A Literature Review on Pedagogical Conversational Agent Adaptation

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Completed Research Paper

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Abstract

Conversational agents (CAs)—software systems emulating conversations with humans through natural language—have been widely used to communicate and collaborate with humans in various settings. A rising application domain is education since so-called Pedagogical Conversational Agents (PCAs) hold the potential for individualized learning and thus the long-term improvement of learning success. However, existing research on CA adaptation is scattered across different application domains and user groups, so researchers face difficulty in understanding the current state of the art on the adaptation design of PCAs as an independent field of interest. To address this gap, we systematically analyze existing scientific literature and discuss identified adaptation aspects of PCAs in scientific publications. Our literature review contributes to IS research by providing an overview of existing adaptive and adaptable PCA designs, identified gaps, and future research streams with the rising potential thereupon.

Keywords: Literature Review, Pedagogical Conversational Agent, Learning, Adaptation, Adaptivity, Adaptability.

Introduction

Conversational Agents (CAs) are increasingly enriching interpersonal communication through the use of natural language, either as virtual assistants using spoken language like Siri or Alexa, or text-based as chatbots (Feidakis et al. 2019; McTear et al. 2016). From the launch of initially purely rule-based chatbots to the era of rapidly evolving artificial intelligence, CAs can perform highly complex tasks, act proactively, and provide individualized support to the user. In addition to traditional fields of application, such as customer service, marketing, or health, the research field of CAs in the educational context is also gaining in importance (Diederich et al. 2022; Khosrawi-Rad et al. 2022). In everyday learning, students and teachers have to overcome and solve a variety of obstacles, be it orientation on campus, motivation, or their time management (Hobert and Meyer von Wolff 2019). There is often a lack of individual support, which is particularly evident at universities, where typically the number of teachers and learners is unbalanced (Chun Ho et al. 2018; Winkler et al. 2019). So-called *Pedagogical Conversational Agents* (PCAs) provide digital assistance for learners and form an educational context-specific subgroup of CAs. They are characterized by the fact that they communicate with the user in a human-like manner, accompany the learner, and adapt human behavior by simulating human language - often also supplemented by an avatar (Wellnhammer et al. 2020; Winkler et al. 2019). They offer the advantage of being easily scalable, location-independent, and permanently available (Khosrawi-Rad et al. 2022).

As with any technology-enhanced form of learning, it is both a challenge and an opportunity to respond to the given heterogeneity of the learner group on an individual basis through PCAs (Slavuj et al. 2017). Typically, learners differ in several individual characteristics, such as cognitive performance, knowledge level, learning style, personality traits, or motivation to achieve the personal learning goal (Marković 2014). As a result, unique requirements and preferences of each learner emerge, which - if addressed user-individually - can purposefully improve the learning success of the particular individual (Oxman and Wong 2014). Bidirectional approaches are conceivable for this purpose - either through customizable settings in the PCA, in which the learners themselves determine configurations (e.g., difficulty level, avatar design, use of media) according to their selected preferences (Paul et al. 2021) or through a smart, technically adaptive system that can constantly better adapt to its user based on the collected learners' data (Slavuj et al. 2017).

However, this promising branch of interest still shows a large research gap. Although many scientific publications already address adaptation aspects of CAs in general (e.g. Ling et al. 2021; Wald et al. 2021; Xiao et al. 2007), these mostly have specific foci, such as personality adaptivity (Ahmad et al. 2020, 2021; Hanna and Richards 2015), adaptive empathy learning (Wambsganß et al. 2021; Wardhana et al. 2021) or customizability of CAs (Kocaballi et al. 2019; Paul et al. 2021), and do not focus on PCAs in particular. Yet, it is essential to adapt a CA (e.g., in terms of locus of control and duration of relation) to its purpose (Følstad et al. 2019), which leads to the necessity of considering PCAs as an independent group for adaptation. For example, PCAs address their own target group (mainly students in academia), verse longer-term use, and offer the potential of individual support in the learning context (Khosrawi-Rad et al. 2022) to individualize learning through cognitive, affective, motivational, and sociocultural variables (Plass and Pawar 2020). Thus, their targeted adaptation results more relevant than in other application scenarios such as customer service with standardized, short-term interactions of CAs (Følstad et al. 2019). Individualized learning with PCAs holds the social potential to increase educational equity and enhance individuals' learning success (Karrenbauer et al. 2021; Schlimbach and Khosrawi-Rad 2022). Therefore, we conclude that there is great added value in analyzing the adaptation aspects for the specific category of PCAs. Wollny et al. (2021) as well identify in their publication the need for an intensification of research to *"explore and leverage adaptation capabilities for chatbots in education"* (p.12), after their systematic literature review on chatbots in education revealed only six articles on adaptive pedagogical chatbots. Among these were five in the context of quizzes - for personalized feedback (Kerly et al. 2008; Kerly and Bull 2006; Vijayakumar et al. 2019) or learning content selection (Davies et al. 2021; Ruan et al. 2019) - as well as another one that deals with personality adaptation (Jia and Chen 2008). We aim to fill this gap (extended to all types of PCAs) by answering the following research questions based on a systematic literature review (SLR):

RQ1: *Which aspects of adaptation in the application field of Pedagogical Conversational Agents are already addressed in scientific literature and how can these be structured?*
RQ2: *What are research gaps and future research streams resulting thereupon?*

Our article is organized as follows: In the next chapter, we present the research background before the methodological procedure of this systematic literature review is explained in the subsequent chapter. We then outline our core findings and consolidate them in a table of adaptation variables identified in PCA literature. After that, we discuss the resulting research gaps, discover the discrepancy between theoretical potential and practical implementation of PCA adaptation, reflect on limitations, and suggest future research streams in the discussion. Finally, we summarize our work in the conclusion.

