify the learning content" (S14) "Individually tailored tasks enable personalized support." (T10)
	Practical learning support	
	Organizing tasks	"You can ask it, and it will explain how to proceed with the different tasks." (S13) "Many students struggle with organizing tasks, but PA could be a personal learning companion. (T7)
	Reminders	"It would be nice, if there was a PA that would remind me of the upcoming tasks." (S4) "Reminders, reminders—many students would benefit from having a personal assistant." (T9)
	Language learning	"PA could help when learning languages, grammar, and words." (S9) "An obvious area where PAs can be highly beneficial is language learning." (T7)
	Math learning	"It would be nice to see how a mathematical problem is solved, and PA would show the steps." (S6) "In areas where learning requires repetition, such as mathematics, students can practice their skills with a PA." (T10)
Technological aspects	Usability	"It is problematic, if PAs do not function well. It causes distrust." (S1) "PAs should be easy to use, and for example, offer automated assessment." (T6)
	Learning analytics	"PA could provide information to the teacher and student about learning progress." (S8) "Learning analytics support teachers' work and provide ready-made data." (T6)
	Emotion detection	"PA needs to recognize emotions, or it can't respond to a student's communication right." (S14) "Interacting with students requires recognizing emotions, which should also be PA's capability." (T3)
	Trustworthiness	"I should know who is behind a PA and has created it." (S15) "PAs should be ethical, with firmly established, universally known values." (T11)
	Privacy and reliability	"I need to be sure that my information will not be misused." (S13) "Above all, data security must be handled with certainty; students' information must not leak." (T3)
Characteristics of students who would benefit from PAs' support	Students with learning difficulties	"Someone who has difficulties in math or mother language, dyslexia or concentration, would like to study with a PA." (S5)

(*continued on next page*)

Table 1 (*continued*)

Theme	Sub-theme	Sample quote
		"If there is a student with special needs, whether advanced or requiring additional support." (T2)
	Neurodivergent students	"PA could work for autistic students or those who have difficulties in concentrating and therefore need additional support." (S11)
		"Neurodivergent students often need some form of special support, and PAs could be of great help in this regard." (T9)
	Gifted students	"Some students learn faster and could benefit from a PA." (S16)
		"Gifted students are often forgotten, but with a PA, could create an individualized learning path." (T7)
	Socially inhibited students	"For students who are afraid to ask a teacher, it could be easier to ask for help from a PA." (S14)
		"Interaction is difficult for some students; it could be easier to practice with a PA." (T3)

their willingness to engage with the PA. One student commented, "Can a PA be used in learning if it always says that it does not understand? It is a waste of time and worsens study results" (S4). However, the students did not expect a PA to communicate flawlessly. In fact, many students mentioned that if a PA's communication is too perfect and anthropomorphic, it could be unsettling and create an uncanny valley effect. Two students offered the following comments: "My first thought is oh no, definitely not, but in the future, PAs will be a normal thing" (S4), and "It is a little dystopic to think that a PA would have humanlike features, such as empathy" (S12). Teachers and students felt that current technologies lacked the advanced communication capabilities needed to establish or maintain meaningful relationships with students. One student commented that, "It is difficult to think that a PA would say that I am doing a good job. Keep up the good work" (S7), and another student stated: "I cannot trust PAs like I trust humans because it is easier to interpret human gestures. PAs do not have gestures, or if they do, the gestures are not authentic" (S3). The students pictured PAs as assistant teachers or learning companions and said that they did not want fully machine-based instruction. As one student said, "I want my teacher to be a real person and not just a talking block" (S4). Supportive communication from PAs was viewed as reducing students' fear of making mistakes and helping them utilize their resources for learning more effectively, particularly in independent online study environments.

4.2. PAs' activities

A PA *scaffolds* students' self-regulated learning by assisting their internal learning processes; helping them to concentrate, set goals, assess learning progress, and personalize learning tasks to meet students' individual needs. In one teacher's opinion, "It should help build individualized learning paths and accommodate the level of difficulty and offer tasks that match a student's interests" (T11). According to the interviewees, a PA could assist students in regulating their learning and tracking their progress by helping them set personal learning goals and providing feedback. Teachers also noted that PAs should evaluate a learner's prior knowledge, tailor learning materials and tasks to individual needs, and continuously assess and adjust the learning content based on the student's progress. One teacher said, "A PA could ask preliminary questions through which it can identify what type of learner a student is" (T6). Additionally, a PA can suggest personalized learning content and learning strategies for students. As commented by one teacher, "PAs can individualize teaching and give different students different learning tasks discreetly" (T8). The teachers thought that one of their most important skills was motivating students to learn. The students said that high school studies are demanding and that they need a teacher's motivation and encouragement; however, they thought that PAs could also boost their motivation and self-efficacy. The teachers emphasized that when a PA supports a student, it should avoid directly providing the solution. Instead, it should gradually offer hints and pose questions that encourage students to think critically and solve problems on their own, which is more effective for learning and retention. One student commented, "A PA could give little hints, if a teacher cannot help, a student can receive help from it" (S4). In classroom settings, where students increasingly struggle to maintain attention, a PA could offer methods to stay focused by detecting students' emotional states and adjusting its communication accordingly. One teacher said, "A PA should be sensitive and emotionally intelligent to interpret a student's motivation" (T6). The teachers found competing distractions in digital worlds frustrating (i.e., students checking social media or playing internet games instead of studying). As one teacher said, "A PA could redirect students by gently reminding them to continue studying if they are daydreaming or playing internet games" (T9). The students and teachers also envisioned a PA offering *practical learning* support. This could involve helping students manage their learning activities, such as reminding them of upcoming deadlines and assisting with homework and assignments. As said by one teacher, "It will be an assistant that is used to support learning" (T1). PAs were seen as effective learning companions in math and foreign languages because they could rehearse learning tasks with students that are more effective with repetition. One teacher noted, "A PA should be able to teach concepts, train students with calculation equations, and help with mathematical applications" (T7).

