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# Pedagogical Conversational Agents in Virtual Worlds

## A Systematic Literature Review

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**Zusammenfassung**

Pädagogische Sprachassistenten (PCAs) in virtuellen Welten kommen im Bildungsbereich mehr und mehr zum Einsatz. Dies wird durch den Trend der zunehmenden Veröffentlichungen in diesem Bereich belegt. In dieser systematischen Literaturanalyse werden Forschungsbeiträge untersucht, die sich mit der Implementierung von PCAs in virtuellen Welten zur Lernunterstützung in der Hochschul- und Weiterbildung befassen. Wir identifizieren explorativ die folgenden Gestaltungskategorien: Optische Darstellung und Charakter, die Anpassung der PCAs an die Gefühle der Lernenden und ihre Rolle als Mentoren, die Anwendung von Gamification, Kommunikationstechnologien, Privatsphäre und das Vorhandensein von Designwissen. Die 668 gefundenen Artikel wurden auf 45 kodierte Artikel reduziert. Aus den Ergebnissen unserer Forschungsschwerpunkte haben wir zukünftige Forschungsrichtungen abgeleitet. Die Ergebnisse zeigen Forschungslücken im Bereich des Datenschutzes, der Existenz von Designprinzipien und komplexerer Kommunikationstechnologien. Abschließend kommen wir zu dem Schluss, dass das Potenzial des Einsatzes von PCAs in virtuellen Welten noch nicht ausgeschöpft ist und strukturierter und tiefergehend untersucht werden sollte.

**Stichwörter:** e-learning; Pädagogische Agenten; Virtuelle Welt; Hochschulbildung; Literaturanalyse

**Abstract**

Pedagogical conversational agents (PCAs) in virtual worlds are increasingly used in the field of education. This is evidenced by the trend of increased publications in this area. This systematic literature review examines research contributions that study the implementation of PCAs in virtual worlds to promote learning in higher and further education. We exploratively identify the following design categories: Embodiment and character, the PCA's adaptation to learners' feelings and their role as mentors, the application of gamification, communication technologies, privacy, and the existence of design knowledge. We reduced the 668 articles found to 45 coded articles. From the results of our research foci, we derived future research streams. The results show research gaps in privacy, the existence of design principles, and more advanced communication technologies. Finally, we conclude that the potential of using PCAs in virtual worlds has not yet been exploited and should be investigated more structured and more deeply.

**Keywords:** e-learning; Pedagogical Agents; Virtual World; Higher Education; Literature Review

## 1 Introduction

COVID-19 and the resulting increased pace of digitalization have changed teaching in higher and further education (Grogorick & Robra-Bissantz, 2021; Luebcke et al., 2022). Therefore, teaching via digital media has gained more frequent application and focus, in practice, research and politics (Atif et al., 2021; Prattico et al., 2022). Another influencing factor is technological progress in the field of artificial intelligence that led to the development of conversational agents, which have a wide range of applications (Allouch et al., 2021; Feidakis et al., 2019; Perez et al., 2020). One area of application is education. These so-called pedagogical conversational agents (PCAs) offer personalized support adapted to the learner's individual needs and reduce the teachers' workload or help cope with increasing numbers of students (Hobert & von Wolff, 2019; Schlimbach et al., 2022). Individually supporting a learner with a PCA enhances the learning process and success (Schlimbach et al., 2022). Even friendship-like relationships with the PCA have become possible (Strohmann, 2021). To additionally promote learning progress online, a learning environment that is perceived as pleasant for the user is recommended (Khosrawi-Rad et al., 2022). Virtual worlds (VWs) could support creating that pleasant atmosphere due to their spatial and social presence (Lecon & Koot, 2015; Riva et al., 2007). There are studies underpinning that VWs also improve the learning process and success (Girvan, 2018). Combining both technologies promises scalability and individualization at the same time. Therefore, the combination is a promising field for theoretical and practical implementation in the context of the current development of the *Digital Networked Infrastructure for Education*. This educational infrastructure is meant to support life-long learning for all target groups, academic and non-academic. The infrastructure it is not meant to be another learning environment but rather it is designed to connect current and future educational platforms like virtual worlds and related technologies to perform steps toward the vision of the metaverse.

There are literature reviews on PCAs in education (e.g., Khosrawi-Rad et al., 2022; Schlimbach et al., 2022) and VWs in education (e.g., Clutterbuck et al., 2015; Dalgarno & Lee, 2010) but to our knowledge, there is no literature review with a combined view. Since this combination raises new questions, e.g., in terms of technical compatibility or the visual design of the PCA, an isolated view of both technologies is not sufficient.