Research Background

The Evolution of PCA Adaptation

First developments of PCAs started already in the 1980s and 90s (Bendel 2003), whereas the subject area has gained increasing popularity in the last years as shown by the rising number of scientific publications (Hobert and Meyer von Wolff 2019; Karrenbauer et al. 2021; Khosrawi-Rad et al. 2022). Although almost 20 years ago, conceptual ideas for PCAs in their role of learning companions were mentioned in literature (Bendel 2003; Kim et al. 2006), their key competence of establishing a close social bond with their users, similar to a friendship-like relationship (Krämer et al. 2011) has matured recently by the progress of artificial intelligence (AI) and machine learning methods, allowing to communicate intelligently and proactively, to remember learning statuses and progress, and to support the user's individual needs (Lee et al. 2021; Skjuve et al. 2021; Strohmann 2021). As a corollary, these virtual companions, in adding to the functional orientation, particularly force a trusting and long-term bond with the learner (e.g., Replika[1]). According to Rawlins (2017), the "potential of peer friends [...] begins to emerge with the mode of equality and reciprocity" (p.46). Consequently, adaptation plays a major role in the formation of a friendship-like bond with the PCA; for example, it has already been demonstrated that anthropomorphic design and AI-supported interaction promote trust building between the user and CA (Wald et al. 2021; Zierau et al. 2020) and that the time horizon of usage plays a major role on trust building as well (Nißen et al. 2021). Not only thanks to the growing technical progress but also due to the increased research activities in that field (e.g., Diederich et al. 2022; Weber et al. 2021), learning outcomes can be positively affected by adaptive systems or adaptable configurations (Plass and Pawar 2020). We therefore look into the concept of PCA adaptation from different angles in the next section and connect it to the educative sector.

The Concepts of Adaptation, Adaptivity, and Adaptability for PCAs

In computer science, the umbrella term *adaptation* refers to the process, when an interactive system adapts its behavior and settings user-specifically. The term decomposes into the complementary terms *adaptivity* and *adaptability*. While adaptivity means the automatic adaptation to users according to changing conditions induced by collected data (= adaptive system), adaptability refers to users that can substantially customize the system through tailoring settings manually (= adaptable system) (Oppermann 2005). *Adaptivity* in pedagogical systems can be broadly defined as the ability of a system to automatically adjust instruction based on learners' abilities, context, and/or personality at any point in the learning process to act on learners' individual characteristics to improve learning effectiveness and efficiency (Oxman and Wong 2014). In addition to accommodating learner diversity, adaptive systems also promote interactivity with users, as their goal is to mimic or support human teachers and their pedagogical and subject matter expertise (Oxman and Wong 2014). Figure 1 visualizes the definitions of the explained terms supported by practical examples in the context of PCAs.

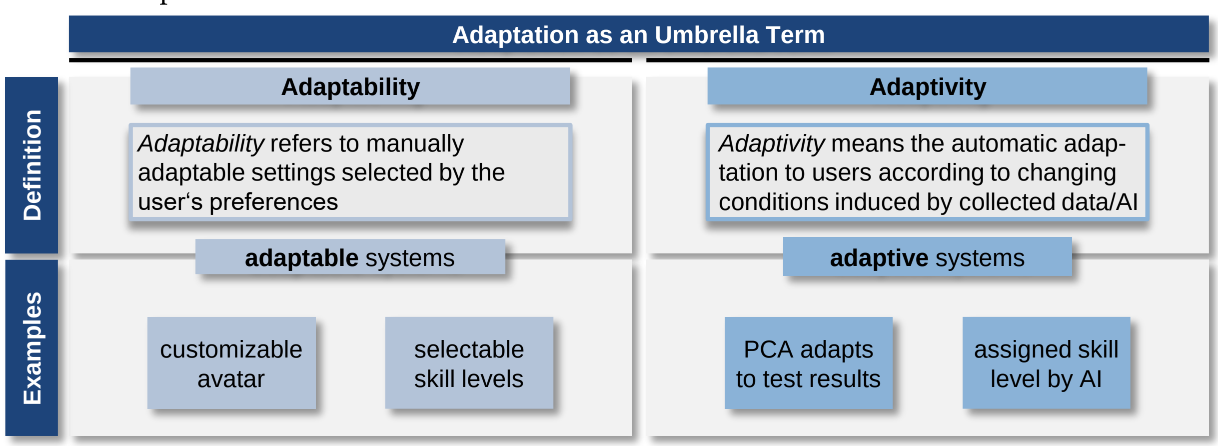

Figure 1. Explaining Terms for Adaptation

Although it is challenging to address the characteristics of each learner, which is even more difficult in contexts where differences are very significant, adaptive teaching systems can prove to be an efficient solution (Slavuj et al. 2017) to respond to learners in a personalized manner (e.g., to their personality, learning level, or learning type), especially promoted by the progress in artificial intelligence (Hobert and Meyer von Wolff 2019; Janati et al. 2020). The use and targeted analysis of data play a major role in capturing the needs of users individually (Strohmann 2021; Stucki et al. 2020) - sometimes even by responding to latent user needs that they have (initially) not been aware of. To enable such intelligent services, a wide range of user data is necessary, either in real-time to permanently adapt to the current situation or on the foundation of a rich data set collected over a longer period (compare p. 6). Enabled by machine learning the dialog can be designed more naturally and match the learner's situation and personality in a human-like manner for facilitating individual assistance (Gubareva and Lopes 2020). In contrast, the *adaptability* approach permanently leaves the learner in control of the PCA settings in the PCA (e.g., design of the avatar, language settings, or freely selectable difficulty levels) and also allows for

[1] https://replika.ai/

adjustments to elements that are difficult to capture via usage data (e.g., appearance or current mood). Admittedly the identification of latent learner needs is not possible in this scenario, but usually, the technical implementation of the configurations is easier and algorithmic bias is prevented since all adjustments are made manually instead of relying on potentially discriminating algorithms.

Key Variables for Learning Adaptation

Although variables for adaptive learning and personalization have long been of great interest to developers, designers, and educators, recent technological advances are opening up a range of new possibilities, such as emotion-aware learning technologies (Harley et al. 2017), adaptive and personalized educative games (Plass et al. 2020), adaptive tools for empathy learning (Wambsganß et al. 2021), or adaptive instruction (Aleven et al. 2017). To categorize the multiple variables these adaptive learning systems adapt to, Plass and Pawar (2020) developed a taxonomy for adaptive learning. The authors analyze relevant factors in learning environments that favor the user's learning performance. Their literature-based categorization reveals four meta-levels for adaptive learning variables, represented by cognitive, emotional, motivational, and social/cultural parameters (Plass and Pawar 2020). Figure 2 illustrates these four categories with exemplarily assigned variables.

