OPEN ACCESS

Sakellariou S, et al. (2024): 15
DOI: 10.47991/2024/IJTLS-102

Research Article

International Journal of Teaching and Learning Sciences

# On the Effectiveness of Pedagogical Agents

**Silvestra Sakellariou, Anastasios Molohidis and Euripides Hatzikraniotis***

Laboratory of Science Education & Educational Technology, School of Physics, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

***Corresponding author:** Euripides Hatzikraniotis, Email: evris@auth.gr, Tel/fax: +302310998216

**Citation:** Sakellariou S, Molohidis A, Hatzikraniotis E (2024) On the Effectiveness of Pedagogical Agents. Int J Teach Learn Sci: IJTLS-102.

**Received Date:** 31 August, 2024; **Accepted Date:** 06 September, 2024; **Published Date:** 11 September, 2024

## Abstract

*Pedagogical Agents (PAs) have attracted considerable attention due to their ability to personalize learning experiences, enhance student engagement, and provide tailored support in digital educational environments. These agents are increasingly recognized for their potential to fulfill various educational functions, which are critical for improving learning outcomes. This review is grounded in the Pedagogical Agents Conditions of Use (PACU) and Pedagogical Agents Levels of Design (PALD) frameworks which are widely recognized for the effectiveness of PAs. It synthesizes insights from 6 systematic reviews and 5 meta-analyses to provide a comprehensive understanding of PA effectiveness across diverse educational contexts. This study is based on existing literature to categorize the functions of PAs, distinguishing them to cognitive, metacognitive and emotional functions to clarify the often-ambiguous concept of "coaching." The review also highlights that, while gender is often considered a detailed design feature, it has a notable impact on learner perceptions and outcomes, potentially reinforcing stereotypes, which can have negative implications. Additionally, the review underscores the importance of balancing interactivity and complexity in PA design. While these elements can enhance engagement, they must be carefully managed to avoid cognitive overload. This review builds on existing literature to integrate functions within the PACU-PALD frameworks to enhance their application.*

***Keywords:*** *Pedagogical Agents, review, PACU (Pedagogical Agents Conditions of Use), PALD (Pedagogical Agents Levels of Design).*

## 1. Introduction

Pedagogical agents (PAs) have garnered significant attention from researchers due to their crucial roles in enhancing learning outcomes. The body of research on PAs is extensive, with many reviews and meta-analyses published. These previous studies provide valuable insights and often report a wide range of factors influencing the effectiveness of PAs. However, the frequent combination of mixed moderator variables makes it challenging to isolate the specific effects of PAs on learning resulting in a less clear landscape.

In response to this gap, the present study focuses exclusively on meta-analyses and reviews that specifically assess the effectiveness of PAs. This approach is guided by the PACU (Pedagogical Agents and Conditions of Use) and PALD (Pedagogical Agents Levels of Design) models, initially proposed by Heidig & Clarebout [1], and further refined by Peng & Wang [2] for providing a structured framework for analyzing the effectiveness of PAs across different educational contexts.

PACU and PALD address the complexity and diversity of PAs in e-learning environments. These frameworks were developed to offer a more systematic approach to analyzing and reporting on the use of PAs in educational research. By breaking down the elements of PAs into more manageable and clearly defined components, these frameworks make it easier to study and understand their effects on learning.

Guided by this framework, the research questions are as follows:

1. How does the learning environment influence the effectiveness of PAs in enhancing learning outcomes?
2. What functions of PAs are most effective in promoting learning?
3. How does the design of PAs influence learning outcomes?
4. How do learner characteristics impact the effectiveness of PAs?

## 2. Theoretical Framework

A Pedagogical Agent (PA) is a simulated character within a digital learning environment, specifically designed to facilitate the achievement of educational goals. A PA can take the form of a human, an animal, or even an object. Regardless of its appearance, the agent is humanized in the sense that it possesses human-like qualities, such as the ability to think and to speak or write. This anthropomorphism allows the agent to communicate with users, creating the feeling of interacting with another being within the e-learning environment.

The communication between a Pedagogical Agent (PA) and the user can occur across a broad spectrum, ranging from free dialogue (either written or spoken) using artificial intelligence technology to pre-defined or rule-based conversations [3-4].

Pedagogical Agents have attracted the interest of many researchers, and studies indicate a wide range of findings, often with conflicting results. One reason for these inconsistencies is the complexity of PAs and how they interact with users. Heidig & Clarebout [1], identify four key factors that influence the effectiveness of PAs:

- The educational environment and subject matter in which a PA is implemented
- The learners' characteristics
- The functions of the Pas
- The design principles of the PAs

The functions of PAs can be categorized, according to Clarebout at al. [5], as providing information such as educational content, demonstrating to the user how to perform a specific task, coaching the user through personalized feedback, and assessing the user's knowledge of the content.

Dai et al. [6], add an additional function identified in their review. In some studies, PAs acted as Peer Learners, eliciting information from a proficient PA (Expert or Mentor) through interactions. This added a new category to the functions of PAs, allowing Peer Learner PAs to elicit information from a specialist and proficient PA playing the role of the Expert or Mentor.

The function of coaching within Pedagogical Agents (PAs) is often ambiguous, as noted by Peng & Wang [2]. This ambiguity arises because the term "coaching" is used to describe multiple, sometimes overlapping, functions. According to Clarebout et al. [5], coaching involves instructional agents providing "hints and feedback" and "activate learners when they perform the tasks," which may include a combination of explaining and questioning. Similarly, Dai et al. [6], define coaching as assisting learners by "providing feedback or tips that are not part of the instructional content." The phrase "activate learners" implies an emotional or motivational role, while Dai et al.'s emphasis on "tips that are not part of the instructional content" suggests both motivational and metacognitive support. These definitions indicate that coaching encompasses cognitive guidance, the development of metacognitive skills, and motivational support.