4.3. PAs' technological aspects

Above all, it is crucial that PAs are easy to use, convenient, and reliable for students and teachers. As one teacher stated, "It is the kind of technology that eases teachers' work. It should have good design, the possibility of making modifications, and of course, it should be easy to use" (T2). The teachers noted that new learning technologies are often complex and time-consuming, and if a PA is

difficult to integrate into teaching, it discourages teachers from adopting it. The teachers' main requirements for PAs were that they help reduce teachers' workloads and scaffold student's individual learning. For example, "A PA could generate the level of the learning tasks or offer individualized learning materials" (T1). However, the teachers believed involving themselves and the students in the development and testing of the PA was essential. This would provide developers with insights into the features needed for the PA to be effective in real-life contexts. One student noted, "Some agents are really elementary, but more advanced agents can provide teacher-level responses" (S7). The teachers also observed that students are not as proficient with technology as often assumed. While some students are adept with digital tools, many have limited skills, mostly confined to social media. PAs should be easy for everyone to use, as one teacher remarked, "Students should be able to use learning technologies with minimal difficulty; it shouldn't be complicated" (T6).

The teachers were especially interested in applying learning analytics to PAs, which would allow them to monitor students' learning performance and help identify students who require additional assistance. As one teacher said, "Learning analytics is an important part of supporting teachers' work, providing the data that is ready for use" (T6). The teachers suggested that a PA could send notifications when a student was performing unusually poorly. One teacher said, "It could also help in self-assessment, so that a student gets a more realistic picture of what they know and what their challenges are" (T9). Information collected through learning analytics also offers teachers an opportunity to assess the effectiveness of their teaching and whether they need to adjust their teaching methods. The teachers said that they adjust their teaching methods to fit students' emotional states in a classroom. Thus, PAs should similarly detect and analyze students' learning progress and adjust their assistance and communication to fit each student's needs. Furthermore, the teachers assumed that AI-driven technologies would induce emotions in students when they communicated with PAs. One teacher commented, "When AI can teach itself, then it can learn from students' reactions, and it is only a positive thing" (T3). This kind of affective interaction simulates the teacher-student relationship, fostering a sense of closeness between the student and the PA, potentially leading to increased motivation and effort from the student.

4.4. Characteristics of students who would benefit from PAs' support

The teachers welcomed PAs into the classrooms to assist them because they believed that teachers' role in guiding and supporting students' learning with technology was changing. The teachers also agreed that sharing some of their teaching responsibilities with a PA would reduce their workload, allowing them to focus on students who need enhanced learning help. As one teacher said, "If a teacher has pedagogically planned an individual learning path, a student can test their knowledge level, and a PA could ask if a student needs help to proceed" (T3). However, the teachers also believed that students require personal support, as one teacher commented, "There can be a lot of things where students need human contact, and problems that need a teacher's help" (T5). In addition, teaching is inherently complex, for instance, designing a comprehensive curriculum, as stated by a teacher, "I do not believe that AI could determine what is useful at the moment" (T2).

Although the concept of a PA replacing a teacher seems far off, both teachers and students recognized significant potential for PAs to assist with learning and teaching across various contexts. In the teachers' and students' opinions, three different student groups stood out as potential groups to particularly benefit from the use of a PA. The first group was neurodivergent students, such as individuals with autism spectrum disorder or attention deficit hyperactivity disorder, who are challenged by inattentiveness, impulsivity, or an inability to communicate with their peers. The second group consisted of students with learning disabilities who require additional repetitions to learn effectively, particularly in subjects like math and languages. One student said, "Someone can have challenges in math or languages or difficulties in reading and writing" (S5). The third, and oft-forgotten, group was highly gifted students. They usually study independently and follow tailored learning paths at their own pace but lack sufficient support from their teachers. As one teacher noted, "These days, teachers do not have time to have an encounter with every student, and gifted students are often self-directed. They would benefit from tailored learning paths with a PA" (T11). PAs could help individualize gifted students' learning and offer additional information and support to those who are ahead of others. Fourthly, PAs could also benefit students who dislike social interactions by offering a more comfortable way to practice communication skills, such as in language learning, without having to ask for help from the teacher. One teacher said, "Students who are shy and introverted, who are afraid of encountering others, could practice their thinking skills with a PA" (T2).

5. Discussion

The interviewed high school teachers and students represented the end-user segments that must be considered when designing PA communication. This discussion bridges the gap between teachers' instructional communication and PAs' communication capabilities. The first research question asks which of the communication characteristics are essential and should thus be implemented in PA communication. The second research question addresses teachers' and students' insights into the technological aspects that are necessary for a PA to effectively scaffold students' learning. Finally, we reflect on this study's contributions to the theoretical knowledge of HMC in the instructional context by discussing how teachers and students employ human-to-human scripts to identify the desired PA communication behavior. By doing so, we inform researchers and developers of the communicational, pedagogical, and technological aspects that must be considered when designing communicative PAs that scaffold students' learning.

5.1. How PAs should communicate with students

People seek to employ the same patterns to evaluate interactions with machines as they do when they are communicating with

other people (Edwards et al., 2019). This study's results show that teachers and students apply teachers' instructional communication behavior to PA communication, and teacher's communication is the baseline teachers and students use to assess what communicative behaviors PAs should perform. Both the teachers and students believed that a PA should communicate similarly to a good teacher and described PA communication as having two dimensions that are known from the instructional communication literature: *relational* and *task-related communication*.