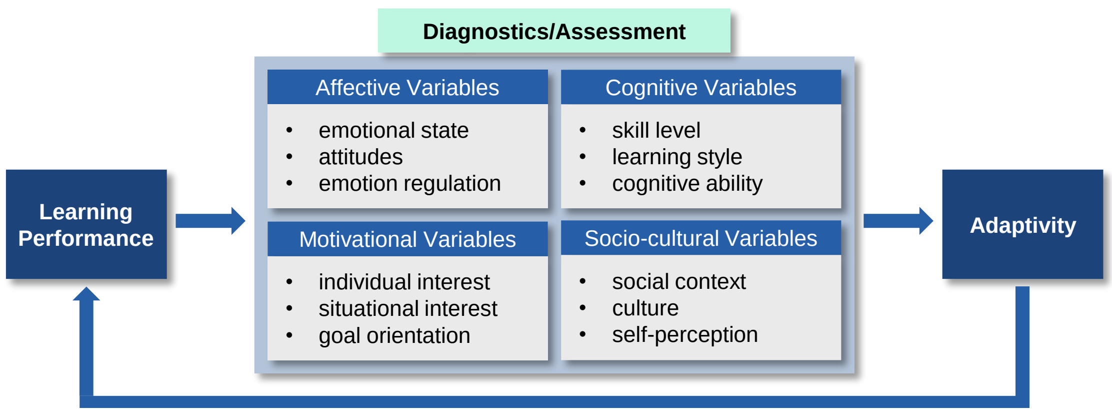

Figure 2. Examples of adaptive learning variables according to Plass and Pawar (2020)

While Plass and Pawar (2020) refer in their taxonomy mainly to the component of adaptivity with learning performance as the target variable, they emphasize that their mapping is not exhaustive and should be seen much more as a "work in progress" (p.295) that should also take into account new variables and targets optimizing for, as well as the tension between system-side adaptations to the learner's experience (adaptivity) versus adaptable features (adaptability). In our analysis, we follow this broadening idea and therefore consider both strands of adaptation. In doing so, we exploratively analyze all adaptation aspects of the PCA research we studied and thus include aspects that are not directly related to learning outcomes. These include, for example, demographic aspects such as age, gender, and nationality (Nakic et al. 2014) or personality traits and individual preferences in learning (Ranjbartabar and Richards 2018), location-aware adaptation to incorporate the environment into the learning process (Ako-Nai and Tan 2013), or cultural responsiveness through embodiment and interaction (D'Andrea Martínez and Johnston 2019). We will then reflect on their affiliation with the four addressed meta categories and explore the sole or combined presence of adaptivity and adaptability in scientific PCA literature.

Methodology

To identify relevant scientific contributions for answering our RQs, we conducted an SLR (Brendel et al. 2021; Page et al. 2021). We included peer-reviewed scientific journal articles and conference papers. To collect high-quality contributions of interdisciplinary research domains (Information Systems (IS), Computer Science, Education & Pedagogy), following Khosrawi-Rad et al. (2022) we queried the following databases: *Scopus, ACM Digital Library, AIS eLibrary, IEEE Xplore Digital Library, ERIC, Taylor & Francis, and the International Conference on Artificial Intelligence in Education (AIED)*. Scopus was chosen since it contains more than 80 million documents and refers to itself as the "largest abstract and citation database for peer-reviewed literature" (Elsevier 2021). ACM Digital Library, AIS eLibrary (containing the *"basket of eight"*), and IEEE were selected consistent with Levy and Ellis' (2006) recommendation since the database indexes relevant IS conference proceedings and journals. ERIC and Taylor & Francis were added as they aggregate scientific contributions from an educational and pedagogical perspective. The international conference AIED supplements articles linking AI and education. We conducted the SLR in December 2021 by applying the following search phrase to the title, abstract, and keywords in the above-mentioned databases:

TITLE-ABS-KEY ("Learning" OR "Education" OR "E-learning" OR "Instruction") AND ("Conversational Agent" OR "Collaborative Agent" OR "Chatbot" OR "Virtual Assistant" OR "Virtual Companion" OR "Interactive Agent") AND ("Adaptation" OR "Adaption" OR "Adaptability" OR "Adaptivity" OR "Customization" OR "Personalization" OR "Individualization")

The search query resulted in a total of 354 hits. Figure 3 presents the search and selection process in a PRISMA flow diagram as proposed by Page et al. (2021).