In everyday contexts, the term "coaching" often encompasses a broad range of activities, including training, emotional support, enhancement of metacognitive skills, and fostering self-regulation—much like what coaches do for their teams. This common understanding of coaching highlights its multifaceted nature, which is mirrored in the roles that PAs fulfill. To better clarify these overlapping functions, we propose distinguishing "coaching" into more specific terms: "scaffolding," "enhancing metacognitive skills," and "motivating" or "encouraging". Scaffolding refers to providing personalized feedback and cognitive support to help learners progress through tasks. Enhancing metacognitive skills involves helping learners monitor and evaluate their own learning processes, teaching strategies for effective learning, such as time management and approaching complex tasks. Motivating or encouraging focuses on maintaining learner engagement, offering support to prevent discouragement, and encouraging persistence and effort.

Therefore, the functions of PAs are as follows:

- Providing information, such as educational content
- Demonstrating
- Scaffolding.
- Enhancing metacognitive skills
- Motivating
- Testing and
- Eliciting information

This proposal to expand the categorization of PAs' functions is further supported by recent findings in the field. Sikstrom et al. [7], identified several key functions of PAs, particularly highlighting scaffolding, enhancing metacognitive skills, and motivating students as crucial elements that positively influence learning outcomes. They emphasize that scaffolding through feedback, prompts, and instructional guidance helps students navigate learning tasks more effectively. Moreover, PAs play a significant role in fostering metacognitive skills by helping students in planning, monitoring, and evaluating their own learning processes, thus promoting greater self-regulation. Additionally, the motivational role of PAs, as emphasized by the same researchers [7], is critical in enhancing student engagement and persistence, further validating our proposal to recognize "motivating" as a distinct function within the broader "coaching" role.

Furthermore, Ortega-Ochoa et al. [8], underline the significance of empathic Pedagogical Conversational Agents (PCAs) in both cognitive and affective learning dimensions. Their research highlights how these agents foster metacognitive skills through functions such as encouraging reflection, providing tailored feedback, and promoting active learning. This aligns with our proposed function of "enhancing metacognitive skills" further supported by the emotional support these agents provide, which directly contributes to maintaining student engagement and motivation. By incorporating these nuanced functions—scaffolding, enhancing metacognitive skills, and motivating—we can more accurately define the multiple functions that PAs execute in educational contexts, ensuring that their contributions to learning are clearly understood and effectively utilized.

The design principles of PAs are divided into three levels in Heidig & Clarebout [1], (PALD Pedagogical Agents Levels of Design):

- Global Design: Decisions on whether the PA will be non-human or human, and whether it will be an animation or a static image.
- Medium Design: Decisions about voice, speech style, gestures, expressions, associated with the role of the PA.
- Detailed Design: Decisions regarding age, gender, and clothing.

Further analyzing the medium level design, it refers to the role PAs play in educational contexts. According to Kim & Baylor [9-10], the roles of PAs are categorized as:

- Experts
- Mentors
- Motivators and
- PALS - Pedagogical Agents as Learning Companions

The Expert provides information and explains educational content. Experts have great authority and high level of expertise, with minimal emotional interaction with the user. To appear more convincing as teachers, their appearance often aligns with certain stereotypes. They are typically portrayed as middle-aged, dressed in a more formal, classic style (e.g., wearing a tie), and are serious and expressionless, offering very limited emotional support to students while their speech tends to be monotonous.

Mentors, on the other hand, are slightly older than the users and dress more formally than the users, but not as formally as Experts. Their age is intended to convey reliability and knowledge, while their tone of speech remains friendly. Mentors express their emotions in a calm and measured way, providing a balance between authority and empathy.

Motivators are peers of the users and do not possess in-depth knowledge of the educational content. They encourage users to continue their efforts, using expressive language and gestures. Their speech style is closer to the informal language used by the users, and their dressing is casual.

PALs are peers of the users but can vary in their knowledge level. They can be designed to represent an exceptionally high-performing student who can offer guidance and demonstrate expert-level knowledge, or they can represent a less knowledgeable peer who asks questions, makes mistakes, and learns alongside the user. Their flexibility allows them to interact with users in multiple ways such as collaborating with the learner, offering explanations, or even competing in a friendly way to activate or to further engage the learner.

