BOARD # 76: Pedagogical Agents in the age of Generative Artificial Intelligence: Opportunities and Challenges in K-12 STEM Education.

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Abstract

Immersive technologies like Virtual Reality (VR) and Augmented Reality (AR) have provided a promising shift in many areas, especially in education. Additionally, using Pedagogical Agents (PA) in education has improved student's learning in many fields like computer science, math, engineering, and English. Recently, Generative AI (GenAI) was introduced in many educational fields (e.g., English and STEM), where studies showed the significant impact of using these techniques on students' performance, behavior, and understanding of their courses. In this paper, we aim to better understand the field of PA, and the advances that evolved after the GenAI revolution. To explore these advances, a comparison between the modern AI techniques and PA with immersive techniques is provided to understand what has changed and what kind of improvements have been made. Therefore, this paper paves the way for researchers who are interested in education and technology to explore potential directions in the latest technologies in education. This paper also helps researchers and practitioners learn about the current approaches and technologies that connect GenAI and PAs in K-12 education, providing a guide to those who are interested in these fields.

1. Introduction

The use of Artificial Intelligent (AI) has become essential in our daily lives. Researchers have been investigating this area for a long time, but recently it has become widely used in almost every field [72]. To keep up with this technology, researchers were interested in applying AI techniques to education, particularly Generative AI (GenAI), which is a technology that allows users to create content, initiate conversations, or seek particular information by generating content by prompts [52]. Before the AI boom, Pedagogical Agents (PAs) and Immersive technology were and still are some of the leading technologies in most of the fields, specifically in education [2], [6], [5], [12], [13]. Many studies have shown their positive impact on the student's performance, and until this day, Virtual Reality (VR), Augmented Reality (AR), and Pedagogical Agents (PA) are still in the scoop of research interests for researchers [73], [74], [75]. Since PAs and GenAI are among the leading technologies, many researchers have focused on using both technologies in education. Thus, our research question in this paper is: What are the PA advances that evolved after the GenAI revolution?

The structure of this paper is as follows: The first section is 1. Introduction, then 2. Pedagogical Agents (PAs), which discuss 2.1 Pedagogical Agent's types, 2.2 Pedagogical Agents in Education, and 2.3 Gaming in Education. The next section is 3. Artificial intelligence (AI), including 3.1. Artificial Intelligence vs. Generative Artificial Intelligence, then 3.2. Generative Artificial Intelligence types, and 3.3. Artificial Intelligence in STEM and NON-STEM education. Then, the next section is 4. Pedagogical Agents (PA) VS. Generative Artificial Intelligence (GenAI), followed by section 5. Discussion then section 6. Future Research Direction and 7. Conclusion.

2. Pedagogical Agents (PAs)

Pedagogical Agents (PAs) are virtual intelligent characters that are used to guide and help users through the environment assigned to [1]. They are widely used tools that were and still are being used not only in educational environments, but also in different areas like marketing, advertisements and technical support [2]. There are many examples that showed techniques that have been used related to PAs interaction in the educational system. For example, in [3], the authors used a PA that depended on dialog and commands to solve Law-related scenarios using Alexa, therefore using voice technique. Also, in [4], PA was animated and explained the instructions to the learners using voice and lip synchronization.

Moreover, multi-agent-systems were used to explain instructions to users via voice [5]. Another example is shown in [6], where a study mentioned using Chatbots to improve the cognitive aspects in science class for sixth grade students, which means that they used "text technique" to interact. All these different uses of the PAs in different situations showed the important role of PA in the educational environment, and the shift it makes towards a more interactive educational process. To better understand this tool, we categorized it into groups regarding presentation forms, and their way of interaction.

2.1. Pedagogical Agent's types

In this section, we have listed types of PAs according to their appearance, and their way of interaction. Firstly, PAs regarding their appearance are divided into three main types; visual, audible, and textual [7]. The table below shows the differences between those three types.

Table 1: Types of Pedagogical Agents according to their appearance

Visual	Audible	Textual
1. They are presented in the form of human-like, cartoon or animated and gestures like using drowning or images of human gestures. 2. In the Human-like and Cartoon forms, the Pedagogical Agent can have additional features like gaze, lips synchronization, gesture, and body movement.	They guide the learner by talking in the background.	They guide learners by providing instructions or explanations through words and sentences.