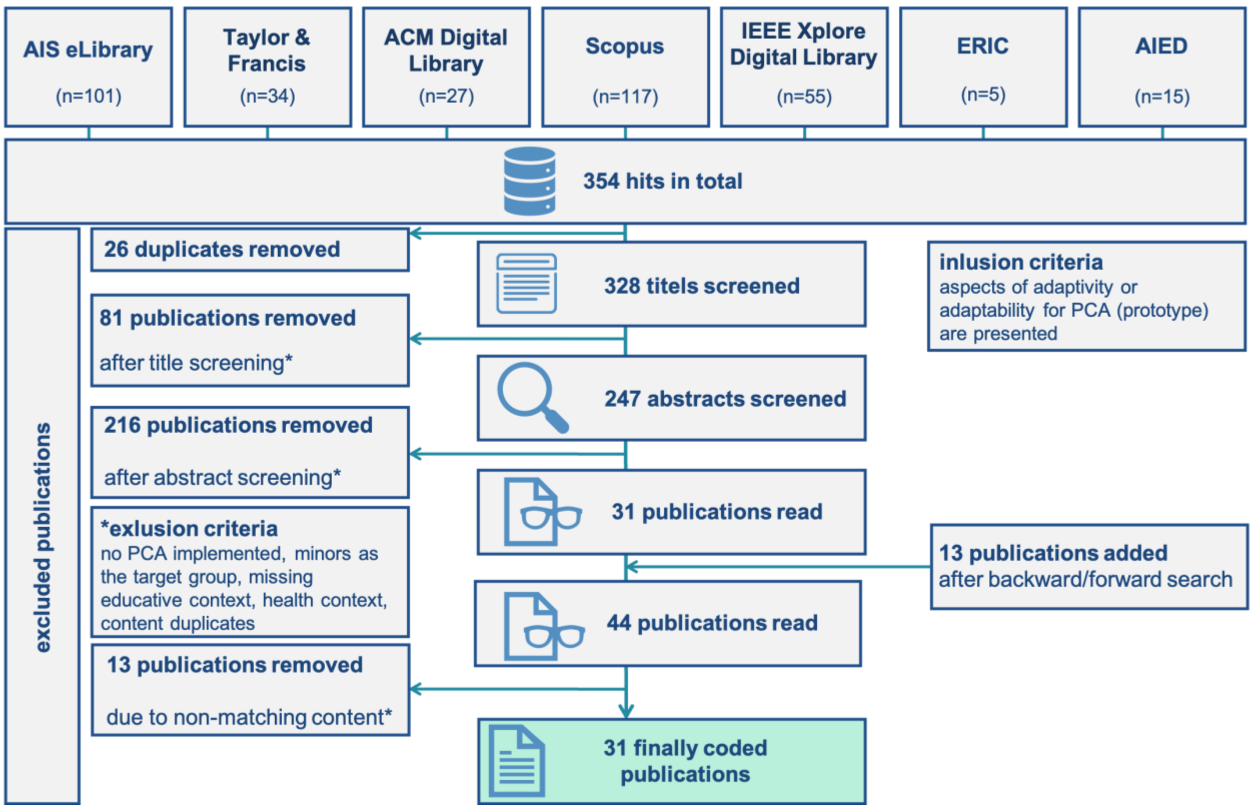

Figure 3. PRISMA Statement

The column in the middle enumerates the number of reviewed publications during each step, the column on the right lists the documents additionally added via backward search as well as the inclusion criteria valid for each selection step, while the left column illustrates the successive removal of excluded publications after each process step according to our pre-defined exclusion criteria. While we only included articles that addressed adaptive or adaptable aspects for PCAs, the exclusion was guided by pre-defined criteria: missing PCA implementation, target groups other than students, lack of educative context, health focus as well as duplicates, to ensure they fit with our RQs. We applied a peer-reviewed screening process to strengthen the objectivity of the SLR. Following the suggestion of Bandara et al. (2015), we coded the finally detected 31 articles supported by the software MAXQDA. Our code system aligned to the two strands of adaptation and we exploratively discovered adaptable and adaptive PCA aspects enriched by the technological evolution of the respective publication and various further dimensions (e.g., learning setting or education level). A joint and explorative derivation of the (sub-) codes following Mayring (2015) was created, which ensured a shared understanding for attributing codes during the further coding process and analysis of the results.

Results

The 31 finally selected articles were published in the years 2006-2021, among these two before 2010, another three before 2015, 18 in the period 2015-2020, and eight in 2021 alone, reflecting the growing popularity of this branch of research. When looking at the technological complexity of adaptation, purely configurative settings, in the beginning, evolved to increasing test-based classifications of the learner to a rise of AI-based adaptivity in recent years. Although a combination of the three forms of implementation is conceivable, only Griol et al. (2017) and Sharef et al. (2020) combine AI with configurations, and Vladova et al. (2019) with test-based classification, respectively. Figure 4 illustrates those findings per year with the most complex form depicted per coded publication.

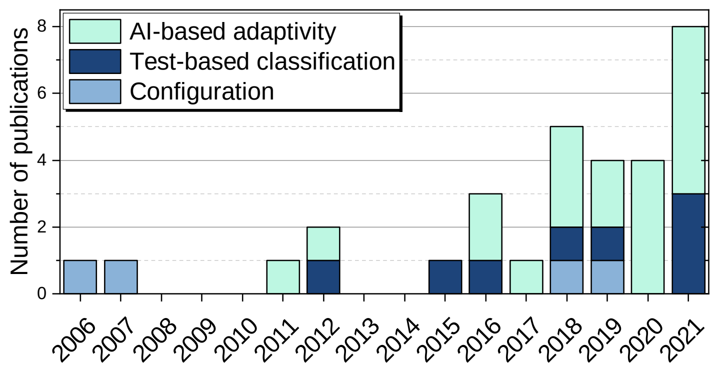

Figure 4. Number and Technological Complexity of Coded Publications per Year

With a presence in 22 of the 31 articles, formal learning settings dominate. The academic level prevails with 18 related publications compared to three publications that can be assigned to the lower or middle educational level. Half of the analyzed articles lack a solid theoretical grounding by simply focusing on the practical perspective in their study (e.g. Ruan et al. 2019; Zhang et al. 2020) without referring to a kernel theory. Theoretical grounding on learning or motivational theories dominates. While 13 introduced PCAs do not refer to a specific domain of application, the others cover instructional planning (Kim et al. 2006), argumentation (Wambsganß et al. 2020, 2021), speech training (Zhang et al. 2020), creativity/idea generation (Vladova et al. 2019), engineering (Taoum et al. 2018), serious game implementation (Gamage and Ennis 2018), mathematics (Cai et al. 2021), literacy/numeracy (e.g., Schouten et al. 2021) as well as language learning (e.g., Hassani et al. 2016) and IT (e.g., Latham et al. 2012), with the latter two slightly dominating with four and three mentions respectively.

During our analysis we came across four different adaptation scenarios: scenarios 1 and 2 create a learner profile at a fixed point in time, based on static elements - either in the form of a configuration that can be set by the customer (1) or a pre-test that the learner must first complete and is then assigned to a category based on the results obtained (2). Scenarios 3 and 4, on the other hand, describe a permanent adaptation based on dynamic data - either after the collection of sufficient user data (3) or, in scenario 4, by adapting to real-time data sources such as skin sensors or camera input. Each scenario then transfers the adaptations from the PCA backend to the frontend by adapting to the learner as shown in Figure 5 on the next page. 19 articles use permanent adaptation (scenario 3+4), while the remaining rely on static elements, thereof nine contributions on a one-time pre-test. The source of data classification for adaptation often goes back to only one identifier like selectable learning activities (e.g., Courtine and Renault 2007) in scenario 1, a cognitive diagnostic pre-test for classification (e.g., Kularbphettong et al. 2015) in scenario 2, a learner profile of achieved scores in previous tests (e.g., Baesa and Caballero 2018) in scenario 3, or the learner's heart rate as biological reaction data (Sharef et al. 2020) in the fourth scenario. Only Griol et al. (2017), as well as Sharef et al. (2020), make use of scenarios 1, 3, and 4 in parallel, while Vladova et al. (2019) combine scenarios 2 and 3 for a learning avatar that adapts to the results of a survey and later on to collected learner profile data. Thus, the synergetic combination of the four scenarios remains largely unnoticed. Also, adaptivity to real-time data sources is only present in three cases, potentially for the reason that it requires sophisticated additional technology like sensors close to the user measuring body functions or the processing of video signals in real-time.