This paper aims to determine the current state of research on the design of PCAs in VWs and to identify research gaps relevant in the context of the *Digital Networked Infrastructure for Education*. Thereby we focus on design areas that become relevant when combining PCAs and VWs. We aim to identify relevant design knowledge and its applicability so we can conclude on design knowledge research gaps. For this purpose, we use the methodology of a systematic literature review (SLR) as proposed by Webster & Watson (2002).

## 2 Related Work

The definition of VW and related terms is ambiguous (Girvan, 2018). *"Virtual worlds are persistent online computer-generated environments where multiple users in remote physical locations can interact in real time for the purposes of work or play"* (Dionisio et al., 2013, p. 1). The definition of Pannicke & Zarnekow (2009) is more generic and does not include the aspect of persistency nor the application for playing. It defines VWs as 3D environments that can be entered using avatars to navigate and communicate with. Both definitions stress the synchronicity and the multi-user capability in a virtual environment that can be entered. We regard these aspects as the core elements of the definition and ground our work on it. Following Dionisio et al. (2013), VWs can be regarded as a subset or predecessor of the metaverse, which has, besides other factors, gained importance through the renaming of "Facebook" to "Meta" and the corresponding efforts (Zhang et al., 2022). Bringing the metaverse idea of the convergence of the virtual and real world to practice, additional technologies like artificial intelligence (AI), haptic communication, and motion capturing are necessary (Zhang et al., 2022). Social presence, one of the key features of VWs (e.g., Edirisingha et al., 2009), is defined as *"the degree of salience of the other person in the interaction and the consequent salience of the interpersonal relationships"* (Short et al., 1976, p. 65). Thus, it supports the social aspect of learning due to the multi-user attendance (Stahl, 2004). VWs can also be used for simulations, e.g., the operation and maintenance of technical systems like airplanes or automobiles (e.g., Pletz & Zinn, 2020). Another application example is behavioral training in critical situations (e.g., the detonation of a nuclear reactor) without any real risks (Méndez et al., 2004). Despite the positive aspects and the high potential for the educational context, for a productive operation, the aspect of data protection has to be considered (Pirner, 2018).

In the last decade, conversational agents evolved significantly due to technological advances (Brown et al., 2020; Russell & Norvig, 2016). A conversational agent is software that communicates with the user either text-based or speech-based (Gnewuch et al., 2017; McTear et al., 2016). In educational contexts, there is also the more specific term pedagogical (conversational) agent (PCA). PCAs can be used to support and improve the learning process in VWs. They can provide scalable individual support, e.g., for organizational or content-specific questions and problems (Khosrawi-Rad et al., 2022).

Learners often differ in their characteristics, cognitive performance, knowledge level, and motivation (Hobert & von Wolff, 2019; Schlimbach et al., 2022). A person-centered focus of a PCA can lead to an increased learning outcome (Khosrawi-Rad et al., 2022).

Ethics in the context of AI, and in particular the protection of the privacy of users of PCAs, has attracted increasing interest in recent years. This is particularly the case in Europe, where the introduction of the General Data Protection Regulation (GDPR) has led to the regulation of privacy in technology-based systems and services. The GDPR represents a milestone in terms of personal data protection and thus helps to raise awareness and promote ethical considerations in the context of AI. Four main aspects have to be considered in terms of GDPR: lawful basis & transparency, data security, accountability & governance, and privacy rights (European Union, 2020). It is necessary to note that ethical and privacy challenges have relevance concerning the use of PCAs. This is because sensitive information is often stored in this context or vulnerable groups, such as in the health and education sectors, are affected (Følstad et al., 2021). E.g., quizzes can lead to sensitive information about the users' skill level. Adding personality to the PCA can lead to friendship-like relationships where users are more likely to share personal information (Strohmann, 2021). Furthermore, when PCAs ask sensitive questions, users are likely to share confidential information, leading to an increased risk of data breaches (Belen-Saglam et al., 2022; Ho et al., 2018).