The other categorizations consider the way PAs interact with users. Through reading several articles, different terminologies appeared regarding how PAs interact, such as conversational PA [8], [9], [10], [2], and communicational or Interactional PA [11]. Although there are different names, they all react almost the same way. The most usable terminology is Pedagogical Conversational Agent (PCA). To understand how PCAs interact, we need to clarify what Conversational Agents are. Based on [2], Conversational Agents (CA) are informative systems that use natural language as a way of communication, which could be via buttons, text, or voice like Siri, Alexa, and Chatbots. PCAs have been commonly used in educational environments under the name of Intelligent Tutoring Systems since the 1970s. PCAs can be divided into three characteristics regarding their design: Embodied PCA, Personification, and Non-Visual. Their interaction varies between text, speech, or multimodal. These types are designed for several roles, like in [2] the role of acting as shown in table 2 below:

Table2: Pedagogical Conversational Agents role of acting.

Motivator	Tutor	Peer	Mixed role
Suitable for Kindergarten and Elementary school students because it relies on preparation like Linguistics.	Suitable for high school students because it relies on initial/actual learning like Computer Science and Engineering.	Suitable for Higher education because it relies on practice and repetition like Mathematics.	Fit with Continuous Education and Cross-Level-Education like Natural Science and Special Needs.

2.2. Pedagogical Agents in Education

Since the COVID-19 pandemic started, educators have changed their way of teaching and PAs quickly became a helpful tool in this alteration. These well-designed AI agents are programmed to assist in teaching, tutoring, and engaging students, and have shown promising influence in enhancing educational outcomes in many subjects. The flexibility of PAs highlighted their potential as an educational resource in both face-to-face and online environments.

Many studies have addressed the effect of PA presence on the improvement of the academic performance of students. For instance, Research in [12] and [13] found this effect on students, who used PA as a learning tool and scored higher compared to the other ones, who used traditional methods. This suggests that the PA learning approach can advance the educational experience effectively, especially when students are engaged through interactive, personalized instruction rather than passive learning techniques.

PA's potential in foreign language learning was a widely explored topic. In a study by [14], the impact of PAs in foreign language education was explored by comparing it to traditional methods such as watching movies with subtitles. The results revealed that students working with PAs showed marked improvements in comprehension and performance. This reflects a bigger vision, where language learners gain knowledge from interactive figures with the material, which PAs are well-equipped to provide.

Meanwhile, being connected with a topic in online courses continues to be a major challenge, particularly when face-to-face interactions became restricted during the pandemic. According to [15], PAs can tackle this challenge in e-learning environments by increasing interaction and engagement. The research found that the correct application of PAs enhanced student performance in addition to helping students stay connected with the course content in a more meaningful way. This benefit of PAs helps overcome the limitation of traditional e-learning platforms by providing the one thing often missing in online self-learning and training courses, which is interaction.

In the mathematics education field, the effectiveness of Educational Agents has been evaluated in studies like [16], where students learned mathematical concepts through interactions with a PA, online tools, or a human tutor. The results from this study emphasized that PAs can be highly effective in supporting mathematics learning, showing better results than traditional tutoring methods. This is consistent with the findings from [10], where students who were exposed to PAs in both formal and conversational learning environments demonstrated improvement in understanding and retention of the material. These research studies participate in this huge growing research idea indicating that in certain subjects PAs can be a substitute for human tutors, especially in subjects that need practice and feedback.

However, teaching students how to interact with PAs is very important for the success of the educational process. For example, research by [17] explored how students' characteristics can influence their interactions with PAs such as their level of responsiveness and productivity. The study found that students with better academic outcomes had highly responsive and productive conditions, which supports the idea that PAs are most effective when matched to students' individual learning styles. On the other hand, students in the low-efficiency groups showed an enhanced sense of self-esteem and improved results when working with the PA, suggesting that these agents can help boost confidence and motivation among struggling participants.