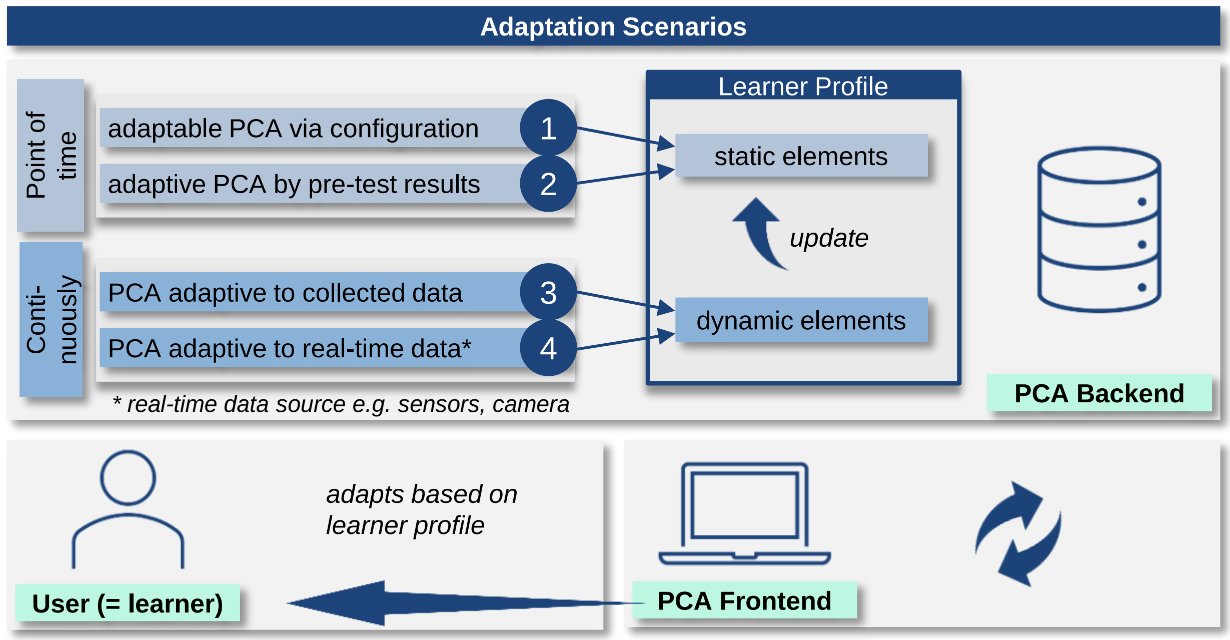

Figure 5. PCA Adaptation Scenarios

In addition to the prevalence of the four adaptation scenarios, we also exploratively examined the presence of adaptation aspects in the strands of adaptability and adaptivity, as well as other characteristics of the PCA research like a field of use and long-term orientation. Table 1 on the next page illustrates, in aggregate, those (adaptation) aspects identified in the 31 publications examined. Each traced form of adaptation was coded and marked accordingly with a cross in the table. As a result, gaps, as well as strongly represented dimensions, can be identified at a glance. It is striking that there were fewer adaptable PCA categories (embodiment, proactivity, cognitive level, unspecified user preferences) found in the strand of adaptability, and also fewer hits within each of them (just six explicit adaptability mentions in total were detected in the 31 articles examined) than in the other adaptation strain. In the adaptivity strand, in contrast, we were able to identify twice as many adaptive dimensions (personality (traits), embodiment, emotion, learning style, tailored feedback, motion, unspecified others), which appeared much more frequently with a total of 41 mentions. PCA adaptation research thus appears to focus more on the aspect of adaptivity, potentially due to the given growing technological opportunities for data adaptivity and is also in line with the growing use of permanently adapting systems (scenarios 3 and 4) in recent years.

Even though many language learning apps like Chinese Skill[2] or Duolingo[3] work with (non-human) adaptable avatars and skill levels in practice, we did not find scientific PCA research in that context and only one (human-like) avatar was adaptable (Gamage and Ennis 2018). The simultaneous encounter of adaptable and adaptive aspects in a PCA remained mostly unconsidered, although their purposeful, synergistic application seems promising for adapting to the complex learner's needs multi-dimensionally. The synopsis indicates that research studies tend to be fragmented, embedding only a single aspect of adaptation. However, some PCAs adapted to at least two elements in parallel, for instance, personality-adaptive speech patterns paired with ethnicity and emotion (Ranjbartabar and Richards 2018), peer students' recommendation paired with tailored learning resources adapted to the learner's skill level (Sharef et al. 2020), adaptive skill levels paired with adaptive facial expressions of the PCA's avatar and autonomous navigation options (Taoum et al. 2018), adaptability of the ethnicity, style, and gender of humanoid avatars (Gamage and Ennis 2018) as well as adaptable PCA cognitive levels together with proactivity in interaction (Kim et al. 2006). Although two articles (Adel et al. 2016; Crockett et al. 2011) do not cover the concrete adaptation itself, they address learning style classifications with the target of tailored instruction.

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[2] https://www.chineseskill.com/

[3] https://www.duolingo.com/

Scientific Publication	Adaptability				Adaptivity								Adaptation Scenario				PCA Research			
	Embodiment	Proactivity	Cognitive Level	Unspecified Preferences	Personality (Traits)	Embodiment	Emotion	Learning style	Skill level	Learning Path	Motion	Unspecified others	Adaptable via Configuration	Adaptive via Pre-Test (2)	Adaptive via Aggregated Data	Adaptive via Real-Time Data	Educative Level*	Formal Learning Setting	Generic Field of Use	Long-Term Study**
Adel et al. 2016 🧠								×							×		○		×	
Baesa & Caballero 2018 🧠									×						×		◎			
Bakouan et al. 2018 💙 🧠							×								×		●	×	×	
Cai et al. 2018 🧠									×						×		○			
Courtine & Renault 2007 🧠			×										×				●	×		
Crockett et al. 2011 🧠								×							×		●	×	×	
Davies et al. 2021 🧠 ⚙					×				×	×				×			○	×		
Dennis et al. 2016 💙 🧠 ⚙					×				×					×			○	×	×	
Filho et al. 2021 🧠								×						×			●	×	×	
Gamage & Ennis 2018 🧠 🌎	×												×				○			
Gonzáles-Castro et al. 2017 🧠									×					×			○			
Griol et al. 2017 💙 🧠				×					×		×		×		×	×	●	×	×	
Haefner et al. 2021 💙							×									×	◎	×	×	
Hassani et al. 2016 🧠									×						×		●	×		
Janati et al. 2020 🧠									×						×		○		×	
Kim et al. 2006 🧠 ⚙		×	×										×				●	×		
Kularbphettong et al. 2015 🧠 ⚙					×			×						×			●	×		
Latham et al. 2012 🧠 ⚙								×	×	×					×		●	×		
Ranjbartabar & Richards 2018 💙 ⚙					×	×	×							×			●	×	×	
Redondo-Hernández & Perez-Marín 2012 ⚙					×			×						×			●	×	×	
Rooein 2019 🧠 ⚙									×	×		×			×		○			
Ruan et al. 2019 🧠			×										×				●	×	×	
Schouten et al. 2021 🧠 ⚙									×						×		◎	×		
Sharef et al. 2020 💙 🧠 ⚙									×				×		×	×	●	×	×	
Taoum et al. 2018 🧠						×			×			×			×		○			
Vijayakumar et al. 2019 🧠									×					×			○			
Vladowa et al. 2019 🧠 ⚙ 🌎					×	×			×					×	×		○			
Wambsganß et al. 2020 🧠									×						×		●	×		
Wambsganß et al. 2021 🧠									×						×		●	×		
Wang et al. 2021 🌎												×			×		●	×	×	
Zhang et al. 2020 🧠									×						×		○			