## 3 Methodology

To reach our research aim we conduct an SLR following Webster & Watson (2002) and Page et al. (2021). We searched the databases *Scopus, AIS eLibrary, ACM Digital Library, IEEE Xplore, ERIC, and Taylor & Francis*. These cover the relevant subject areas of economics, information systems, pedagogy, and education. This selection is also supported by literature (Levy & Ellis, 2006). We included journal articles, conference papers, and book chapters. The search was conducted in December 2022. The search term was developed iteratively and exploratively. It consists of synonyms for PCA, VW, and learning. These synonyms are linked with an OR operator, the three different aspects with an AND operator. The search term was targeted at title, abstract, and, if applicable, keywords. The final search term we used was:

> *("conversational agent" OR "collaborative agent" OR "virtual assistant" OR "virtual companion" OR "interactive agent" OR "pedagogical agent" OR "pedagogical conversational agent") AND ("virtual world" OR "digital world" OR "online world" OR "virtual environment" OR "digital environment" OR "learning environment" OR "metaverse" OR "visualization") AND ("learning" OR "education" OR "e-learning" OR "instruction" OR "immersive learning" OR "intelligent tutoring systems")*

We defined inclusion and exclusion criteria for the title, abstract and full-text screening. We included English-language results only and there had to be a reference to PCAs, virtual worlds, and learning in higher or further education. Articles related to minors as well as duplicates were excluded. We also excluded learners with special needs since we targeted for generalizable results. Other SLRs found were searched for research areas but not included in the analysis itself.

The search resulted in 668 articles in total with 66 duplicates being removed in the first step. Title and abstract screening resulted in 105 contributions, and the full-text screening in 45 articles meeting the predefined criteria. The following figure reveals the screening process in the form of a PRISMA statement as proposed by Page et al. (2021). The numbers behind the database designations represent the respective number of hits.

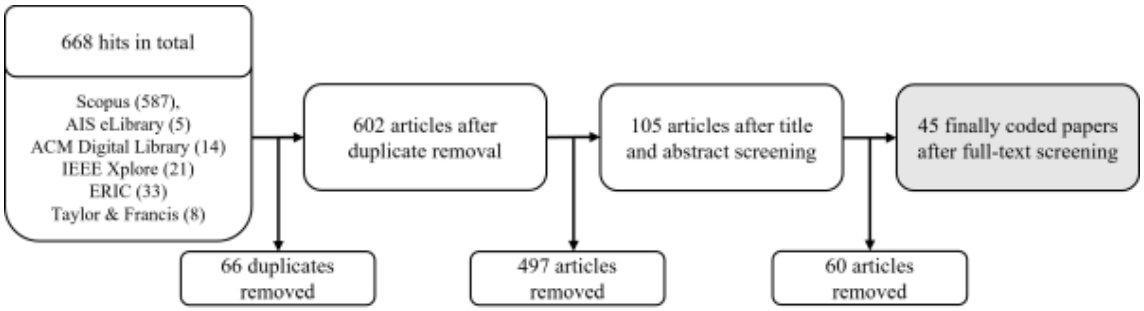


*Figure 1: PRISMA Statement*

For the detailed analysis of the contributions, a coding system was set up using Microsoft Excel software. The creation of the coding guide is based on Mayring (2015) and is two-stage. First, six main categories were derived iteratively and exploratory from the abstracts in the context of the *Digital Networked Infrastructure for Education* In the second step, these main areas were commonly defined in the team. The sub-categories were added exploratively during the full-text coding and iteratively added and defined in the code book. The analysis was performed from mid-December 2022 to early January 2023. Subsequently the results were abstracted.

## 4 Results

The increasing number of publications per year is revealed in the following figure. The trend line shows a rise in publications per year since 1998 when the topic first came up. We conclude that the topic has gained relevance up until today.

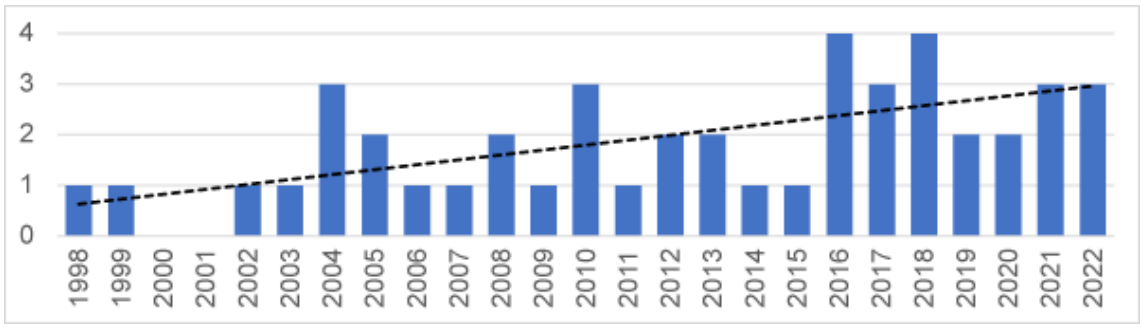


*Figure 2: Analyzed Publications per year*

The first article included in our analysis was published in 1998 (Rickel & Johnson, 1998). Many articles published in the following years refer to the PCA named Steve described there. This is one of the first human-like PCAs to live with students in a learning environment. It assists the learner in performing physical procedural tasks and can be