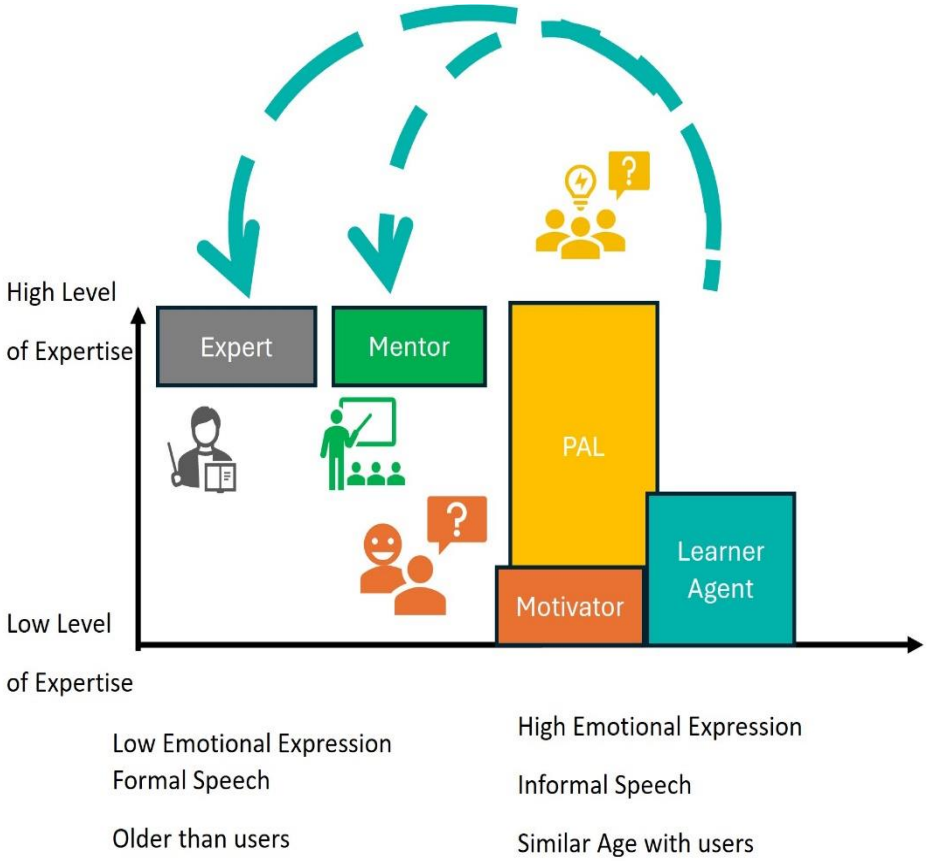


**Figure 1:** Different Agents' Roles. The arrows show that Learner Agents mainly interact with Expert or Mentors and not the user. All other agents interact with users.

Dai et al. [6], in their review identified an additional agent role in double-agent settings. They refer to this agent as a Learner Agent, which appears on the screen alongside with Expert or Mentors Agents. This Learner Agent primarily interacts with the High Expertise Agent on the screen. The Learner Agent is deliberately less knowledgeable and often asks questions, expresses doubts, or makes mistakes. By doing so, the Learner Agent and not the user who might have the same questions, absorbs the "blame" or correction or “criticism” from the Expert, thereby resulting in a less stressful e-learning environment for the user.

While functions refer to what pedagogical agents do, the levels of design determine how these functions are performed by the agent, including decisions not only about the technology used but also the agent’s appearance. A critical part of the design process is ensuring that agents are quickly associated with their roles, avoiding ambiguity unless it is intentionally introduced. For example, an agent designed to teach may adopt the role of a PAL Mentor, or Expert, depending on the educational goal. The agent’s visual representation plays a key role in this process, as learners form immediate, intuitive associations based on appearance. An expert might be visually portrayed as older and authoritative, while a PAL is designed to look like a peer, reinforcing relatability and shared learning experiences.

Despite these visual distinctions, the same function (e.g., teaching or motivating) can be fulfilled by different roles. An expert may deliver content efficiently, while a PAL can additionally foster self-regulation by modeling challenges and persistence. Thus, while functions and design levels are distinguished, they are closely interrelated, as the agent's role and appearance work together to support different learning objectives. This interdependence allows designers to create agents that not only perform their functions but do so in a way that aligns with learners' expectations and cognitive ease.

Figure 1 illustrates the different roles of PAs based on their levels of expertise, emotional expression, speech formality, and age. Most agents directly interact with users, except for Learner Agents, who primarily engage with Expert or Mentor Agents on the screen. Motivators, PALs (Pedagogical Agents as Learning

Companions), and Learner Agents are characterized by high emotional expression, though their levels of expertise vary among them. Notably, the overlap between PALs and Mentors in the figure indicates that PALs can sometimes possess a level of expertise comparable to Mentors, offering both peer-like interaction and expert guidance while Learner Agents seem less knowledgeable. Learner Agents possess a higher level of expertise compared to Motivators as they act as mediators between Experts/Mentors and users, digesting and delivering knowledge in an understandable and more accessible way though their proficiency or competence does not reach the level of Experts/Mentors. Motivators, by contrast, focus on emotional engagement and encouragement without referring to educational content.

Figure 2 presents the PACU and PALD framework, which outlines the key factors influencing the effectiveness of Pedagogical Agents (PAs). These factors include the learning environment, the specific functions performed by PAs, the design levels (global, medium, and detailed), and learner characteristics. The PACU-PALD framework is designed from a researcher's perspective, but researchers should also consider learners' perceptions, which are shaped by the agent's role. The role, in turn, is shaped by both function and appearance, acting as a bridge between the two, and is key in conveying the intended function to learners. The figure also shows that these functions and appearance interact to shape PAs' roles, such as Expert, Mentor, Motivator, PAL (Pedagogical Agent as Learning Companion), and Learner Agent.