Teachers use *relational communication* in day-to-day encounters with students when they chat about things unrelated to schoolwork, such as common interests and everyday news. They also show care for students by asking, for example, how they are doing. Contrary to predictions that teachers will be replaced (Bodkin, 2017), the teachers and students said that technology cannot replace in-person encounters and communication. Supportive teacher communication fosters student learning (Burleson, MacGeorge, Knapp, & Daly, 2002), and positive and equal teacher–student relationships are important to both students and teachers (Claessens et al., 2017; Li et al., 2022). The students perceived teachers who communicated relationally and shared personal information as relatable and easy to approach, which was especially important if a student had concerns, they wanted to share with a teacher. Emotions are essential in a classroom environment, and teachers use different strategies for affinity seeking and getting students excited about the subject being taught (Gorham et al., 1989). PAs should also be able to induce emotions in students and respond accordingly to students' emotions. Many studies have shown that affective PAs positively impact students' emotions. For example, a happy PA increases students' happiness (Wang et al., 2022a), and an enthusiastic PA results in positive effects and increased retention (Beege & Schneider, 2023). Learning with a positive PA resulted in better learning outcomes, as students paid attention to relevant elements while learning (Wang et al., 2023a,b). Affective interactions also positively impact information's perceived usefulness (Schroeder et al., 2017). To respond to a student's emotions, a PA requires integrated emotion detection technology that recognizes the communication situation and adjusts the conversation according to the student's personal preferences and prior discussions.

Students have individual ways of learning, and teachers adapt their teaching methods to address students' cognitive and affective learning goals. In the same way, a PA should scaffold students' personal strengths and provoke learning processes by providing feedback, questions, prompts, hints, and supplementary information, together with assistance in managing learning tasks and sending reminders of upcoming deadlines. Clear teacher communication helps students select, understand, and remember lesson content (Titsworth & Mazer, 2016). Similar to a teacher's *task-related communication*, clear, concise, and friendly PA communication helps students understand the essentials of the learning material. In prior studies, students preferred PAs' instructional communication style (Lin et al., 2020), and behavioral modeling improved students' self-efficacy beliefs, declarative knowledge, and task skills (Fountoukidou et al., 2019). A PA's task-related communication can stimulate students, as well as activate, encourage, and clarify learning content to inspire students to use individualized learning strategies, which can foster learning and improve the learning experience. A teacher's credibility, clarity (Mazer & Graham, 2015), immediacy, and support for students' self-efficacy beliefs enhance their learning and motivation (Frymier & Houser, 2000). Similarly, a PA must support students' self-efficacy (e.g., their belief in their ability to complete learning tasks) and induce their intrinsic motivation during the learning process. Additionally, clear and timely task-related communication can help students regulate their learning processes and manage learning tasks. To sum up, PA's relational communication increases students' trust and engagement, and task-related communication fosters students' learning progress.

According to Social Agency theory (Mayer, 2014), social and emotional cues, such as personalized language (Lin et al., 2020; Moreno et al., 2001) and non-verbal communication (Castro-Alonso et al., 2021; Li et al., 2019), can prime social responses leading to deeper cognitive processing and learning (Mayer, 2014; Horovitz & Mayer, 2021). Embodied PAs communicate verbally and non-verbally displaying gestures and facial expressions. Learners have preferred embodied PAs compared to non-agent multimedia learning systems (Mayer et al., 2003; Schroeder & Adesope, 2014). The embodiment principle suggests that people learn better when a PA expresses humanlike behaviors such as gestures, movements, eye contact, and facial expressions (Mayer, 2014). We argue in line with Xie et al., 2023; Sinatra et al., 2021 that a PA's physical appearance and *visual non-verbal communication* can foster comprehension and feeling of connectiveness with a PA. Furthermore, if students had an opportunity to modify an embodied PA's appearance, for example gender or ethnicity, and communication style to fit their own preferences, a PA's support might be perceived as more personalized and effective. However, it is important to ensure when developing PA communication that verbal and non-verbal communication are cohesive and mutually supportive (Isbister & Nass, 2000).

Communicative technologies have been perceived as socially present (Schuetzler et al., 2020), and anthropomorphism increases likelihood of achieving the desired communication (Munnukka et al., 2022). Students wanted to feel immediacy, and the PA's reciprocity impacts their perception of its social presence, which furthermore is likely to increase student–PA engagement. Researchers have suggested designing relational PAs that assess the relationship with a learner and apply social behaviors within the relationship (Walker & Ogan, 2016). We claim that embodied PAs are perceived as more authentic and relatable when they offer both verbal and non-verbal cues that increase the perception of humanlikeness of the PA. To improve PA's visually expressed non-verbal communication, we suggest prioritizing high quality graphics that display PA's facial expressions, gestures, postures and eye contact recognizably for better overall communication experience and the perception of engagement and relatedness.