classified as a tutor. Other contributions consider Steve as a template for their PCA development (Marin et al., 2004) and are guided by its architecture as well as its capabilities (Barange et al., 2017).

Furthermore, we exploratively identified the following categories following our research target:

(1*) PCA embodiment and character:* When a PCA is integrated into a VW the question arises of how its avatar should look like, move, and behave. Therefore, the analysis of the visual appearance and behavior aims at identifying different design aspects of PCAs in VWs. We identify and report the influence on the learner and the learning outcome.

(2) *PCA adaptation and role*: We target at identifying the link between emotional adaptation and the PCA's role as well as different options for implementation. This is of interest for the research question, since PCAs in VWs offer additional design options when adapting to the user, e.g., in terms of mimics. We identify different aspects, detecting the learners' emotions and the PCA reacting emotionally consistently.

(3) *Application of gamification*: Gamification refers to the application of game mechanics in non-game contexts to encourage positive behavior like learning (Zichermann & Cunningham, 2011). The use of games in education promotes interactivity, and engagement, and increases motivation (Manesh & Schaefer, 2010). VWs are often perceived as game-like environments (e.g., Gao et al., 2021) and PCAs can add gamification elements (Vijayakumar et al., 2019). Therefore, we examine the use of gamification of PCAs in VWs over time.

(4) *Communication technologies*: The metaverse trend leads to emerging technologies being implemented into VWs affecting the PCAs verbal and non-verbal reaction. In addition to the standard communication methods (acoustic, visual, and text-based), haptic communication and motion capturing were identified. With more communication technologies offered in parallel, the solution becomes more immersive and inclusive (Zhang et al., 2022).

(5) *Data protection and privacy*: The protection of private information is important, especially when the artifact is meant for a productive environment at a later stage. PCAs could receive private information and learning analytics in VWs could collect sensitive data. Therefore, the current data protection situation needs to be examined for the prototypes described in the contributions.

(6) *Design Science Research application*: Research following the Design Science Research (DSR) paradigm makes sure the design knowledge is both, relevant and rigorously derived. Generalizable design knowledge gives answers to design questions one has to ask when implementing artifacts. We scan articles for DSR applications and identify common kernel theories to support future developments.

The resulting coding system is previewed below. It consists of main categories with their corresponding sub-categories, in case available:

- PCA embodiment and character: animal, human, male, female, diverse, personality
- PCA adaptation and role: adaptation to learner, mentor, tutor, troublemaker
- Application of gamification

- Communication technologies: visual, audio, text-based, haptic, motion
- Data protection and privacy
- DSR application and kernel theories: DSR application, kernel theory name and category

The detailed results of this coding system are presented below.

## (1) PCA embodiment and character

The following table reveals the results on the different types of embodiments and characteristics covered in the analyzed articles. The characteristics of this main category are divided into human and animal design. These are extended by the assignment of gender (male, female or diverse) and personality. In total, the designated characteristics were described in 36 contributions.

| Publications | animal | human | male | female | diverse | personality |
|---|---|---|---|---|---|---|
| (Liew et al., 2022) | | x | x | | | x |
| (Sloan et al., 2022) | | x | | x | | x |
| (Petersen et al., 2021) | | x | | x | | x |
| (Laeeq & Memon, 2021) | | x | | | | |
| (Grivokostopoulou et al., 2020) | | x | | x | | |
| (Soliman & Guetl, 2020) | | x | x | | | |
| (Christopoulos et al., 2019) | x | x | | x | x | x |
| (Maryadi et al., 2018) | | x | x | x | | |
| (Bendou et al., 2018) | | x | | x | | x |
| (Grivokostopoulou et al., 2018) | | x | | | | |
| (Barange et al., 2017) | | x | | | | x |
| (Nakhal et al., 2017) | | x | | | | |
| (Bian et al., 2016) | | x | x | x | | |
| (Liew et al., 2016) | | x | x | | | |
| (Mohanty, 2016) | | x | | | | |
| (Hassani et al., 2016) | | x | | | | |
| (Liew et al., 2015) | | x | | | | x |
| (Terzidou & Tsiatsos, 2014) | | x | | | | |
| (Leung et al., 2013) | | x | | | | |
| (Soliman, 2013) | | x | | | | x |