Additionally, PAs can also act as tutors or learning companions, which is apparent from the work conducted by [8]. In their study, students worked with a Conversational Pedagogical Agent who explained concepts and participated in discussions that simulated the tutor's interactive, question-answer style. The results showed that this type of engagement can impact the students' understanding of the material and their ability to recall key concepts in a positive way. This presents similar findings from [11], where the use of a PA in mathematical transposition training led to outcomes on par with those achieved by human instructors. These examples highlight PA's potential to simulate the relationship between a tutor and the student and provide a high level of interactivity, which is often lacking in traditional instructional environments.

In fact, PAs as both learners' companions and trainers have shown a great level of adaptability, and was underlined by several studies, in addition to examining how they can help students process critical thinking and problem-solving skills. The PA's role as a personalized assistant who adapts to individual learning needs aligns well with findings from [79], where PAs were used to provide help to students in different areas, like improving mathematical reasoning and maintaining science education. Correspondingly, higher levels of student engagement and retention were connected to PAs' ability to provide immediate feedback and guidance during interactive problem-solving, as seen in [80].

Overall, the above studies have indicated that personal assistants are active and emotional tools in the learning process. Although personal assistants have acted as coaches, teachers, or companions, they have shown flexibility, adaptability, and effectiveness in enhancing educational achievements. In addition, as technology evolves, the role of personal assistants is expected to grow, providing more opportunities for personalized, engaged learning that is focused on the needs of students in their learning journey as an active contributor to the educational process and overcoming the limitations of traditional teaching methods.

2.3. GAMING IN EDUCATION

Game-based applications have become a significant tool in modern education. It is mainly used to enhance learning and engage students in a fun and interactive approach. These technologies provide resources for teachers to motivate students and support learning outside traditional classroom settings, particularly PAs. Having PAs embedded in game-based platforms, allows them to act as assistants to guide students through material in addition to the role of engaging companions that enhance the learning experience. To have this approach effective is through game-based applications that simulate real-world scenarios, that make learning more dynamic and contextual [18]. This approach has proven to improve student motivation, interaction, and overall skills, especially in areas, like mathematics and science.

While educational institutions offer students many learning technologies, it is noticeable that the students are in need of resources that support them after school hours. One way to help fill this gap is by using PAs implemented in game-based platforms and providing students with interactive opportunities to review topics after school hours. Students' engagement, motivation, and learning outcomes have shown improvement when using game-based applications. Studies have confirmed that using these types of technologies improves students' skills and abilities, especially in subjects that are traditionally difficult for many students [19]. Platforms like Prodigy Math in the U.S. and other international tools such as Adventure Academy, Khan Academy, and Buzzmath have been successfully implemented to support students both in and outside the classroom [19], [20], [21]. These platforms are popular, providing teachers and parents with accessible tools to track students' academic development.

Math-Wizz is a leading example of a virtual tutor embedded in a game-based platform. This program promises to improve students' problem-solving abilities in mathematics by dedicating just one hour per week for 18 months. The primary advantage of Math-Wizz is its ability to provide personalized learning experiences, which is the case with other virtual tutors. After identifying the student's specific needs, the platform provides the material to improve the weaknesses in a fun, engaging way, making it a more flexible and cost-effective alternative to traditional one-on-one tutoring [22]. This flexibility is a significant benefit of game-based applications, which allow students to learn at their own convenience. Moreover, to ensure receiving personalized guidance, reinforcing learning, and fostering greater engagement, the students were advised to use PAs within these platforms ensuring receiving all the benefits.

In [23], a meta-analysis conducted the positive effects of using games in educational settings, by showing that game-based learning encourages students to participate in a more active way, and enhances their learning outcomes. Another benefit of game-based applications is allowing students to engage with any content at their preferred time, which shows a high level of flexibility. The engaging and interactive nature of games with this level of flexibility, helps create a more productive and enjoyable learning experience, promoting both academic achievement and personal growth.

In conclusion, game-based applications with embedded PAs represent a powerful tool in modern education. These platforms help students improve their skills, by offering interactive, engaging, and personalized learning experiences, whether in mathematics, science, or other subjects. These tools will most likely play an effective role in education as technology continues to grow, both in traditional school settings and after school hours, by providing engagement, flexibility, and personalized learning in ways that are accessible to all students.