5.2. Practical contributions

PAs can improve learning when they have human-like features (Dai et al., 2022). The type and maturity of technologies influence how accurately a teacher's instructional communication behavior can be replicated in PA communication (Sikström et al., 2022). Generative AI's and LLMs' rapid development, together with emotion detection technologies, are prominent venues for engineering emotionally intelligent and adaptive student–agent communication. The use of LLMs can engage students in communication that generates various ways of expressing ideas, developing arguments, conducting research, solving problems, facilitating design

processes, creating stories, and providing tools for exploring and interpreting data (Sharples, 2023). Teachers' and students' expectations of PA communication capabilities influence their perceptions, attitudes, and adoption of PAs. A recent review noted that "perceived usefulness, performance expectancy, attitudes, trust, and effort expectancy significantly and positively predicted behavioral intention, willingness, and use behavior of AI across multiple industries" (Kelly et al., 2022, p. 1). In this study, the teachers and students emphasized that usefulness and ease of use are key requirements. If a PA appears to be difficult to use or learn, it becomes a barrier to adoption. PAs should be developed to meet users' expectations to avoid frustration and dissatisfaction (Chaves & Gerosa, 2021; Dai et al., 2022). Therefore, it is important to involve end users in the development and testing processes and explore their preferences regarding a PA's design and communication.

The increased use of conversational technologies raises the demands of social behavior that are characteristic of communication between humans (Chaves & Gerosa, 2021). Predictable behavior is prevalent in human–human interactions. Similarly, agents with predictable behavior positively impact task performance, reliance, and trust, while decreasing cognitive load (Daronnat et al., 2020). Researchers argue that trust is the key element in human–technology interactions addressing the following three trust-enhancing areas: transparency, predictability, and explainability (Ciechanowski et al., 2019). Social agents in education are predicted to be able to acquire, consolidate, remember, and transfer knowledge from internet sources in the future (Sharples, 2023). Therefore, adequate, logical, adaptive, and relational PA communication (Sikström et al., 2022) is likely to enhance the perception of predictable and reciprocal communication. Explainable AI can foster teachers' and students' trust in PAs by enabling users to anticipate interactions with the technology, ensure reliable functioning, and maintain data privacy and security. Transparency is especially crucial when a PA is connected to the internet, as teachers and students need to understand how information is selected and validated. Enhancing trust through predictability, transparency, and explainability is important as it can reduce teachers' and students' technology-related stress.

5.3. Theoretical contributions to human–machine communication research

Guzman and Lewis (2020) have outlined three aspects in the HMC research agenda of communicative AI: (1) how people understand communicative AI as a communicator, (2) the relational dynamics of humans and communicative AI, and (3) the metaphysical implications that blur ontological boundaries between humans and machines. PAs are increasingly driven by general AI, and this study specifically addresses the first two, but implications for the third one can be made too.

Concerning the first aspect, the findings contribute to a better understanding of the PA's functional dimensions which focus on "how certain AI technologies are designed as communicators and how people perceive them within this role" (Guzman & Lewis, 2020, p. 75). The teachers and students predicted that PAs play assistive roles in scaffolding students' learning and lessening teachers' workloads. PA communication should be reciprocal and adaptive, but a PA's technological capabilities impact how accurately PAs can replicate human communication (Sikström et al., 2022). The teachers and students adjusted their expectations according to their impressions of a PA's communication capabilities. Humans do not expect a machine to have communication abilities as strong as another human, so they attempt to manage communication situations by interpreting communication mistakes and reformulating their own communication (Mavrina et al., 2022; Rosenthal-von der Putter & Koban, 2023). For example, people experienced fewer negative and uncanny valley effects when interacting with a simple text-based chatbot than when interacting with an animated character (Chiu, Moorhouse, Chai, & Ismailov, 2023). A realistic understanding of a PA's functionality and communication capabilities helps teachers and students anticipate PA's communication, thereby reducing technology-related stress. Difficulties and misbehavior violate communication with and trust in the PA, which would negatively impact students' learning and willingness to interact with PAs. Future research could explore how teachers' and students' expectations regarding positive and negative deviations in PA communication impact their perception of communication.

Regarding the relational dimension, which explores "how people understand AI in relation to themselves and themselves in relation to AI" (Guzman & Lewis, 2020, p. 77), human-to-human interaction scripts influence interactions with machines, as prior experiences shape how individuals select, modify, and use communication scripts (Edwards et al., 2019). For example, a teacher's positive social presence affected students' anticipation and generated positive expectations of an educational agent (Kim et al., 2022). This study confirms that students and teachers employ human-to-human interaction scripts and use the teacher's communication as a baseline for identifying their expectations of a PA's communication capabilities. Technology is a new kind of communicator (Guzman & Lewis, 2020), and people evaluated humans' and chatbots' functional communication aspects similarly, but not the relational aspects (Lew & Walther, 2023). In this study, the students were more receptive to the idea of task-related communication from PAs, such as hints and additional information, and showed more reluctance towards the idea of PAs' relational communication. We suggest aligning with Gambino et al. (2020), that while students and teachers use human-to-human communication scripts, they do so with mindful consideration rather than mindlessly. However, it is notable that students and teachers often have limited experience with PAs, leading them to rely on communication scripts from human-to-human interactions, which they adapt to the context of interacting with a PA.

Lastly, our study contributes to research on these technologies' metaphysical dimensions which focus on "how this ontological divide between person and technology is shifting along with it" (Guzman & Lewis, 2020, p. 79). Early research shows that people expect their communication partners to be human (Westerman et al., 2020), and people experience less uncertainty, higher approval, and a higher social presence when interacting with a human rather than a robot (Spence et al., 2014). In this study, we found that teachers and students desired human-like communication. However, further research is needed to determine what specific types of communication they consider human-like. Conceptualizations of the ontological boundaries between humans and machines shape our understanding of technology as communicators (Guzman, 2020). Anthropocentric expectancy bias in communication suggests that people generally expect their interaction partners to be humans or behave in human-like ways; otherwise, their communication

experiences can be violated (Edwards et al., 2019). However, anthropomorphism appears to have dual effects. While human-like communication can enhance usefulness and perceived trustworthiness, it can also be unsettling and induce feelings of the uncanny valley. Communication researchers have conceptual knowledge to explain HMC based on their expertise in human communication theories (Rosenthal-von der Putter & Koban, 2023). In line with Guzman and Lewis (2020), we propose that human communication theories provide a foundation for exploring interactions between humans and machines. However, researchers should also investigate how teachers and students adapt and modify their human-to-human communication scripts when interacting with PAs.