Legend: * ○ = generic; ◎ = middle/lower; ● =higher education; **PCA was used and tested for > 6 months
Covered Meta Categories of Learning Variables:
💙 = affective; 🧠 = cognitive; ⚙ = motivational; 🌎 = socio-cultural

Table 1. Identified Adaptation Aspects in PCAs

Four additional papers also deal with learning style adaptivity (e.g., Kularbphettong et al. 2015), often by referring to the *Index of Learning Style* (e.g., Latham et al. 2012) or the Felder-Silverman learning style test (e.g., Filho et al. 2021; Redondo-Hernández and Pérez-Marín 2012). Most frequently, adaptivity was detected to the learner's skill level (18 cases), sometimes even combined with other characteristics, for instance, context adaptation like motion, orientation, and further unspecified environmental conditions (Griol et al. 2017; Rooein 2019), the calculation of a personalized learning path (e.g., Davies et al. 2021) or mimicking a human tutor by using knowledge of learning styles (Latham et al. 2012). Adaptation to personality was found six times, thereof four times according to the Big Five personality traits (Dennis 2011; Ranjbartabar and Richards 2018; Redondo-Hernández and Pérez-Marín 2012; Vladova et al. 2019). Kim et al. (2006) demonstrate that high-competency PCAs positively influence students' application of learning, while low-competency PCAs are perceived as more motivational due to a stronger feeling of self-efficiency by the learner – the cognitive level adaptability refers hereby to the competence of the PCA instead of the learner's cognitive skills (e.g., Ruan et al. 2019).

Comparing our findings with the four proposed meta-categories (cognitive, motivational, affective, socio-cultural) from the taxonomy of adaptivity for learning (Plass and Pawar 2020), these help answer RQ1. Identified PCA adaptation criteria can be decomposed to the adaptability and adaptivity strands. The upper category of adaptivity by cognitive variables strongly dominates, as skill level and learning style are particularly frequently adapted in PCAs. Cognitive variables are addressed in 27 of the 31 papers examined, with the main goal of improving learning outcomes. Adaptive motivational variables were identified in eleven of the articles studied. In the dimension of adaptive affective variables, the first emotion-aware PCAs are arising (e.g., Haefner et al. 2021). The socio-cultural level is adapted only sporadically in terms of personality (Vladova et al. 2019), the (ethnic) embodiment of an adaptable avatar (Gamage and Ennis 2018), and the PCA's language perception (Wang et al. 2021). Thereby, in addition to the learning outcome, also other variables, e.g., perceived likeability, anthropomorphism, intelligence, and the impact on learner engagement are considered (Gamage and Ennis 2018; Wang et al. 2021). However, the culture-specific and social context remains widely untouched. In addition, it is striking that all of the publications examined are based only on a short-term perspective of fewer than six months, so long-term statements about the effect of the adaptation cannot be made, although being crucial for their sustainable design and usage. For instance, these would be relevant for describing a trusting, social relationship (Nißen et al. 2021), since learners' perception of the PCA's andromorphism and intelligence changes already within ten weeks of regular interaction (Wang et al. 2021).

Discussion

In this paper, we have investigated the state-of-the-art in adaptation aspects of PCAs using an SLR. Our core findings are reflected in this chapter by discussing discrepancies, limitations, and arising future research streams.

Theoretical Potential vs. Current status of PCA Adaptation in Literature

Our results show a discrepancy between the expectations towards adaptive and adaptable PCAs addressed in the examined literature and their actual implementation status: The expectations toward PCAs are manifold and profound. The authors of the articles under study promise at least teaching or learning support (e.g., Cai et al. 2021; González-Castro et al. 2021) - in some cases even *"to replace a human tutor in some circumstances"* (Courtine and Renault 2007, p. 22) with the goal of an improved companionship-like relation (Redondo-Hernández and Pérez-Marín 2012) and individual support like personalized guidance (Cai et al. 2021). They desire an individualized, more comfortable learning experience (Crockett et al. 2011; Latham et al. 2012) and adaptivity to skill level (e.g., Hassani et al. 2016; Schouten et al. 2021), attention spans or pace (Davies et al. 2021; Dennis 2011; Haefner et al. 2021). However, according to our analysis, this is contrasted by the uncovered, mostly prototypical, and technically underdeveloped state of adaptive PCA implementations, which mostly rely on pre-test classification and frequently just adapt to a single feature. Also, the human adaptability to emotions, personalities, and social needs, which is necessary for the idea of companionship as well as a long-term view on adaptation impact, has not been considered so far, or only in a rudimentary way and without a long-term perspective (e.g., Dennis 2011; Ranjbartabar and Richards 2018). Although the argument that a PCA has better memory (Ranjbartabar and Richards 2018) and greater access to learning content than a teacher (González-Castro et al. 2021; Haefner et al.

2021; Vladova et al. 2019), at least the current status quo does not suggest that human teachers with their social skills and holistic view of the learner could be replaced in practice in the near future. Rapid progress in AI-based adaptivity opens new chances for promising innovations.