3. Artificial Intelligence (AI)

3.1. Artificial Intelligence (AI) Vs. Generative Artificial Intelligence (GenAI)

Artificial Intelligence (AI) can be referred to as the ability of a machine to communicate, reason and operate independently in both familiar and new scenarios in the same way as a human being [24]. AI has many types like Analytical AI, Functional AI, Interactive AI, Textual AI, and Visual AI as shown in Fig 1. Each of these types serves a different purpose. AI has become essential daily, whether it is used in business, education, transportation, healthcare, banking, retail, entertainment, and E-commerce. Researchers have been

investigating this area for a long time, but recently it has become wildly used in every field. Additionally, to keep up with this technology, the urge to use AI in education was addressed and researchers were interested in applying AI techniques to education, like Khanmigo in Khan Academy [21]. Many studies showed the positive effect of using AI in STEM, non-STEM, and online education. One of the reasons behind this is that using AI is customizable, where teachers can produce a personalized plan for each student depending on their improvement needs. Another reason is fast response, where you are a click away from getting your answer.

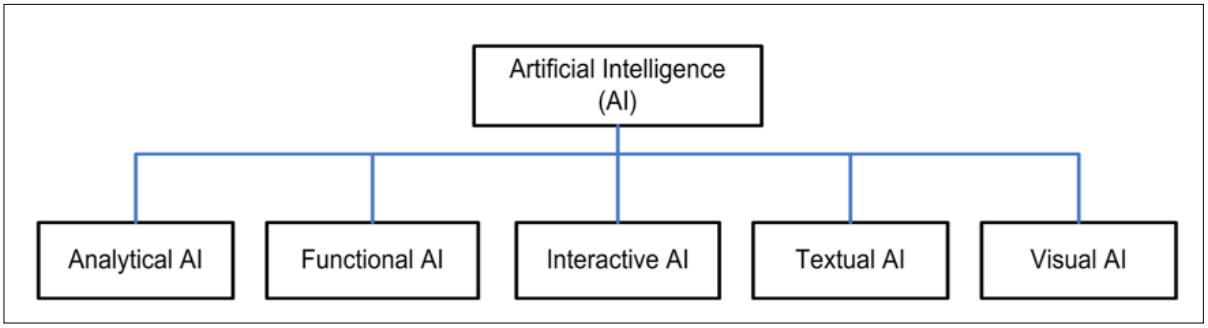

Figure 1: AI types [71].

One promising and most common branch of AI has attracted researchers and developers to benefit in education, which is Generative Artificial Intelligence (GenAI). GenAI is a branch of machine learning that focuses on creating generative models that can generate a variety of AI-generated content, such as text, images, and audio that sound like human [29]. Therefore, it is a subset of artificial intelligence (AI) in general, which is the endeavor to build machines that can demonstrate (or surpass) human intelligence. Also, it describes computer techniques that can use training data to produce meaningful text, image, or audio outputs, such as Dall-E 2, GPT-4, and Copilot [26]. The most amazing thing about Generative AI systems is they can and will be used to assist humans by functioning as intelligent question-answering tools, as well as being used artistically to create new text that imitates authors or new graphics that imitate illustrators. The reason behind this is a kind of deep learning neural network called generative models, sometimes referred to as "large language models (LLMs)," is made to resemble the human brain. They are created by using large datasets to train intricate algorithms. GenAI can create original content in response to a wide range of user inputs, enabling it to react flexibly to users' needs in real time, whereas traditional AI is usually built to execute a limited range of tasks repeatedly [29].

What made the focus on using GenAI in education increase is the noticeable advantages of using it for students and teachers, like, assisting the instructor in creating course materials, offering suggestions, virtual tutor, answering questions, promoting collaboration, research assistance, automated grading, writing coach, make lesson plans, help to make progress reports, also helping the teachers how to teach a subject [76], [77], [78]. Although GenAI is a powerful technology in education, it still needs to be used with extra caution to ensure using it safely and responsibly. For example, in [70], the article discusses the application of Artificial Intelligence in online learning and distance education, based on a systematic review of empirical studies. The application of AI in these settings has been shown to enhance the learning experience by personalizing the content, facilitating peer interaction, and providing real-time feedback. Nevertheless, it also warns of the ethical and legal implications of widespread AI use in education, such as the risk of bias in AI algorithms and the need to ensure transparency and accountability in AI decision-making processes.