6. Conclusion

This study explored Finnish high school teachers' and students' perspectives, indicating that affirmative and relational PA communication can strengthen the student–PA relationship while supporting effective learning management. Students and teachers desired PA communication that elicits positive feelings and adapts according to the student's emotional state. Thus, we suggest that verbal communication (relational and task-related) and non-verbal communication (facial expressions, gestures, postures and eye contact) are complementary and should be considered as equally important in the development processes. Many of the identified communication characters are integrable to disembodied systems, but *visual non-verbal communication qualities*, such as gestures and facial expressions, can be achieved only through embodied PAs. To enhance PAs' visual non-verbal communication, we recommend borrowing from commercial video games, where characters' facial expressions, gestures, and postures are displayed remarkably genuinely. In addition, personalizing the PA's appearance and communication style further can enhance the perceived effectiveness of the support.

Emotions are essential in learning (Pekrun, 2017; Pekrun et al., 2017), and PA's happiness has been shown to increase students' positive emotions and motivation for learning (Horovitz & Mayer, 2021). Research on detecting and responding to learners' emotions has been in the focus for decades. For example, affective AutoTutor (D'Mello et al., 2007; D'Mello & Graesser, 2012), or an affective agent that provided feedback, expressions, hints, questions, and supportive comments, fostering students' motivation, enjoyment, perceived usefulness and behavioral intention (Guo & Goh, 2016; Guo et al., 2015). However, emotions do not need to be positive; cognitive disequilibrium can benefit learning when it is properly induced, regulated, and resolved (D'Mello & Graesser, 2011; D'Mello & Graesser, 2012; D'Mello, 2013). We suggest, consistent with prior studies, (Horovitz & Mayer, 2021; Sinatra et al., 2021; Walker & Ogan, 2016), that PAs should incorporate social and communicative behaviors in their interactions with students. The rapid development and increased usage of general AI and LLMs offer relevant venues for developing relational and adaptive PA communication. This study's results show that PAs have the potential to enhance students' perceptions of themselves by supporting self-efficacy and self-regulated learning. Thus, we recommend that future research should investigate the underlying mechanisms that support students' agency when learning with a PA.

7. Limitations

Although the research contributes to our knowledge of how PAs should communicate, it is important to recognize the limitations of the study. The primary limitation is the disconnection between the interviewees' insights and experiences of PA communication. By pairing research on teachers' and students' expectations and actual experiences of different kinds of agents would enhance the understanding of students' and teachers' preferences, while making research findings more grounded and applicable. Once teachers and students have gained more experience with communicative PAs, observations can be a productive way to collect novel first-hand information of teachers' and students' experiences. It is worth noting that the data was collected before the significant emergence of generative AI and LLMs. The quick shift might prompt teachers and students to reassess their perspectives, and thus we recommend continuing research on teachers' and students' experiences and expectations on PA's communication. Another limitation is the study's rather small sample size. This study aims to establish the foreground on user-centered development of PA communication and HMC in instructional settings. We used an explorative approach and chose convenience and snowball sampling methods to gain presentative insights by delving deeply into the participants' thoughts and perspectives that should inform PA communication development. By understanding this, we note that the study findings may not be fully generalizable, which could have been achieved with larger and more diverse samples.

CRediT authorship contribution statement

Pieta Sikström: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Chiara Valentini:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Anu Sivunen:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Tommi Kärkkäinen:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Data availability

The authors do not have permission to share data.

References

Ali, O., Murray, P. A., Momin, M., Dwivedi, Y. K., & Malik, T. (2024). The effects of artificial intelligence applications in educational settings: Challenges and strategies. *Technological Forecasting and Social Change, 199*, Article 123076.

Alrajhi, A. S. (2024). Artificial intelligence pedagogical chatbots as L2 conversational agents. *Cogent Education, 11*(1), Article 2327789.

Andersen, J. F., Norton, R. W., & Nussbaum, J. F. (1981). Three investigations exploring relationships between perceived teacher communication behaviors and student learning. *Communication Education, 30*(4), 377–392.

Araujo, T., & Bol, N. (2024). From speaking like a person to being personal: The effects of personalized, regular interactions with conversational agents. *Computers in Human Behavior: Artificial Humans, 2*(1), Article 100030.

Ba, S., Stein, D., Liu, Q., Long, T., Xie, K., & Wu, L. (2021). Examining the effects of a pedagogical agent with dual-channel emotional cues on learner emotions, cognitive load, and knowledge transfer performance. *Journal of Educational Computing Research, 59*(6), 1114–1134.

Backlund, P. M. (2008). Pedagogy, communication in. In W. Donsbach (Ed.), *The International Encyclopedia of Communication*. https://doi.org/10.1002/9781405186407.wbiecp017.

Bano, M., & Zowghi, D. (2015). A systematic review on the relationship between user involvement and system success. *Information and Software Technology, 58*, 148–169.

Baylor, A. L. (2018). Three research directions for affective learning technologies. Retrieved October 28, 2022 from https://repository.isls.org//handle/1/865.

Baylor, A. L., & Kim, S. (2009). Designing nonverbal communication for pedagogical agents: When less is more. *Computers in Human Behavior, 25*(2), 450–457.