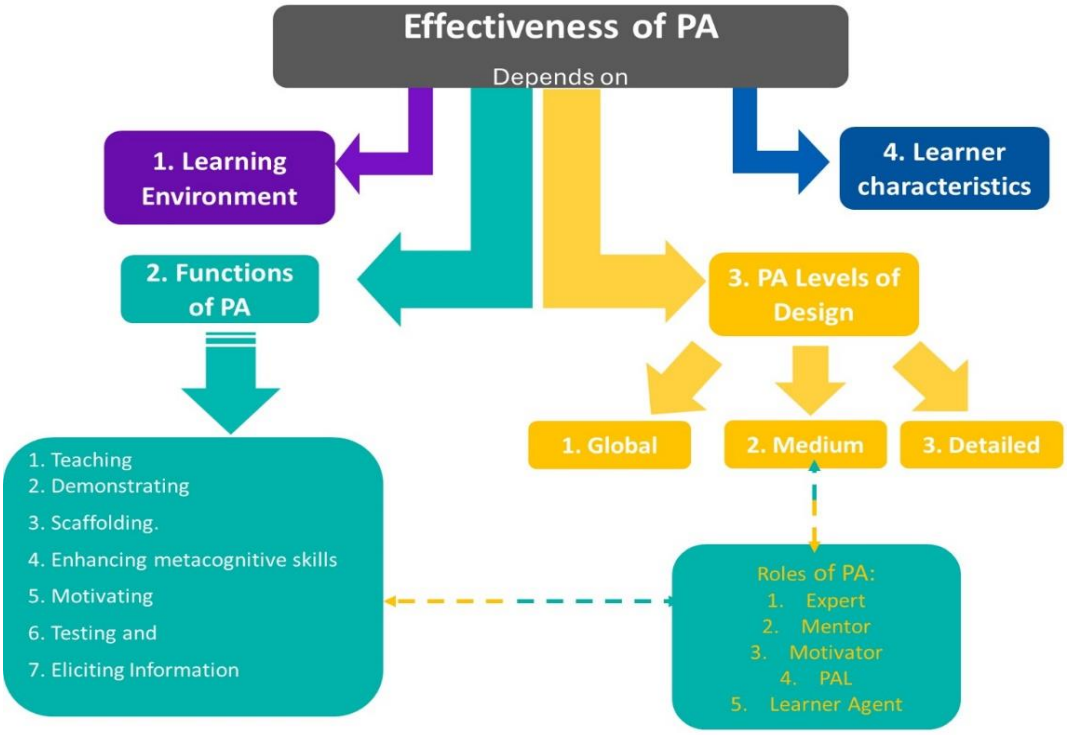


**Figure 2:** The PACU and PALD models expand on Heidig & Clarebout [1] foundational framework, incorporating additional roles and functions introduced by Dai et al. [6]. This study further analyzes a specific function within this enhanced framework. While functions define what agents do and medium-level design addresses what agents look like, the roles of PAs act as a bridge between appearance and function. The dashed line in the figure illustrates this interdependence, highlighting how roles connect the PA's functionality with its design.

## 3. Methodology

A search was conducted using ERIC and Google Scholar databases to identify relevant studies for inclusion in this review. The search was performed using the key terms "pedagogical agent*" and ("analysis" or "review") in the titles of articles. The search yielded 12 articles from ERIC and 37 articles from Google Scholar.

In this preliminary review, only articles that were systematic reviews or meta-analyses focusing on the effectiveness of PAs in relation with the PACU and PALD frameworks were included. Articles were excluded if they were not in English or focused primarily on the technical implementation of machine learning techniques, rather than the educational and pedagogical functions of PAs or generally were out of the scope of this review.

Five meta-analyses and 6 systematic reviews, a total of 11 articles were included in this study. Data were extracted from the included studies regarding their research questions, methodology, key findings, and relevance to the PACU and PALD models. The extracted data were then synthesized to provide a comprehensive overview of the effectiveness of PAs under the lens of PACU and PALD frameworks.

## 4. Results

All meta-analyses included found a positive impact on PAs on learning [2, 4,11-13]. Before presenting the results, it is essential to report how the effectiveness of Pedagogical Agents (PAs) is typically measured in the literature. A recent review by Dai et al. [6] analyzed 67 articles encompassing 75 studies published between 2010 and 2021. Their analysis revealed that most studies (42 out of 75) assessed learning outcomes using multiple-choice questions within a pretest posttest design framework. However, they noted a significant limitation: such questions, according to Bloom's Taxonomy, are often inadequate for evaluating higher-order thinking skills.

Additionally, Dai et al. [6] reported that nearly one-third of the studies (22 out of 75) investigated the impact of PAs on students' motivation. These studies predominantly utilized established measures such as the ARCS (Attention, Relevance, Confidence, and Satisfaction) model and the MSLQ (Motivated Strategies for Learning Questionnaire) to assess motivational outcomes.

Given the extensive period covered by the mentioned review [6], it is reasonable to assume that the use of multiple-choice questions is the primary method of assessing learning across the studies examined. Consequently, references to "increased learning" or "effectiveness" in this review primarily pertain to improvements measured by these commonly used assessment tools, which often focus on basic recall and motivation rather than higher-order cognitive skills.

### 4.1. Research Question 1 How does the learning environment influence the effectiveness of pedagogical agents in enhancing learning outcomes?

Pedagogical agents (PAs) are used across various educational settings, including primary, secondary, and tertiary education, in both distance and blended learning environments. Their effectiveness varies depending on factors such as the subject matter, the technology used, the degree of user or software control, and the level of interactivity.

Apoki et al. [14], argue that PAs are particularly effective in e-learning environments, where they can fulfill roles typically handled by humans in classroom settings. These agents provide personalized support, monitor learning activities, and offer real-time feedback, significantly enhancing learning outcomes in digital contexts.

Heidig & Clarebout [1], reviewed studies from 2002 to 2010 and concluded that there is no evidence suggesting that more complex learning environments, such as virtual reality, do facilitate learning. Davis et al. [15], explored the impact of agent personas in multimedia settings and found no clear evidence that one-way interactions in multimedia environments benefit learning. They recommended integrating virtual reality or artificial intelligence elements to better mimic human interaction, which could lead to improved outcomes.

Different levels of interactivity have also been a focus of examination in the literature. Heidig & Clarebout [1], reported that the effectiveness of varying levels of interactivity in educational settings remains uncertain and inconsistent. More than a decade later, Sikstrom et al. [7], observed a similar pattern, noting that while AI technology is being utilized in pedagogical agents, its potential for enabling fully reciprocal and interactive communication remains underdeveloped, leaving the impact of interactivity on learning outcomes, still ambiguous. Schroeder, et al. [13], in a meta-analysis of 28 experimental and quasi-experimental studies, compared groups with and without control over the pace of learning. Although groups with control performed better, the difference was not statistically significant.

The impact of PAs also varies by subject. Schroeder, et al. [13], found a statistically significant positive impact of PAs in Science and Mathematics, but not in Humanities. Peng & Wang [2], similarly reported a positive effect in Science and a smaller but still positive in Liberal Art, while Castro-Alonso et al. [11], noted positive impacts in STEM fields but negative effects in History. In terms of educational levels, Castro-Alonso et al. [11], reported that PAs had a statistically significant positive impact only among post-secondary students, with no significant benefits for primary or secondary students. Peng & Wang [2], found that PAs benefited students across all levels, except those in grades 10-12.