3.2. Generative Artificial Intelligence types

GenAI is a leading technique in the present time and the direction that most likely all fields are going toward. The core of most GenAI systems is LLMs and FMs (Foundation Models), which are neural networks trained on massive data that is usually collected from the internet without intellectual rights or privacy. By doing this, the system will learn the patterns of using images, videos, codes, melodies, and human language. Additionally, LLMs will learn how to generate new but relative content after understanding the concept of the users' input [38].

There are many types of GenAI but the most sorted types based on the input and output formats are eleven types as shown in Table[3], which are Text-to-Text, Text-to-Image, Text-to-3D, Text-to-Audio, Text-to-Video, Text-to-Code, Text-to-Scientific text, Text-to-Chemical Formula, Text-to-Synthetic data, Text-to-Algorithm and Image-to-Text [38]. There are also some subtypes such as Image-to-3D, Image or Video-to-3D, Text-to-Video, Image-to-Science, Text-to-Speech, Speech-to-Text, and Speech-to-Speech. We will talk about each type correspondingly [39].

- Text-to-Text is the most well-known type of all that generates texts based on text inputs. An example of this type is ChatGPT. To generate a text response, we need to use machine learning, and existing data in addition to the user input. This type of AI can be used to understand text, answer questions, translate, in education, research, write, debug codes, create content, as a virtual assistant, summarize, and many more [28].

- Text-to-Image, which is a machine learning model that generates a picture that corresponds to a natural language description given as input by the user such as DALL-E3. Large datasets of (text, picture) pairings, frequently scraped from the internet, are used to train text-to-image models [27].

- Text-to-3D, which uses text inputs to present 3D images as an output. An example of this type is Dream Fusion, which uses large datasets of aligned images and texts and scalable generative model architectures [40].

- Text-to-Audio, which uses text inputs to generate audio outputs. For example, AudioLM is a framework for making high-quality audio for long-term stability [41].

- Text-to-video, which is machine learning that outputs a video that uses natural language as an input, allows the user to create videos in any style preferred. An example of this type is Runway[43] and Phenaki [42], which is a model that can synthesize realistic videos when presented with a series of textual cues.

- Text-to-Code, where the user enters a text explaining the code and what it should do, then the code will be generated based on the entry text. For example, GitHub copilot [44] and Codex [45], where the database contains natural language and massive lines of open-source codes.

- Text-to-Scientific text, which uses text inputs to generate scientific text such as Galactica. This application uses an open-source LLM and is trained on 120 billion parameters of scientific knowledge [46].

- Text-to-Chemical Formula, which uses text inputs to create chemical compounds. An example of this type is polyBERT [48] and AlphaFold [47].

- Text-to-Synthetic data, which creates new samples that closely mimic the original data distribution by learning from the data that already exists [49]. For example, the OpenAI family and the LLaMA family [50].

- Text-to-Algorithm, which uses text inputs to generate algorithms based on user needs. An example is Alpha Tensor [51].

- Image-to-Text, which executes a descriptive text based on a given Image, for example, LLaVA (Large Language and Vision Assistant). It demonstrated remarkable skills in comprehending images and answering questions about them while being taught on a comparatively small dataset. It does very well on activities requiring profound visual perception and following instructions [36].