| | | | | | | |
|---|---|---|---|---|---|---|
| (Soliman & Guetl, 2012) | | x | x | x | | |
| (Domagk, 2010) | | x | x | | | |
| (Mehlmann et al., 2010) | x | | x | x | | |
| (Veletsianos et al., 2010) | | x | x | x | | x |
| (Jerjir & Neji, 2009) | | x | | | | |
| (Bouhadada & Laskri, 2008) | | x | | | | |
| (Harbouche & Djoudi, 2007) | | x | | | | |
| (Botsios et al., 2006) | | x | | | | |
| (Buche et al., 2005) | | x | | | | |
| (Pan et al., 2005) | | x | | | | |
| (Marin et al., 2004) | | | | | | x |
| (Buche et al., 2004) | | | | | | |
| (Johnson, 2003) | | | | x | | |
| (Atkinson, 2002) | | | | | | |
| (Lester et al., 1999) | | | | | | x |
| (Rickel & Johnson, 1998) | | | | | | |
| **Sum** | **2** | **354** | **9** | **11** | **1** | **11** |

**Table 1: PCA embodiment and character**

There is a clear domination of human-like PCAs (35 out of 36 articles). In four articles the PCA is male, and in six articles female. In five articles the prototype offers the option to manually configure the gender. The only article covering gender diversity is from Christopoulos et al. (2019).

The human appearance of the PCA was chosen because it takes over a natural person’s function (Marin et al., 2004). This realism positively influences the learner's immersion and increases the associated learning efficiency (Méndez et al., 2004). In addition, the human form of representation is a prerequisite for the use of human mimics and a human-like personality (Lester et al., 1999). Personality models found are Eysenck’s traits (Liew et al., 2016) and the five factors (Bian et al., 2016).

Two articles include animal avatars for PCA (Christopoulos et al., 2019; Mehlmann et al., 2010). The first article uses a monkey as a troublemaker. However, the monkey is of no interest to the students due to its limited abilities and distracting nature (Christopoulos et al., 2019). In the second article, a hamster is used for culture neutrality while gender is selectable (Mehlmann et al., 2010).

Complementing the human and animal appearance, eleven of the 36 contributions refer to a human-like personality of the PCA. The PCA's personality is intended to enhance learning by also addressing the social aspects. In addition, the PCA's human-like behavior is targeted at extending the time students spend in the VW for learning because it is perceived as more fun (Lester et al., 1999; Marin et al., 2004). The personality of a PCA can be implemented by certain human behaviors, interactions, or life stories. The design depends on the application and the subject area of the PCA (Mohanty, 2016).

## (2) PCA adaptation and role

The dominating role of the PCA found (37 of 45) is the tutor role, providing content and asking and answering questions. More advanced topics were considered over time. E.g., the PCA's response to the learner's feelings and the introduction of the mentor role to support emotionally. In 2008, the first paper addressed the PCA's perception of the user's feelings (Bouhadada & Laskri, 2008). The following year, the PCA was introduced as an emotional mentor (Jerjir & Neji, 2009) and continuously developed (e.g., Bian et al., 2016; Grivokostopoulou et al., 2020; Mehlmann et al., 2010). In general, the PCA's reaction to emotions and its role as a mentor can have a significant positive effect on learning (Jerjir & Neji, 2009). 13 articles contain PCAs in a mentor role, whereas five of them (38%) adapt to the learners' emotions or express emotions themselves (e.g., Mohanty, 2016; Ranjbartabar et al., 2018; Xie et al., 2021). In contrast, from 37 tutor PCAs without an additional mentor role, only three (1%) adapt to learners' emotions (e.g., Bendou et al., 2018; Liew et al., 2015). We conclude that the importance of adaptation to emotions is dependent on the role the PCA takes. It is most important for the mentor role.

In addition to the roles found in the SLR by Khosrawi-Rad et al. (2022), we identified the role of a troublemaker who e.g., gives wrong answers (e.g., Bouhadada & Laskri, 2008; Buche et al., 2004).