### 4.2. Research Question 2 To what extent different functions of PAs promote learning?

PAs enroll a variety of functions such as providing information, or demonstrating how to perform a specific task, scaffolding, motivating, testing the user, developing metacognitive skills or eliciting information. As the Figure 2 illustrates, these functions are closely related to the roles that PAs are supposed to adopt [2, 6].

Among the various functions of PAs, providing information emerges as the most common. Both Peng & Wang [2], and Dai et al. [6], highlight this function's prevalence, with the meta-analysis of Peng & Wang [2], showing a small to moderate but significant overall effect size ($g = 0.423$), indicating that PAs providing information contribute positively to learning outcomes by enhancing knowledge acquisition.

Coaching is another frequently mentioned function, though it is often subject to varied interpretations. Dai et al. [6], describe coaching as providing feedback and tips beyond instructional content, while Peng & Wang [2], note the ambiguity around coaching, as it sometimes overlaps with other functions like information provision. Despite this, when coaching involves clear guidance and scaffolding, it is associated with positive learning outcomes, although the specific effect size for coaching alone is not distinctly provided.

Sikstrom et al. [7], discuss the impact of self-regulated learning (SRL) within the context of Pedagogical Agents (PAs), highlighting that SRL is a crucial factor in promoting independent learning. They note that PAs can support the development of self-regulation through metacognitive prompts and tailored feedback, which helps students plan, monitor, and adapt their learning strategies.

Demonstrating, while less frequently implemented compared to providing information or coaching, remains an important function of PAs. This function involves showing learners how to perform specific tasks, which is particularly effective in skill-based subjects where visual or step-by-step instructions are necessary. Although Peng & Wang [2], did not provide a specific effect size for demonstrating as a separate function, it is implied that demonstrating supports learning by offering procedural guidance.

Assessing, where PAs evaluate learners' knowledge, plays a critical role in reinforcing learning by ensuring that learners can recall and apply knowledge effectively. However, Peng & Wang [2], highlight a potential downside to this function, noting that frequent testing or quizzing by PAs can interrupt the flow of learning, leading to discomfort among learners. This disruption can diminish the effectiveness of the PA by creating a sense of intrusiveness, which may reduce engagement and hinder the overall learning experience. Therefore, while assessing is important, it should be carefully balanced and thoughtfully integrated into the learning process to avoid interrupting learner engagement.

Lastly, motivating is a function that, while not always explicitly categorized, is crucial for maintaining learner engagement and persistence. Schroeder & Adesope [4], report that the overall effect sizes for motivational outcomes were generally positive, indicating that learners in environments with PAs were, on average, more motivated than those in environments without PAs. However, these effect sizes were not consistently large or statistically significant across all studies. This suggests that while there is a trend towards increased motivation in PA-based environments, the strength and reliability of this effect vary depending on the specific study or context. In a more recent meta-analysis, Peng & Wang [2], report a moderate effect size for Pedagogical Agents (PAs) that provide affective support, indicating that such PAs can positively impact learning outcomes.

### 4.3. Research Question 3 How does the design of PAs influence learning outcomes?

Based on the PALD model this research question will be addressed separately aligning the three levels of design.

*Global Design: Decisions on whether the PA will be non-human or human, and whether it will be an animation or a static image.*
The Global Level in the PALD framework encompasses the fundamental design features of Pedagogical Agents (PAs), such as whether they are human-like or non-human in form, and their general embodiment, including whether they are presented as static images or animations. These core design decisions significantly influence learning outcomes, as they shape the initial impressions and overall perceptions that users form about the PAs. The effectiveness of these agents is often determined by how well these first impressions align with the educational context and the expectations of the learners. While the framework focuses on these essential elements, it may also be worth considering, at this stage, the integration of AI technology and the extent to which it supports reciprocal interaction, even though this is not explicitly mentioned in the original draft of Heidig and Clarebout [1].

Heidig & Clarebout [1], reported the impact of using human-like versus non-human characters as PAs on learning. They highlighted that while human-like PAs can enhance engagement due to their social presence, there is no consistent evidence that leads to significantly better learning outcomes compared to non-human characters. The effectiveness seems to be context-dependent, with some studies showing no significant differences in retention between human-like and non-human PAs.

Peng & Wang [2], also found that non-human PAs, such as those represented by animals or objects, were sometimes more effective than human-like PAs in promoting learning outcomes. This effectiveness may arise from the lower expectations learners have of non-human characters, allowing them to focus more on the educational content without being distracted by the social cues associated with human-like PAs. This finding challenges the assumption that human-like PAs are inherently more engaging and effective.

The impact of PA's dimensionality was also explored. Martha & Santoso [16], conclude that 3D pedagogical agents tend to have a more positive impact on learning outcomes compared to 2D agents, mainly due to their enhanced realism and ability to engage learners more effective. However, Castro-Alonso et al. [11], in their meta-analysis of 22 articles (32 studies) from 2012-2019 found that 2D PAs tend to be more effective in supporting learning compared to 3D PAs. With a moderate effect size ($g+ = 0.38$) favoring 2D agents, the findings align with cognitive load theory, which suggests that simpler, less visually complex agents reduce cognitive load and enhance learning by avoiding unnecessary visual information.

The debate between animated and static PAs adds another layer to the design considerations. Heidig & Clarebout [1], pointed out that animated PAs, which can show expressions, tend to be more engaging. However, they also warned that increased engagement from animations is not equivalent to better learning outcomes. In some cases, animations can introduce cognitive overload, particularly if they are not directly relevant to the learning task. Peng & Wang [2], emphasized that while animated PAs can enhance interactivity and focus attention, their benefits must be weighed against the risk of cognitive overload. Both static and animated PAs can be effective, but the added complexity of animations requires careful management to avoid detracting from learning.