Table [3]: GenAI Eleven Model's Types [38]

Input	Output	Type	Example Models
Text	Text	Text generation	GPT family, LaMDA, PEER, Speech from Brain
Text	Images, 3D, Video	Image and Video generation	DreamFusion, Magic3D, Videopoet, Phenaki
Text	Audio	Audio generation	AudioLM, OpenAI Jukibox, Amazon Polly, google WaveNet
Text	Code	Code generation	GitHub Copilot, Code Whisperer
Text	Science	Sciences generation	Galactica, Minerva, SciBERT
Text	Chemical Formulas	Chemical compounds and proteins	PolyBERT, AlphaFold
Text	Synthetic Data	Synthetic Data generation	GPT Family, LLaMA Family
Text + Data	Analytics	Data Analytics generation	GPT 3.5/ 4 Family
Voice	Text or Image	Voice-to-Text/ Image generation	Amazon Transcribe, DeepSpeech (Baidu), AzureAI, OpenAI Whisper
Image	Text	Image-to-Text	Flamingo, Visual GPT
Text, Audio, Image, Video	Text, Audio, Image, Video	Multimodal models	GPT-4V, Gemini

Other subtypes [39] are shown in Fig 2. like Image-to-3D, which uses images as inputs and produces 3D as outputs. This type is used in all applications that require using 3D outputs, like games applications, animation, architecture, and many more [37]. An example of this type of AI is Magic3D. This type leads us to the next one, which is Image or Video-to-3D, which share the same concept. Examples of this type are CSM AI, Immersity.AI, and more. There are also Image-to-Science, Text-to-Speech, Speech-to-Text, and Speech-to-Speech.

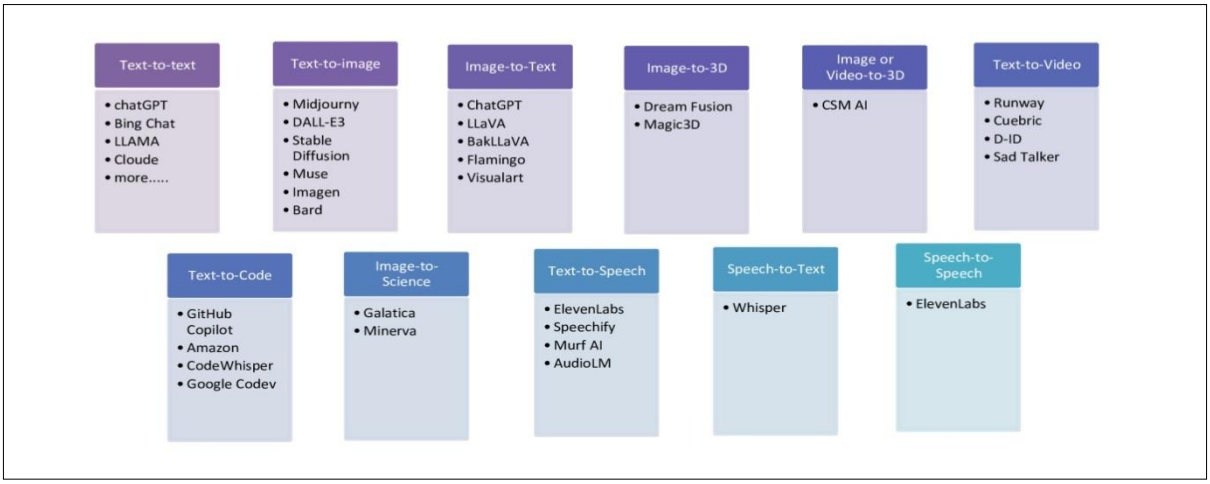

Figure [2]: Examples of Subtypes of GenAI Models [39]

It is worth mentioning that AI models are divided into uni-modal models and multimodal models. Instructions for uni-modal models come from the same input type as their output. However, multimodal models can receive input from multiple sources and produce output in a variety of formats [26].

3.3. Artificial Intelligence in STEM and Non-STEM education

The Implementation of artificial intelligence (AI) in education has gained attention, especially since it offers promising innovations across both STEM and non-STEM disciplines. The use of AI has become more common in classrooms, and it has shown a noticeable effort in enhancing the learning experiences and providing students with essential 21st-century skills. Teachers' attitudes are one important factor in the success of importing AI into education. The more accepted and aware these teachers are of technology, the easier the adaptation of this technology will be, according to [63]. The paper discusses the need to provide teachers with a program that introduces the necessary resources and training for the professional development of AI into their teaching methodologies to ensure its potential is fully understood through teaching disciplines.