Beege, M., & Schneider, S. (2023). Emotional design of pedagogical agents: The influence of enthusiasm and model-observer similarity. *Educational Technology Research & Development*, 1–22.

Bodkin, H. (2017). *Inspirational' robots to begin replacing teachers within 10 years*. The Telegraph. https://www.telegraph.co.uk.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Burleson, B. R., MacGeorge, E. L., Knapp, M. L., & Daly, J. A. (2002). Supportive communication. *Handbook of interpersonal communication, 3*, 374–424.

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, 33*, 989–1015.

Chaves, A. P., & Gerosa, M. A. (2021). How should my chatbot interact? A survey on social characteristics in human–chatbot interaction design. *International Journal of Human-Computer Interaction, 37*(8), 729–758.

Chiu, T. K., Moorhouse, B. L., Chai, C. S., & Ismailov, M. (2023). Teacher support and student motivation to learn with Artificial Intelligence (AI) based chatbot. *Interactive Learning Environments*, 1–17.

Ciechanowski, L., Przegalinska, A., Magnuski, M., & Gloor, P. (2019). In the shades of the uncanny valley: An experimental study of human–chatbot interaction. *Future Generation Computer Systems, 92*, 539–548.

Claessens, L. C., van Tartwijk, J., van der Want, A. C., Pennings, H. J., Verloop, N., den Brok, P. J., & Wubbels, T. (2017). Positive teacher–student relationships go beyond the classroom, problematic ones stay inside. *The Journal of Educational Research, 110*(5), 478–493.

Croucher, S. M., & Cronn-Mills, D. (2014). *Understanding communication research methods: A theoretical and practical approach*. Routledge.

D'Mello, S., & Graesser, A. (2012). Dynamics of affective states during complex learning. *Learning and Instruction, 22*(2), 145–157.

Dever, D. A., Wiedbusch, M. D., Romero, S. M., & Azevedo, R. (2024). Investigating pedagogical agents' scaffolding of self-regulated learning in relation to learners' subgoals. *British Journal of Educational Technology, 55*(4), 1290–1308.

D'Mello, S. (2013). A selective meta-analysis on the relative incidence of discrete affective states during learning with technology. *Journal of Educational Psychology, 105*(4), 1082.

D'Mello, S., & Graesser, A. (2011). The half-life of cognitive-affective states during complex learning. *Cognition & Emotion, 25*(7), 1299–1308.

Dai, L., Jung, M. M., Postma, M., & Louwerse, M. M. (2022). A systematic review of pedagogical agent research: Similarities, differences and unexplored aspects. *Computers & Education*, Article 104607.

Daronnat, S., Azzopardi, L., Halvey, M., & Dubiel, M. (2020). Impact of agent reliability and predictability on trust in real time human-agent collaboration. In *Proceedings of the 8th international conference on human-agent interaction* (pp. 131–139).

Davis, R. O. (2018). The impact of pedagogical agent gesturing in multimedia learning environments: A meta-analysis. *Educational Research Review, 24*, 193–209.

Dever, D. A., Sonnenfeld, N. A., Wiedbusch, M. D., & Azevedo, R. (2022). Pedagogical agent support and its relationship to learners' self-regulated learning strategy use with an intelligent tutoring system. In *International conference on artificial intelligence in education* (pp. 332–343). Cham: Springer International Publishing.

D'Mello, S., Picard, R. W., & Graesser, A. (2007). Toward an affect-sensitive AutoTutor. *IEEE Intelligent Systems, 22*(4), 53–61.

Durall Gazulla, E., Martins, L., & Fernández-Ferrer, M. (2023). Designing learning technology collaboratively: Analysis of a chatbot co-design. *Education and Information Technologies, 28*(1), 109–134.

Edwards, C., & Craig, M. (2023). In A. L. Guzman, R. McEwen, & S. Jones (Eds.), *The SAGE handbook of human–machine communication* (pp. 243–251). SAGE Publications.

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, A., Edwards, C., Westerman, D., & Spence, P. R. (2019). Initial expectations, interactions, and beyond with social robots. *Computers in Human Behavior, 90*, 308–314.

European Commission. (2020). The digital economy and society index. *Retrieved October 28, 2022 from Digital Economy and Society Index (DESI) 2020 | Shaping Europe's digital future (europa.eu)*.

Finnish National Agency for Education. (2022). Finland- the home of world-class education. *Retrieved October 28, 2022 from Home | Education Finland*.

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.

Frymier, A. B., & Houser, M. L. (2000). The teacher-student relationship as an interpersonal relationship. *Communication Education, 49*(3), 207–219.

Gambino, A., Fox, J., & Ratan, R. A. (2020). Building a stronger CASA: Extending the computers are social actors paradigm. *Human-Machine Communication, 1*, 71–85.

Gill, S. S., Xu, M., Patros, P., Wu, H., Kaur, R., Kaur, K., … Buyya, R. (2024). Transformative effects of ChatGPT on modern education: Emerging era of AI chatbots. *Internet of Things and Cyber-Physical Systems, 4*, 19–23.

Goodnow, C. (1992). Strengthening the links between educational psychology and the study of social contexts. *Educational Psychologist, 27*(2), 177–196.

Gorham, J., Kelley, D. H., & McCroskey, J. C. (1989). The affinity-seeking of classroom teachers: A second perspective. *Communication Quarterly, 37*(1), 16–26.

Guest, G., Bunce, A., & Johnson, L. (2006). How many interviews are enough? An experiment with data saturation and variability. *Field Methods, 18*(1), 59–82.

Gunkel, D. J. (2012). Communication and artificial intelligence: Opportunities and challenges for the 21st century. *Communication+ 1, 1*(1), 1–25.