In addition, Gamage and Ennis (2018) draw attention to meta-studies by Schroeder et al. (2013) revealing that study results on the effect of PCAs on learning outcomes are inconsistent, and thus it is unresolved whether and what effects PCAs have on learning. In doing so, they put into perspective the expectations that some authors (e.g., Adel et al. 2016; Bakouan et al. 2018) have for improving learning outcomes. Baesa and Caballero (2018) cite the potential to *"ensure inclusive and quality education"* (p.61) and Ranjbartabar and Richards (2018) underline that user identification with the PCA is related to appearance (e.g., gender, age, ethnicity). In addition, ethical studies of PCAs are gaining relevance (Schlimbach et al. 2022; Spiekermann et al. 2022; Wambsganß et al. 2021a). Provided ethical considerations are taken into account (Wambsganß et al. 2021a), adaptive PCAs offer the potential to revolutionize individualized learning and increase educational equity in the long run (Schlimbach and Khosrawi-Rad 2022). However, in practical implementation, with some exceptions (Gamage and Ennis 2018; Ranjbartabar and Richards 2018), we could not find a PCA that implements inclusion and diversity as adaptation components. Furthermore, none of the publications addresses data protection aspects, although the permanent collection and storage of sensitive, personal data are key to the design of adaptive systems and ethically responsible handling of them is thus essential. These findings underscore the still early stage in which this emerging branch of research is in and thus opens a broad field for further research (Schlimbach and Khosrawi-Rad 2022).

The desire for cost-effective scalability (e.g., Adel et al. 2016; Haefner et al. 2021) conflicts with the core argument of high personalization to the individual learner and his or her needs since an expansion to different (subject) contexts and an even higher heterogeneity of learners naturally also entails quality losses in the precision of the adaptation or extensively drives up development and operating costs. The tension between pigeonholing and over-specialization might be one reason why the analyzed articles research either at a strongly generic or strongly specific level. The frequently referenced advantage of the locally and temporally flexible adaptability of PCA is currently only reflected in its 24/7 availability, but - with a few exceptions (e.g., Griol et al. 2017) - without exploiting the potentials of situational adaptation in the terms of context-awareness. High expectations were set by the investigated articles on the technical progress, especially in the field of AI (e.g., Davies et al. 2021; Janati et al. 2020) and the arising possibilities for real-time adaptation (Taoum et al. 2018). Taking into account that developments on PCAs have been ongoing for more than 30 years (Bendel 2003) and adaptive learning concepts for about 50 years (Davies et al. 2021) from today, our analysis results disappoint by showing the dominance of learners' one-time classification in pre-tests based on a single data source or aggregated data instead of real-time adaptivity. Nevertheless, the temporal clustering of identified adaptive PCAs in the last three years (cf. p.6) also demonstrates that this research field has only recently begun to gain momentum and produce innovative findings.

In line with Wollny et al. (2021), we conclude that we are not there yet, as potentials in adaptive and adaptable PCAs have been identified by researchers but have largely not yet been practically implemented. In this context, concrete design recommendations are lacking. Among the 31 analyzed publications, only Wambsganß et al. (2020) explicitly derive design principles for adaptive PCAs, and this is only for the specific use case of improving students' argumentation skills. To trigger further research for the gaps we have identified, we derive seven future research streams, which we elaborate on in detail in the section after our research limitations also resulting in the need for further studies.

Limitations

As with any SLR, our contribution is subject to certain limitations. Although we followed established guidelines, our search strategy (e.g., selection of databases and search terms) may have missed relevant contributions. In addition, the fast pace of this emerging research strand leads to a constant stream of new publications; however, we were only able to consider those up to and including December 2021. Despite the peer-review screening process and software-based coding, we are aware that this process always produces subjectively made decisions that can never be entirely prevented. Because we focused specifically on adaptation aspects for actually implemented PCAs, research contributions to adaptive CAs in general (addressing other domains than education) were left out and would have led to other prevailing categories and a different categorization and interpretation. However, we find it valuable to highlight the specifics of PCA adaptation like the dominance of cognition-adaptive variables. Furthermore, for our analysis, we chose a classification along the complementary used terms *adaptivity* and a*daptability* (Oppermann 2005), and deducted sub-dimensions exploratory before comparing them to the core categories of the taxonomy of adaptivity for learning (Plass and Pawar 2020). We acknowledge that there might be different classifications for both as well, which would lead again to a different structuring. Besides, since we focused on design elements of PCAs and their adaptation scenarios, we did not explore the specific technical implementation (like architecture, recommender systems, or programmed networks) of adaptive systems in detail. Furthermore, some analyzed contributions were more generically oriented, while others focused specifically on a particular application domain and addressed the adaptation of PCAs for that particular use case. However, we believe that both approaches have merit and that the inclusion of their results enhances the holistic perspective of our contribution - yet the transferability needs to be further explored.

Despite these limitations, we argue that the categorizations we use are appropriate for delineating manual versus automatic user adaptation and their respective implementation in PCAs to represent the state of the art for PCAs against this background. We would like to encourage further research by bringing up potential future research avenues.

Future Research

Answering RQ2, our study offers various promising directions for future research, so we suggest seven future research streams:

(1) **Exploring the transferability of adaptation studies:** PCAs are a highly interdisciplinary field of research, combining for example pedagogical, psychological, and social science aspects with IS research. While adaptation studies for PCAs are still underrepresented, research in this field is already more advanced in other application domains (e.g., Ling et al. 2021; Wald et al. 2021). Therefore, it seems worthwhile to investigate the transferability of existing results to new contexts or from specific use cases to more generic ones and vice versa.

(2) **Considering the ethical perspective**: Further interdisciplinary research is needed to better understand the ethical and societal implications of designing adaptable and adaptive PCAs. Not all adaptation features may be appropriate or desirable for PCAs. For example, adaptive mechanisms could be misused to collect user data for targeted sale, or algorithmic bias (e.g. explained in Casas-Roma and Conesa 2021) might discriminate against certain groups of learners and provoke educational inequality or ignore specific (e.g., cultural) needs. The management of the data required for adaptivity should also be given greater consideration, e.g., from a data security perspective as a basic requirement for implementation (Schlimbach and Khosrawi-Rad 2022).

(3) **Analyzing long-term effects of adaptive PCAs:** Expectations for improved learning outcomes thanks to adaptive PCAs and other positive effects leading to a close and trusting learner-agent-companionship, require the investigation of the long-term perspective. Since only short-term studies are available so far, we recommend pushing for longitudinal studies.

(4) **Leveraging the potential of AI:** The rapid progress in areas such as artificial intelligence suggests new potentials for technological implementation, for example, fully self-learning systems, thus moving away from the current mostly time-delayed and test-based classification of learners to real-time adaptivity to a variety of relevant learning variables in parallel and a sound cost-benefit ratio.