Early adaptive PCAs react based on learners' interaction with the system in the past (Bouhadada & Laskri, 2008). Another option found is to ask the student about his current emotion (Ranjbartabar et al., 2018). But also the expression of human-like emotions via the PCA's mimics is found (Bian et al., 2016).

## (3) Application of Gamification

Gamification can also create an engaging and interactive learning environment enriched with a PCA (Guo & Goh, 2016). It is used in education to make learning processes more effective or make students spend more time learning (Guo & Goh, 2016). Within the study of the selected articles, gamification was used as a type of VW in 11 articles. Although the first article included in this SLR is from 1998, the first publication also covering gamification

was published in 2011. In the following years there is a slight increase in publications. This is represented as slightly rising trend line in the following figure. It must be monitored in future research if this increase of gamification application becomes a real trend.

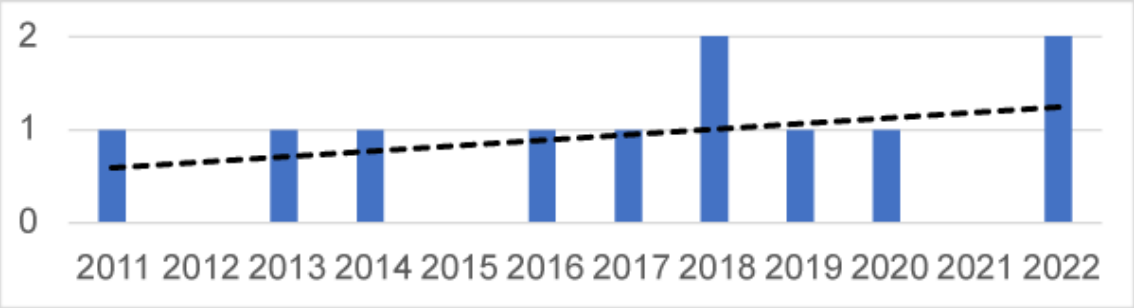


*Figure 3: Application of Gamification per year*

## (4) Communication technologies

We analyzed the means of communication with the learner. Visual or non-verbal communication was described in 32 articles (e.g., Grivokostopoulou et al., 2020; Petersen et al., 2021; Sloan et al., 2022), verbal or audio communication in 27 articles (e.g., Laeeq & Memon, 2021; Liew et al., 2016), and text-based in 26 articles (e.g., Alves et al., 2008; Harbouche & Djoudi, 2007; Moses, 2019). Many PCAs are capable of multiple communication channels (e.g., Liew et al., 2022; Mehlmann et al., 2010; Soliman & Guetl, 2020). Two more advanced technologies were found in one article, namely haptic communication, and motion capturing (Hassani et al., 2016). Haptic communication refers to the transmission of information using tactile perception. It allows users to interact with a digital system through vibrations, oscillations, or other mechanical stimuli. This form of communication plays an important role in human interaction and is closely related to emotions and social behaviors (Hassani et al., 2016; Norman, 2018). Motion capturing is the sensing of body gestures that can either be mirrored to the avatar or analyzed for accuracy (Hassani et al., 2016; Ke et al., 2016; Sun, 2016). The single article using haptic communication and motion capturing explains the influence on learning progress when learning a foreign language. The design of the VW imitates real-world scenarios to offer a natural learning experience. The learner explores the environment by role-playing with the PCA in natural language. The PCA described can perceive haptic and motion input and provide physical output to the learner. The exact form of communication is not described in detail, since the article focuses on technical implementation (Hassani et al., 2016).

## (5) Data protection and privacy

The only study addressing a GDPR-relevant aspect is Tran et al. (2022), a Thai-German collaboration. It explores not only the importance of protecting faculty confidential data but also the need to protect conversations between faculty and PCA from third parties. The system focuses on the PCA and text-based chat as the main components. These require an effective privacy function. The platform integrates several privacy measures in the VW,

including preventing other learners from accessing private information, interrupting conversations between PCAs and other learners, and refusing to share information. However, the study only examines learners' experiences with the user interface and the general concept of privacy measures implemented. The functionality and effectiveness of the privacy measures in the system are not evaluated. Hence, not all GDPR-relevant aspects are covered like accountability and governance or the lawful basis and transparency.