In STEM education, the use of AI chat-bots such as Chat-GPT and Bing Chat has become widely used. As discussed in [64], these AI tools promote critical thinking, problem-solving, and collaborative learning. By offering real-time explanations, answering questions, and providing immediate feedback, students will be able to engage in more active learning experiences. Being involved in an interactive environment will affect the students with deeper understanding, facilitating knowledge retention and encouraging self-directed learning.

Similarly, the focus on preparing students for the future plays a huge part in research interests, particularly AI literacy in K-12 education. In [65], the authors highlight the integration of AI literacy into STEAM curricula for elementary education. Since generative AI technologies such as Chat-GPT become more involved in society, it has become an essential skill for students to learn and gain the necessary skills to understand and use AI tools effectively. The paper illustrates how important it is to promote curiosity and critical inquiry about AI through hands-on and project-based learning, conforming to its value in boosting creativity and collaboration in young learners. These initiatives lay the groundwork for future STEM-related education by equipping students with both technical knowledge and ethical understanding of AI technologies.

The impact of AI did not stop in STEM fields, it expanded to reach areas like language learning. As explored in [66], applying AI tools in language education, particularly for English literacy, has proven effective in personalizing learning experiences. AI helps students improve their language skills at their own pace by providing accurate feedback, adaptive resources, and real-time guidance. However, the paper also addresses concerns about over-reliance on AI tools, particularly regarding teacher autonomy and students' critical thinking skills.

In the K-12 context, it become very important to prepare students for a future overpowered by AI technologies. As emphasized in [67], teaching AI in K-12 settings boosts critical thinking and problem-solving skills in addition to equipping students with the necessary knowledge to succeed in an AI-driven society. Further, [68] discusses the importance of integrating AI literacy into K-12 curricula, under the condition that students must understand AI concepts and the ethical issues of using technologies to be informed and responsible citizens. Also, AI education encourages computational thinking and shows interest in fields like coding and robotics, as discussed in [69]. The paper notes the positive impact of students' proficiency in coding, and problem-solving, and their awareness of AI's ethical implications in interactive and project-based learning methods.

Additionally, the use of AI in online learning and distance education also highlights its transformative potential. In [70], the authors discuss how the learning experience has been enhanced after using AI applications by personalizing content, facilitating peer interactions, and providing real-time feedback. This kind of application has proven valuable in distance education settings, where AI helps fill the gap between students and instructors, reinforce engagement, and improve learning outcomes. The study explains how AI can empower both students and teachers, providing effective learning in virtual environments.

To sum up, AI's merging into education has multiple aspects, affecting a wide range of subjects and educational levels. These technologies are transforming the way students interact with content and develop critical skills. It also supports teachers in using AI to enhance student engagement in STEM, language learning, and even online education. As AI continues to grow, its role in enhancing future curricula and preparing students for a major change in the world will become most needed to integrate educational success.

4. Pedagogical Agents (PA) VS. Generative Artificial Intelligence (GenAI)

The rise of Generative AI (GenAI) has made a significant impact on the field of Pedagogical Agents (PAs), transforming the way these digital tools interact with and assist learners. While traditional PAs have long been designed to support educational activities through pre-programmed responses, GenAI introduces a new level of adaptability and personalization. By leveraging advanced machine learning models, such as ChatGPT, GenAI-powered PAs can generate dynamic, context-aware content in real-time, allowing for more fluid and interactive learning experiences. Despite the similarities in their foundational goals (to assist, tutor, and engage students), GenAI enhances PAs with capabilities such as natural language understanding, real-time problem-solving, and the ability to tailor responses based on individual learning needs. But even while GenAI is more flexible and scalable, it still presents problems with upholding ethical use, avoiding an over-reliance on automated systems, and providing correct advice. This illustrates how the relationship between AI and

education is changing, as traditional PAs and their GenAI counterparts differ not only in technology but also in pedagogy.