Guo, Y. R., & Goh, D. H. L. (2016). Evaluation of affective embodied agents in an information literacy game. *Computers & Education, 103*, 59–75.

Guo, Y. R., Goh, D. H. L., Luyt, B., Sin, S. C. J., & Ang, R. P. (2015). The effectiveness and acceptance of an affective information literacy tutorial. *Computers & Education, 87*, 368–384.

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. (2023). Talking about "talking with machines": Interview as method within HMC. In A. L. Guzman, R. McEwen, & S. Jones (Eds.), *The SAGE handbook of human–machine communication* (pp. 243–251). SAGE Publications.

Guzman, A. L., & Lewis, S. C. (2020). Artificial intelligence and communication: A human–machine communication research agenda. *New Media & Society, 22*(1), 70–86.
Heidig, S., & Clarebout, G. (2011). Do pedagogical agents make a difference to student motivation and learning? *Educational Research Review, 6*(1), 27–54.
Hepp, A., Bolin, G., Guzman, A. L., & Loosen, W. (2024). Mediatization and human-machine communication: Trajectories, discussions, perspectives. *Human-Machine Communication, 7*(1), 1.
Horovitz, T., & Mayer, R. E. (2021). Learning with human and virtual instructors who display happy or bored emotions in video lectures. *Computers in Human Behavior, 119*, Article 106724.
Isbister, K., & Nass, C. (2000). Consistency of personality in interactive characters: Verbal cues, non-verbal cues, and user characteristics. *International Journal of Human-Computer Studies, 53*(2), 251–267.
Jeon, J., Lee, S., & Choe, H. (2023). Beyond ChatGPT: A conceptual framework and systematic review of speech-recognition chatbots for language learning. *Computers & Education, 104898*.
Kasneci, E., Seßler, K., Küchemann, S., Bannert, M., Dementieva, D., Fischer, F., … Kasneci, G. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences, 103*, Article 102274.
Kelly, S., Kaye, S. A., & Oviedo-Trespalacios, O. (2022). What factors contribute to acceptance of artificial intelligence? A systematic review. *Telematics and Informatics*, Article 101925.
Khan, A., Khan, S., Zia-Ul-Islam, S., & Khan, M. (2017). Communication skills of a teacher and its role in the development of the students' academic success. *Journal of Education and Practice, 8*(1), 18–21.
Kim, J., Merrill Jr, K., Xu, K., & Sellnow, D. D. (2021). I like my relational machine teacher: An AI instructor's communication styles and social presence in online education. *International Journal of Human-Computer Interaction, 37*(18), Article 17601770.
Kim, J., Merrill, K., Kun, X., & Sellnow, D. D. (2022). Embracing AI-based education: Perceived social presence of human teachers and expectations about machine teachers in online education. *Human-Machine Communication, 4*, 169–184.
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.
LeFebvre, L., & Keith, W. M. (2023). Communication education scholarship: A reclamation for the future. *Communication Education, 72*(4), 417–422.
Lew, Z., & Walther, J. B. (2023). Social scripts and expectancy violations: Evaluating communication with human or AI chatbot interactants. *Media Psychology, 26*(1), 1–16.
Li, X., Bergin, C., & Olsen, A. A. (2022). Positive teacher-student relationships may lead to better teaching. *Learning and Instruction, 80*, Article 101581.
Li, W., Wang, F., Mayer, R. E., & Liu, H. (2019). Getting the point: Which kinds of gestures by pedagogical agents improve multimedia learning? *Journal of Educational Psychology, 111*(8), 1382.
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.
Mavrina, L., Szczuka, J., Strathmann, C., Bohnenkamp, L. M., Krämer, N., & Kopp, S. (2022). "Alexa, you're really stupid": A longitudinal field study on communication breakdowns between family members and a voice assistant. *Frontiers of Computer Science, 4*, Article 791704.
Mayer, R. E. (2014). Principles based on social cues in multimedia learning: Personalization, voice, image, and embodiment principles. *The Cambridge handbook of multimedia learning, 16*, 345–370.
Mayer, R. E., Fiorella, L., & Stull, A. (2020). Five ways to increase the effectiveness of instructional video. *Educational Technology Research & Development, 68*(3), 837–852.
Mayer, R. E., Sobko, K., & Mautone, P. D. (2003). Social cues in multimedia learning: Role of speaker's voice. *Journal of Educational Psychology, 95*(2), 419.
Mazer, J. P., & Graham, E. E. (2015). Measurement in instructional communication research: A decade in review. *Communication Education, 64*(2), 208–240.
Moreno, R., & Mayer, R. E. (2004). Personalized messages that promote science learning in virtual environments. *Journal of Educational Psychology, 96*(1), 165.
Moreno, R., & Mayer, R. (2007). Interactive multimodal learning environments: Special issue on interactive learning environments: Contemporary issues and trends. *Educational Psychology Review, 19*, 309–326.
Moreno, R., Mayer, R. E., Spires, H. A., & Lester, J. C. (2001). The case for social agency in computer-based teaching: Do students learn more deeply when they interact with animated pedagogical agents? *Cognition and Instruction, 19*(2), 177–213.
Mottet, T. P., & Beebe, S. A. (2006). Foundations of instructional communication. In T. P. Mottet, V. P. Richmond, & J. C. McCroskey (Eds.), *Handbook of instructional communication: Rhetorical and relational perspectives (Ch. 1)*. Boston, MA: Allyn & Bacon.
Munnukka, J., Talvitie-Lamberg, K., & Maity, D. (2022). Anthropomorphism and social presence in Human–Virtual service assistant interactions: The role of dialog length and attitudes. *Computers in Human Behavior, 135*, Article 107343.
Myers, S. A., Tindage, M. F., & Atkinson, J. (2016). The evolution of instructional communication research. In P. L. Witt (Ed.), *The handbook of communication and learning* (pp. 13–42). Boston, MA: DeGruyter/Mounton.
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. *Proceedings of SIGCHI '94 Human Factors in Computing Systems*, 72–78.
Noy, C. (2008). Sampling knowledge: The hermeneutics of snowball sampling in qualitative research. *International Journal of Social Research Methodology, 11*(4), 327–344.
Pătruț, B., & Spatariu, R. P. (2016). Implementation of artificial emotions and moods in a pedagogical agent. In S. Y. Tettegah, & M. Gartmeier (Eds.), *Emotions, technology, design, and learning* (pp. 63–86). Academic Press.
Pekrun, R. (2017). Emotion and achievement during adolescence. *Child Development Perspectives, 11*(3), 215–221.
Pekrun, R., Lichtenfeld, S., Marsh, H. W., Murayama, K., & Goetz, T. (2017). Achievement emotions and academic performance: Longitudinal models of reciprocal effects. *Child Development, 88*(5), 1653–1670.
Richards, R. J., Spence, P. R., & Edwards, C. C. (2022). Human-machine communication scholarship trends: An examination of research from 2011 to 2021 in communication journals. *Human-Machine Communication, 4*, 45–62.
Rosenthal-von der Putter, A., & Koban, K. (2023). Interpersonal interactions between people and machines. In A. L. Guzman, R. McEwen, & S. Jones (Eds.), *The SAGE handbook of human–machine communication* (pp. 294–301). SAGE Publications.
Ryan, G. W., & Bernard, H. R. (2003). Techniques to identify themes. *Field Methods, 15*(1), 85–109.
Scharp, K. M., & Sanders, M. L. (2019). What is a theme? Teaching thematic analysis in qualitative communication research methods. *Communication Teacher, 33*(2), 117–121.
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., & 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., Romine, W. L., & Craig, S. D. (2017). Measuring pedagogical agent persona and the influence of agent persona on learning. *Computers & Education, 109*, 176–186.
Schuetzler, R. M., Grimes, G. M., & Scott Giboney, J. (2020). The impact of chatbot conversational skill on engagement and perceived humanness. *Journal of Management Information Systems, 37*(3), 875–900.
Sharples, M. (2023). Towards social generative AI for education: theory, practices and ethics. *Learning: Research and Practice, 9*(2), 159–167.
Siegle, R. F., Schroeder, N. L., Lane, H. C., & Craig, S. D. (2023). Twenty-five years of learning with pedagogical agents: History, barriers, and opportunities. *TechTrends, 67*(5), 851–864.
Sikström, P., Valentini, C., Sivunen, A., & Kärkkäinen, T. (2022). How pedagogical agents communicate with students: A two-phase systematic review. *Computers & Education, 188*, Article 104564.