### (6) Design Science Research Application

None of the coded articles mentioned the application of the DSR paradigm following Hevner (2007). Many prototypes developed lack theoretical grounding because only 12 articles mentioned one or more theories as a basement for their development (e.g., Liew et al., 2022; Petersen et al., 2021; Xie et al., 2021). Social agency theory is the most common theory with three articles (Domagk, 2010; Liew et al., 2015; Petersen et al., 2021). According to that theory, social cues can increase the feeling of social presence and consequently address the social aspects of learning (Mayer, 2014; Stahl, 2004). Most common are learning theories (five theories), e.g., cognitive load theory (Mohanty, 2016) or activity learning theory (Soliman & Guetl, 2020) and human-computer-interaction theories (four articles) like computers-are-social-actors (Liew et al., 2022) or theory of adaptive hypermedia systems (Alves et al., 2008). Less common are communication theories with three theories in one article (Barange et al., 2017) and two different personality models, namely the five-factor model and Eysenck’s trait model (Bian et al., 2016; Liew & Tan, 2016).

## 5 Discussion and research gaps

The following section is structured in the same way as the results before to demonstrate the link between them. We discuss the results and derive future research streams.

*(1) PCA embodiment and character*: The general aim of adding an embodied PCA is to increase learning engagement and efficiency (Mayer, 2014; Soliman & Guetl, 2020). A human-like design in terms of optical appearance and personality stimulates social feelings and supports the social component of learning (Mayer, 2014; Stahl, 2004). This principle is also transferable to the interaction between PCA and the learner. The learner has the feeling of applying the conditions and rules for a human-human conversation. This human behavior toward a machine is also backed by the Computers-are-social-actors theory (CASA) mentioned by Liew et al. (2022). This leads to higher engagement and learning performance (Grivokostopoulou et al., 2018; Lester et al., 1999). Additionally, human representation is a prerequisite for natural interaction on the part of the PCA. An animated face provides facial expressions that support realistic visual communication. Other body parts serve to realize physical behaviors and non-acoustic interactions (Nakhal et al., 2017). As a result, the learner perceives the virtual environment as more real and can more easily develop a relationship with the PCA's personality. The feeling of loneliness is reduced (Mohanty, 2016). Animal representations, on the other hand, are often designed to be cute and appropriate for children and therefore rare in higher and further education. The

learner is more likely to overlook e.g., technical shortcomings of the VW (Bredeweg et al., 2010; Mehlmann et al., 2010). The advantage of cultural neutrality is underrepresented. Diederich et al. (2022) conclude the design of a consistent character is not a prerequisite. Nevertheless, Lin, the designer of Apple's Siri, argues that a PCA always has a character, either properly or randomly designed (Lin, 2018). Future studies should consider more precise frameworks for the selection of the presentation form and develop scientifically validated criteria. Aspects concerning personality should be included in that framework as well to prevent a random choice.

*(2) PCA adaptation and role*: Theoretical design concepts to gather the learners' emotions, as well as the PCA's role as a mentor, are still rare. Often, only the need to respond to the learner's emotions and the related improvement in the learning outcome is described. The topic of emotion recognition has been addressed in recent articles, but not elaborated upon. Mohanty (2016) may serve as a starting point. The recognition of emotions is supposed to be done via affective signals. To do so, vocal inflection, prosodic qualities of speech, facial expressions, and motor and physiological states of the learner are detected by the PCA. A response of the PCA to a negative emotion could be a verbally expressed question, e.g., "Can I help you?" in combination with a gesture (Soliman & Guetl, 2013). To further develop the role of a mentor, further research should focus on the acquisition, processing, and interpretation of emotions. Based on these results, a concept for appropriate responses of the PCA should be developed. An anthropomorphic PCA design could support to establish long-term friendship-like relationships with the learner (Strohmann, 2021). In that case, the PCA would take the role of a peer.

*(3) Application of Gamification*: The use of game-typical elements has been increasingly applied in the field of PCAs in VWs in recent years. E.g., gamification has been used to help engineering students get hands-on training on craft production. Students were asked to create toy cars according to customer requirements. The learning environment is enhanced by gamification elements such as scoring, game levels, and rankings. Additionally, tutorial levels are employed to learn the game and become familiar with the game mechanics (Sloan et al., 2022). Motivation is increased by adding gamification. Since VWs are often customizable the full potential of gamification can be exploited in combination with AI (Sloan et al., 2022). A framework for implementing gamified elements into the PCA's dialogues could structure research activities and help practitioners.