*Medium Level Design: Decisions about the features and the roles of the PA.*
The Medium Design Level in the PALD framework focuses on the specific features of Pedagogical Agents (PAs), such as speech and gestures, which are closely related to the roles these agents play within the learning environment. These Agents, which include Expert, Mentor, Motivator, PAL and Learner Agent shape the ways learners interact with the material and, consequently, influence the learning outcomes. This section presents the findings in two parts: the specific features that define the PAs' interactions and the roles that these features support.

Schroeder, et al. [13], found that text-based communication between users and PAs had a significantly greater positive impact on learning outcomes. In contrast, when it comes to PA voice, there was no significant difference in effectiveness between synthesized voices and pre-recorded human voices. Similarly, Castro-Alonso et al. [11], observed that PAs using synthetic voices were just as effective as those using human voices. They attribute this to advancements in technology that allow synthetic voices to closely mimic the nuances of human speech.

Davis et al. [12], add that while embodied PAs generally enhance learning outcomes compared to static or non-embodied agents, the specific design features, such as whether the agent is full-bodied or a talking head, and the type of gestures used, significantly influence these outcomes. The study found that full-bodied agents with deictic gestures led to better learning outcomes compared to other designs, reinforcing the importance of careful design choices in the effectiveness of PAs.

Finally, the persona of a PA—how lifelike it feels to the learner—also plays a crucial role. Davis et al. [15] investigated the impact of the PA's persona using the Agent Persona Instrument (API) or its modifications. They found that the perception of a human-like agent is primarily determined by facial expressions, followed by gestures. However, when comparing learning outcomes, they found no evidence that realistic anthropomorphism positively influences learning. Castro-Alonso et al. [11], supported this, finding that neither facial expressions nor gestures and eye gaze had a statistically significant impact on learning. Interestingly, they observed that

static images of PAs had a greater effect size compared to animations.

The design features discussed above—such as speech, gestures, and persona—not only define how a PA interacts with learners but also directly influence the effectiveness of the roles they fulfill within the educational environment. Next, findings regarding the roles (Expert, Mentor, Motivator, PAL and Learner Agent) are presented.

Dai et al. [6], report that the expert role is the most frequently used in educational settings, followed by mentor and motivator roles. The frequent use of expert agents reflects their effectiveness in providing structured guidance and clear explanations, which are crucial for supporting retention and comprehension.

Kim & Baylor [9], provided early insights into the impact of expert and mentor agents. They found that these roles, demonstrating expertise, have a positive effect on learning outcomes, reinforcing their importance in educational settings.

Peng & Wang [2], found that PAs in the expert role, which involves providing detailed information and demonstrating knowledge mastery, are generally effective in enhancing learning outcomes. These agents emulate knowledgeable instructors, guiding learners through complex content. The effectiveness of expert agents is particularly notable in supporting retention and comprehension.

Dai et al. [6], confirmed that the expert role is one of the most used and effective in improving learning outcomes. Most studies employing expert PAs reported positive impacts on student learning, particularly when these agents provided clear explanations and structured guidance.

Heidig & Clarebout [1], highlighted the importance of mentor agents who not only provide information but also offer motivation and encouragement. These agents often combine instructional support with affective feedback, which can enhance learner engagement and persistence. However, the effectiveness of mentor agents can vary depending on how well they balance cognitive guidance with motivational support.

Dai et al. [6], identified mentor agents as those who blend informational support with motivational aspects. These agents are particularly effective in scenarios where learners require both knowledge guidance and encouragement to stay engaged with the learning material.

Peng & Wang [2], discussed the role of motivator agents, which are designed to boost learner confidence and motivation. These agents typically engage in activities such as providing positive reinforcement, setting goals, and encouraging perseverance. While motivator agents can be highly effective in improving learner motivation, their impact on cognitive learning outcomes is less clear and may depend on how motivation is measured and aligned with learning tasks.

Kim & Baylor [10], argue that PALs have a great potential in emphasizing interaction with learners and suggest that it could be highly effective in enhancing engagement.

Kim & Baylor [9], and Dai et al. [6], similarly noted that motivator agents primarily serve to enhance learners' emotional and motivational states. These agents are often used in conjunction with other types of PAs to maintain learner engagement, particularly in challenging learning environments.

However, there is some confusion regarding the role of motivator agents, whose function is reported as coaching. This function often blurs the line between cognitive, metacognitive and emotional support. The emotional support provided by motivator agents is not always clearly defined or consistently measured, highlighting a gap in the existing framework. Given the importance of emotional support in learning, we propose adding "motivating" as a distinct function within the PALD framework. This would ensure that the role of motivator agents is recognized not only for its impact on engagement but also for its clear contribution to learners' emotional well-being, thus improving the alignment of PA roles with the specific needs of learners.

Dai et al. [6], introduced the “Learner Agent" role in their taxonomy, which typically interacts with high-expertise agents like mentors or experts. Unlike the PAL (Pedagogical Agent as a Learning peer) role described by [9-10], which interacts directly with the user, these learner agents in Dai et al. classification primarily engage with other agents on screen. Dai et al. [6], found that these peer learner agents do not necessarily lead to better learning outcomes, particularly when interacting with high proficiency agents, suggesting that their role is more observational and does not directly support the user's learning.

*Detailed Level: Decisions about gender, clothing body type*

The Detailed Design Level in the PALD framework includes specific design features of Pedagogical Agents (PAs), such as gender, body type, and other physical characteristics. These aspects can influence how learners perceive and interact with PAs, which in turn affects learning outcomes, often through psychological phenomena like the halo effect—where a single trait influences the overall perception of the agent.

Castro-Alonso et al. [11], examined the impact of a PA’s gender on learning outcomes. They report that there is not enough evidence to support the idea that males respond differently than females to a PA’s gender. However, they acknowledge that this area of research needs further exploration, as the number of studies included was limited.