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.
Spence, P. R. (2019). Searching for questions, original thoughts, or advancing theory: Human-machine communication. *Computers in Human Behavior, 90*, 285–287.
Spence, P. R., Westerman, D., Edwards, C., & Edwards, A. (2014). Welcoming our robot overlords: Initial expectations about interaction with a robot. *Communication Research Reports, 31*(3), 272–280.
Titsworth, S., & Mazer, J. P. (2016). Teacher clarity: An analysis of current research and future directions. In P. Witt (Ed.), *Communication and learning* (pp. 105–128). De Gruyter, Inc.
Tracy, S. J. (2019). *Qualitative research methods: Collecting evidence, crafting analysis, communicating impact*. John Wiley & Sons.
Vasconcelos, L., Zahn, J., Trevisan, D., & Viterbo, J. (2024). Engagement by design cards: A tool to involve designers and non-experts in the design of crowdsourcing initiatives. *International Journal of Human-Computer Studies, 182*, Article 103166.
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*(2), 713–729.
Wang, Y., Feng, X., Guo, J., Gong, S., Wu, Y., & Wang, J. (2022a). Benefits of affective pedagogical agents in multimedia instruction. *Frontiers in Psychology, 12*, 6639.
Wang, Y., Gong, S., Cao, Y., & Fan, W. (2023a). The power of affective pedagogical agent and self-explanation in computer-based learning. *Computers & Education*, Article 104723.
Wang, Y., Gong, S., Cao, Y., Lang, Y., & Xu, X. (2023b). The effects of affective pedagogical agent in multimedia learning environments: A meta-analysis. *Educational Research Review, 38*, Article 100506.
Wang, Y., Song, W., Tao, W., Liotta, A., Yang, D., Li, X., … Zhang, W. (2022b). A systematic review on affective computing: Emotion models, databases, and recent advances. *Information Fusion, 83*, 19–52.
Westerman, D., Edwards, A. P., Edwards, C., Luo, Z., & Spence, P. R. (2020). I-It, I-Thou, I-Robot: The perceived humanness of AI in human-machine communication. *Communication Studies, 71*(3), 393–408.
Wubbels, T., Brekelmans, M., Brok, P. D., Wijsman, L., & van Tartwijk, J. (2015). Teacher–student relationships and classroom management. In E. T. Emmer, & E. J. Sabornie (Eds.), *Handbook of classroom management* (2nd ed., pp. 363–386). New York, NY: Routledge.
Xie, Y., Zhu, K., Zhou, P., & Liang, C. (2023). How does anthropomorphism improve human-AI interaction satisfaction: A dual-path model. *Computers in Human Behavior, 148*, Article 107878.