*(4) Communication technologies*: We found that more advanced communication technologies are rarely researched in combination with PCAs in VWs. This finding is in line with previous results in educational VW research (Rinn et al., 2023). We conclude that VWs are mostly researched solely or with only one additional technology. However, the combination of technologies supports the practical development of a metaverse. Another advantage of implementing additional communication technologies is that it allows users to interact with digital systems when other sensory channels, such as vision or hearing, are impaired or unavailable (Norman, 2018). This fact supports the inclusion of learners with impediments. More advanced communication technologies for enhancing interaction between people and technologies should be implemented and studied. Especially in combination with each other and in combination with simulations of real-life scenarios that profit from the risk-freedom (e.g., in medical or police training) (e.g., Moskaliuk et al., 2013) and scalability (e.g., engineering) (e.g., Pletz & Zinn, 2020) of a VW. There is a great yet unexploited potential.

*(5) Data protection and data privacy*: Although the issue of privacy is growing in importance and the implications of misuse are enormous, there is still a lack of research (De Guzman et al., 2020; Lebeck et al., 2018; Ruth et al., 2019). There is a need to support further research in this area to ensure that the development and application of PCAs are done per ethical and moral principles (Følstad et al., 2021). The protection of personal data will also have an impact on the learner's conversations with the PCA. The learner will feel more confident in dialoguing with the PCA and will find it easier to share information. Similarly, the issue of privacy in VWs must be considered. In VWs, there are numerous risks regarding privacy, e.g., digital vandalism and invasion of personal space (Ruth et al., 2019). One reason for the still rarely addressed privacy in the use of PCAs, cited by De Guzman et al. (2020), is that most work on VWs in the last two decades has focused on providing the necessary technology. Thus, there is a gap in research regarding privacy. As technology matures, privacy must now receive increased attention. Taking the categorization of Venable et al. (2016), so-called naturalistic evaluation settings are those very close to a productive environment. For productive usage in Europe, GDPR must be followed. Therefore, research that includes data protection and privacy is necessary to fill the gap between theory and practice.

*(6) DSR Application*: None of the articles followed the Design Science Research paradigm. Thus, there is no rigorously derived design knowledge to build upon. Many contributions lack a decent theoretical grounding. This is in line with another VW SLR (Rinn et al., 2023). The frequent use of the social agency theory in that context is also in line with another SLR's result (Martha & Santoso, 2019). A first step in research would be to derive meta-requirements from theories, e.g., the social agency theory and others, or expert interviews.

## 6 Conclusion

This research aimed to conduct a systematic literature review of the state of research on PCAs in VWs to identify implications for research and practice. Following the approaches of Webster & Watson (2002) and Page et al. (2021), 45 relevant articles were identified and coded. An exploratory approach was used to screen and code the articles found. In Chapter 4 (Results), the following research foci were considered: (1) PCA embodiment and character, (2) PCA adaptation and role, (3) application of gamification, (4) Communication technologies, (5) Data protection and data privacy, and (6) DSR application. The forms of PCAs' embodiment are mainly anthropomorphic, although there are also advantages of non-human avatars like cultural neutrality. Evaluations of human against non-human PCAs are missing. Gender diversity has only started to reach research in PCA design. The reactions of PCAs to the feelings of learners are seen more often as technology evolves. With this adaptivity becoming possible, the role of an emotionally supporting mentor arose. An approach for further research is offered by Mohanty (2016) and Soliman & Guetl (2013). The use of gamification has gained importance, due to its capability to increase motivation and learning outcomes. A framework for researchers and practitioners could be supportive. More advanced communication technologies like haptic communication in VWs are rarely used so far. However, it supports the inclusion of students with impediments and paves the way for the metaverse becoming reality. Data protection is a necessity in future research work to bring the solutions developed into practice. Since the learner exchanges personal information with the PCA, this information must be made inaccessible to the public, and

GDPR rules must be followed. We found that many prototypes lack a decent theoretical grounding and none of the articles followed the DSR approach. This fact leads to a lack of reusable and abstracted design knowledge in the area under consideration. In sum, despite the increasing number of publications and the research history dating back to 1998, the state of research is still immature.

This paper is subject to certain limitations. The selection and analysis process is based on subjective decisions by the authors. Our measures to reduce subjectivity as much as possible were a peer-review process, an iteratively updated and communicated coding scheme, and clearly formulated inclusion and exclusion criteria. Furthermore, the exclusion of articles targeted at learners with impediments could have caused the result of identifying a lack of advanced communication technology.

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