Armando et al. [17], conducted a review that focused on the impact of the gender of PAs on learning outcomes. Their study investigated whether the gender of a PA influences how students interact with the agent and whether it affects learning outcomes. They highlighted the concept of "stereotype threat," where societal stereotypes about gender roles may limit students' choices and decisions. For instance, the stereotype that boys perform better in mathematics while girls have stronger language skills could influence how learners perceive and respond to male or female PAs.

In their review, which included 59 articles published between 2000 and 2021, Armando et al. [17], found that gender does play a role in how PAs are perceived and how effective they are in enhancing learning outcomes. Male and female students behaved differently toward PAs based on gender, with female

PAs receiving more aggressive and sexualized comments compared to their male counterparts.

Another interesting finding from this review is the fact that male PAs were generally rated as more trustworthy by students, even when providing identical instruction as female PAs, particularly in traditionally male-dominated fields like STEM. It was found that female PAs were seen as less "expert" in subjects perceived as male-dominated but were more effective in female-dominated fields. This disparity led to differences in learning outcomes, with male PAs generally leading to better academic performance in male-dominated subjects. The review also discussed the risk for reinforcing gender stereotypes if PAs' gender aligns with these societal expectations, potentially limiting the broadening of learners' perspectives.

This disparity in perception could be explained by the halo effect—where the gender of the PA influences overall perceptions of their competence and trustworthiness. For example, male PAs might be perceived as more competent in STEM fields simply because of their gender, which in turn affects how learners engage with the content and their overall learning outcomes.

The review also considered androgynous PAs with mixed male and female characteristics, which allowed students to freely attribute gender to the agent. However, Armando et al. warned that this could still reinforce gender stereotypes, as students might assign gender based on their own biases, further perpetuating stereotype threats. This, too, can be influenced by the halo effect, where learners' preconceptions about gender impact their overall assessment of the PA's effectiveness.

Peng & Wang [2], reported the impact of detailed physical characteristics of PAs, such as body type (muscular vs. non-muscular) and clothing, on learning outcomes. They found that while these features might influence learners' initial perceptions of the PA, they did not consistently lead to improved learning outcomes. For example, muscular PAs in some cases, were less effective as they were perceived as less knowledgeable highlighting the influence of the halo effect once again.

Similarly, the type of clothing worn by the agents, whether professional or more casual, affected how learners initially engaged with the PA but had a minimal impact on actual learning outcomes. These findings suggest that while physical appearance can shape learners' first impressions, it is the agent's instructional and motivational functions that more directly influence learning success [2].

### 4.4. Research Question 4 How do learner characteristics impact the effectiveness of pedagogical agents?

Learner characteristics significantly influence how they respond to pedagogical agents (PAs), with both cognitive and affective factors playing key roles. Cognitive factors such as prior knowledge, cognitive load, and academic achievement are crucial moderators of PA effectiveness, while affective factors include motivation, self-regulation skills and self-efficacy.

Heidig & Clarebout [1], highlight that research on the cognitive and metacognitive influences on PA effectiveness is limited, and there is a notable gap in studies examining the impact of emotional and motivational characteristics. They observed that high-competency learners demonstrate greater motivation and retention when paired with a high-competency agent, whereas low-competency learners benefit more from interacting with a low-competency agent.

Schroeder & Adesope [13], found that statistically significant benefits from PAs were observed primarily in learners with moderate prior knowledge, while those with low prior knowledge did not experience significant gains. Similarly, Sikstrom et al. [7], reported that students' self-efficacy improves when interacting with a low-competency agent or when the agent provides motivation.

Sikstrom et al. [7], argue that PAs require learners to have high self-regulation skills because students are often studying independently in digital learning environments. One potential drawback of PAs is their limited effectiveness if learners possess low self-regulation skills. However, the authors also highlight that PAs can indirectly promote learning by helping to develop these self-regulation skills through metacognitive prompts

## 5. Discussion and Conclusions

In this review, we aimed to clarify the complex interactions between Pedagogical Agents (PAs) and the various factors influencing their effectiveness in educational settings. By analyzing 6 systematic reviews and 5 meta-analyses, we synthesized the findings on PA effectiveness using the PACU-PALD framework. The focus on systematic reviews and meta-analyses offers the advantage of summarizing data from multiple studies, providing a comprehensive overview of significant effects, even when individual studies may have shown only modest or statistically insignificant results.

We identified and categorized the key functions of PAs and proposed a refined framework that distinguishes between different types of coaching. We integrated functions such as scaffolding, enhancing metacognitive skills, and providing emotional support. This distinction aims to address the ambiguity often associated with the "coaching" function, ensuring a clearer understanding of how PAs can be utilized to optimize learning outcomes.

Our findings were presented in the context of four research questions, each addressing a specific aspect of PA effectiveness. Regarding the influence of the learning environment, we found that PAs could be particularly effective in virtual settings, although the complexity of the environment does not necessarily correlate with improved learning outcomes. Learner characteristics such as prior knowledge and self-efficacy also play a significant role, with PAs being most beneficial for learners with moderate prior knowledge and those requiring motivational support.

The analysis of PA functions revealed that providing information remains the most common and effective function, but coaching and scaffolding are equally crucial, particularly when they involve clear guidance and feedback. We also highlighted the confusion surrounding the coaching function, proposing a more nuanced categorization to better capture its impact on learning.

When examining the appearance and role of PAs, we observed that while 3D agents generally enhance engagement due to their

realism, the cognitive load they impose can sometimes reduce their effectiveness compared to simpler 2D agents. Additionally, the role of the PA—whether as an expert, mentor, motivator, PAL or Learner Agent—significantly influences learning outcomes, with expert and mentor roles being the most effective in providing structured guidance.