(5) **Relating desirability to feasibility for PCA adaptation:** Discrepancies, revealed in many directions, between the scientists' expectation and actual implementation status of PCAs requires extensive further research, for example, to define the intended role of the PCA and the limits of (technical) feasibility at that time. As a result, research efforts could be more purposefully channeled.

(6) **Conducting meta-studies on PCA adaptation:** Holistically examined meta-studies should expand the currently scattered landscape of adaptation research by integrating a variety of PCA perspectives in the context of adaptation, potentially resulting in a holistic framework with generic and application-specific cues derived therefrom. In addition, existing conflicting results should be further examined to solve inconsistencies - for example, some of the design recommendations of personality-adaptive CAs contradict each other (Ahmad et al. 2021).

(7) **Deriving adaptable Design Principles:** Sound design principles for adaptive and adaptable PCAs are lacking, and should be thoughtfully discovered and evaluated for consistency and suitability for combination to systematically support researchers and practitioners in designing ethically and socially desirable PCAs with the potential to revolutionize education.

Conclusion

Our research aimed to provide an overview of adaptation aspects addressed in the scientific literature for the design of PCAs. Therefore, we conducted an SLR following the approach by Brendel et al. (2021). Starting from 354 initial hits derived from seven databases, we finally analyzed 31 publications bridging education and IS research on PCA adaptation. We structured our findings based on the dimensions of adaptability or adaptivity and derived adaptation scenarios for PCAs. The identified cues manifesting a variety of adaptation patterns were then classified into a table for further discussion. Our literature review results contribute to IS research by providing an overview of adaptation elements manifested in PCAs and uncovered the following core findings: First, adaptation extends almost exclusively to either adaptability or adaptivity in PCA research; frequently a single trait from the plethora of adaptation elements is adapted and mostly relies on a single data source variable. Second, adaptability options are severely underrepresented, and long-term studies on PCA adaptation are lacking, which is surprising given the growing evolution of socially bonding PCAs aiming for long-lasting, trustworthy relationships. Third, our SLR revealed the imbalance of theoretically detected chances of PCAs and the practical lack of its implementation. However, the rapid technological advances, especially in the field of AI, give hope for a timely resolution of this discrepancy. Intended to provide impetus, we derived seven promising research streams and discussed the arising potentials. Figure 6 illustrates the seven fields of action to explore and leverage the potential of adaptable and adaptive PCAs.

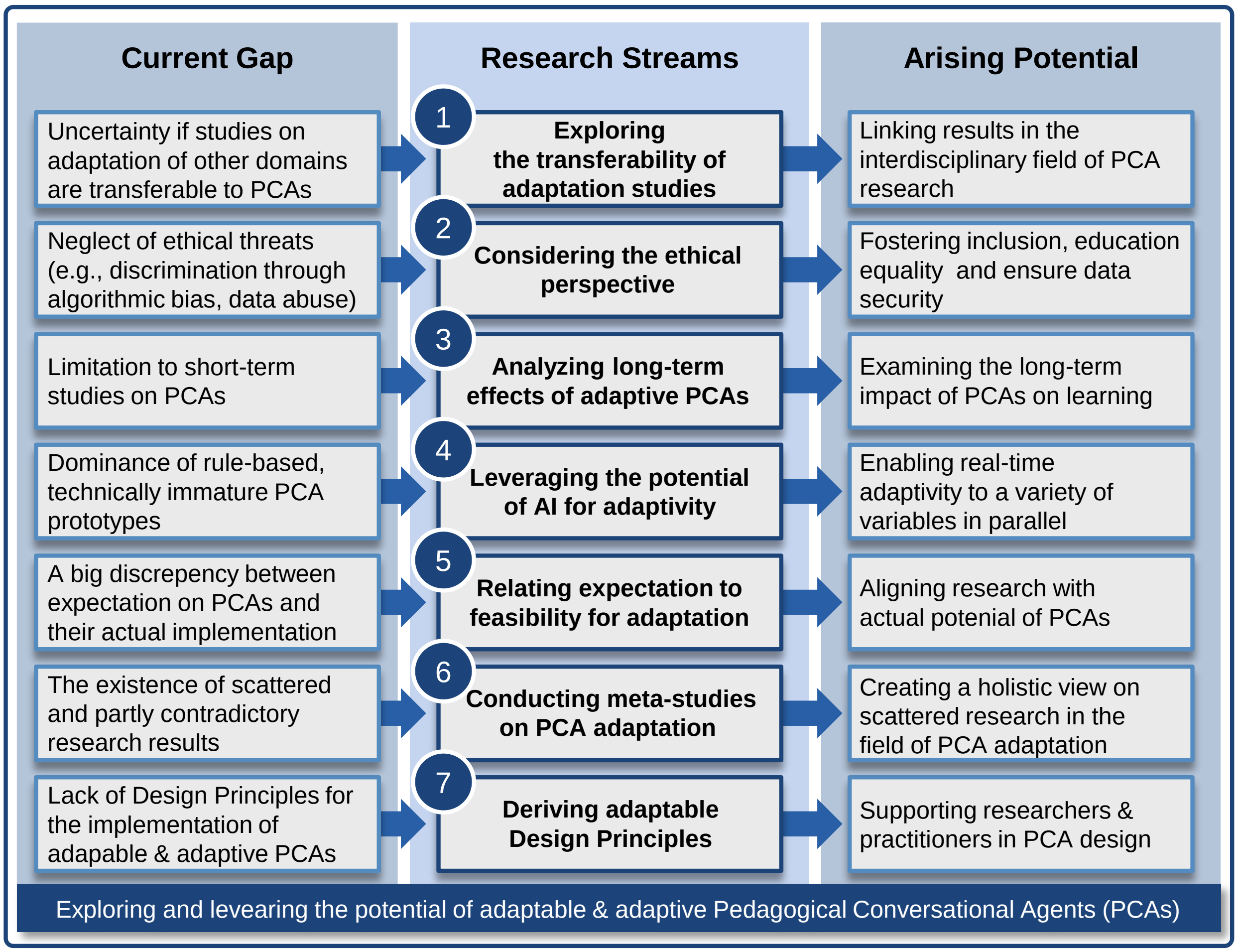

Figure 6. Overview of Future Research Streams

Our findings should be a useful resource for researchers and practitioners to reflect on the actual design of adaptive and adaptable PCAs. Future research thus needs to fill the current blind spots and provide a more complete picture of what exhibits the potential of technologically sophisticated, learner-adaptive, and adaptable PCAs.

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