The interaction effects on Pedagogical Agents (PAs) emphasize the critical role of aligning PA functions and roles with the specific characteristics of learners. Our study reveals that the effectiveness of PAs is heavily influenced by the interplay between learner features—such as prior knowledge, self-regulation skills, motivation, and cognitive engagement—and the particular roles and functions that PAs fulfill, including teaching, demonstrating, scaffolding, providing feedback, motivating, enhancing metacognitive skills, testing or eliciting information. These interactions suggest that the impact of PAs is not uniform but varies according to how well their designed roles and functions meet the unique needs of individual learners. Understanding and optimizing these interactions are essential for maximizing the educational benefits of PAs, ensuring they effectively support diverse learning processes and outcomes.

The impact of a PA's gender has shown that students often perceive agents as more knowledgeable and reliable when they align with typical gender stereotypes, leading to different learning outcomes. However, this raises a critical dilemma: while enhancing learning outcomes may be achieved by leveraging these perceptions, it also risks reinforcing stereotypes, thereby continuing social inequities.

Despite these insights, several gaps remain in the current literature. Notably, the duration of interventions was not explored, which is important because the length of time learners interact with Pedagogical Agents (PAs) could significantly influence their impact on learning and motivation. Furthermore, the long-term effects of PAs on learning have not been thoroughly investigated. Additionally, the interactions between learners' characteristics and the design and functions of PAs require further exploration. Addressing these gaps is crucial for developing even more effective and personalized learning experiences.

In conclusion, as with many reviews, this study is subject to certain limitations that must be acknowledged. The selection criteria may have excluded relevant studies. Additionally, the reliance on published literature means that the findings are influenced by publication bias, where studies with significant results are more likely to be published than those with null or negative outcomes. Despite these limitations, this review provides valuable insights into the current state of research on Pedagogical Agents, particularly through the lens of the PACU and PALD frameworks, highlighting critical areas for future investigation and development.

**Acknowledgment**

The financial support of the European ERASMUS+ /KA2 project entitled "Defining Standards in STEAM+E (Entrepreneurship) Education", KA220-HED-4821BB34, is acknowledged.

## References

1. Heidig S, Clarebout G (2011) Do pedagogical agents make a difference to student motivation and learning? Educational Research Review, 6(1): 27-54. https://doi.org/10.1016/j.edurev.2010.07.004.
2. Peng TH, Wang TH (2022) Developing an analysis framework for studies on pedagogical agents in an e-Learning environment, Journal of Educational Computing Research, 60 (3): 547-578. https://doi.org/10.1177/07356331211041701.
3. Weber F, Wambsganss T, Rüttimann D, Söllner M (2021) Pedagogical agents for interactive learning: A taxonomy of conversational agents in education in Forty-second international conference on information systems 1-17, Dec. Austin, Texas, USA.
4. Schroeder NL, Adesope OO (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. https://doi.org/10.1080/15391523.2014.888265.
5. Clarebout J, Elen WL, Johnson E, Shaw E (2002) Animated pedagogical agents: An opportunity to be grasped? Journal of Educational Multimedia and Hypermedia. 11(3): 67–286. https://www.learntechlib.org/primary/p/9270/.
6. Dai L, Jung M, Postma M, Louwerse, MM (2022) A systematic review of pedagogical agent research: Similarities, differences, and unexplored aspects, Computers & Education. 190, https://doi.org/10.1016/j.compedu.2022.104607.
7. Sikström P, Valentini A, Sivunen S, Kärkkäinen ST (2022) How pedagogical agents communicate with students: A two-phase systematic review, Computers & Education, vol. 188. https://doi.org/10.1016/j.compedu.2022.104564.
8. Ortega-Ochoa E, Arguedas M, Daradoumis T (2023) Empathic pedagogical conversational agents: a systematic literature review, British Journal of Educational Technology, 55(3): 886-909. https://doi.org/10.1111/bjet.13413.
9. Kim Y, Baylor AL (2016) Research-based design of pedagogical agent roles: A review, progress, and recommendations, International Journal of Artificial Intelligence in Education, 26: 160-169. https://doi.org/10.1007/s40593-015-0055-y.
10. Kim Y, Baylor AL (2006) A social-cognitive framework for pedagogical agents as learning companions, Educational technology research and development, 54: 569-596. https://doi.org/10.1007/s11423-006-0637-3.
11. Castro-Alonso JC, Wong RM, Adesope OO, Paas F (2021) Effectiveness of Multimedia Pedagogical Agents Predicted by Diverse Theories: A Meta-Analysis, Educ Psychol Rev, 33: 989–1015. https://doi.org/10.1007/s10648-020-09587-1.
12. Davis RO, Park T, Vincent, J (2023) A meta-analytic review on embodied pedagogical agent design and testing formats, Journal of Educational Computing Research, 61(1): 30-67. https://doi.org/10.1177/07356331221100556
13. Schroeder NL, Adesope OO, Gilbert RB, (2013) How effective are pedagogical agents for learning? A meta-analytic review, Journal of Educational Computing Research, 49(1): 1-39. https://doi.org/10.2190/EC.49.1.a.
14. Apoki UC, Hussein AMA, Al-Chalabi HKM, Badica C, Mocanu ML, (2022) The Role of Pedagogical Agents in

Personalised Adaptive Learning: A Review, Sustainability, 14(11): 6442. https://doi.org/10.3390/su14116442.

15. Davis RO, Park T, Vincent J (2021) A systematic narrative review of agent persona on learning outcomes and design variables to enhance personification, Journal of Research on Technology in Education, 53(1): 89-106. https://doi.org/10.1080/15391523.2020.1830894.
16. Martha ASD, H. B. Santoso HB, (2019) The design and impact of the pedagogical agent: A systematic literature review, Journal of Educators Online, 16(1). https://doi.org/10.9743/jeo.2019.16.1.8.
17. Armando M, Ochs M, Régner I (2022) The impact of pedagogical agents' gender on academic learning: A systematic review, Frontiers in Artificial Intelligence, 5. https://doi.org/10.3389/frai.2023.1302277.