In table [4], a comparison between GenAI and PA [31], [32], [33], [25], [34], [35] based on many factors as shown below:

Table [4]: GenAI Vs. PA

Factors	GenAI	PA
Definition	This is used to describe AI systems that, given input data, may produce content like writing, graphics, or simulations. GenAI can produce customized learning materials, tests, and explanations in the field of education.	These are AI-powered avatars or characters made to aid in learning by offering direction, criticism, and assistance in an interactive way. They frequently mimic human interactions.
Application in STEM education	frequently used to generate complicated problem sets in science and mathematics, and to create dynamic simulations (similar to computer science coding exercises). For instance, through interactive simulations, GenAI can assist students in visualizing scientific ideas.	These agents can boost students' enthusiasm and engagement in difficult STEM courses by offering real-time individualized feedback, recommendations, and assistance as they work through problems.
Application in NON-STEM education	helpful for coming up with writing prompts, telling stories, and producing instructional materials in artistic fields like history or literature. Students can use it to generate ideas or write essays.	They can serve as guides in courses like history, where they can recount events and lead conversations, or tutors in language acquisition, offering conversation practice and cultural context.
User Interaction	usually entails a more passive interaction in which students are given a created content and expected to interact with it on their own.	Enable students to pose questions and receive immediate feedback, which is essential for motivation and comprehension, by fostering a more interactive and responsive learning environment.
Engagement and Personalization	Although it can customize content in accordance with user input, its level of engagement may differ due to its inability to replicate a human presence.	Their interactive nature often results in increased engagement levels, as they adjust their responses to the students' emotions and progress, facilitating a more personalized learning experience.

In brief, while both Pedagogical Agents (PAs) and Generative AI (GenAI) contribute significantly to education, they do so in different ways. Particularly in STEM and artistic topics, GenAI is excellent at producing personalized learning materials, simulations, and exercises. It also provides passive student involvement. Though engagement may be limited by the absence of a human presence, its capacity to produce dynamic information improves the learning experience. In contrast, PAs offer more individualized, interactive support, address students' needs instantly, and increase motivation and engagement, particularly in STEM and non-STEM subjects. PAs make the learning environment more engaging and responsive by adjusting to emotional cues and progress. As a result, even if both technologies have similar functions, their variations in personalization and engagement show how differently they affect the learning process.

5. Discussion

Both generative artificial intelligence (GenAI) and pedagogical agents (PAs) are game-changing technologies that have drawn interest in educational contexts. They both have their own advantages and disadvantages. Although they take distinct approaches to this objective, both technologies seek to improve student performance and learning. While GenAI focuses on producing individualized learning content by evaluating student data and automating educational tasks, PAs offer students advice and feedback through interactive, human-like avatars. Both technologies have their own advantages and disadvantages, despite their potential, which can be highlighted as follows:

Advantages of GenAI:

- Personalized Learning: GenAI is very good at adjusting educational programs to meet the unique requirements of every learner. GenAI can produce personalized workouts, tests, and explanations by evaluating information including prior performance, learning preferences, and styles. Students are guaranteed to obtain content that suits their learning requirements and speed because of this flexibility.
- Efficiency: Teachers' workloads are greatly decreased by GenAI's capacity to automate administrative duties, grading, and feedback. This enables teachers to spend less time on laborious chores and more time engaging with kids. Furthermore, GenAI's effectiveness extends to data-driven, real-time feedback, which is crucial for giving students prompt assistance and modifying their learning patterns.
- Improved Student Outcomes: By continuously evaluating student development, GenAI can pinpoint areas that require improvement by identifying strengths and shortcomings. When students receive targeted treatments, their performance may improve.

However, GenAI does present notable challenges. These include:

- Privacy Concerns: GenAI's need to acquire huge quantities of data in order to tailor learning presents significant privacy concerns. Sensitive student information may be handled carelessly, which could have detrimental effects if it is misused or stored incorrectly.
- Dependency: There's a chance that educators and students will become overly dependent on AI tools, which could impair their capacity for creativity, critical thinking, and problem-solving. This reliance can make it more difficult for students to use conventional teaching strategies or adjust to problems that call for human understanding.
- Equity Issues: Not all students have equal access to the required technology, despite GenAI's enormous potential for personalized instruction. Inequalities in educational achievements may result from this digital gap, especially for children from lower-income families or those enrolled in underfunded institutions.

There are some limitations with GenAI that need to be resolved. Inaccurate outputs are a major problem, as these models may produce responses that contain mistakes, which could deceive consumers or give them false information [26]. Bias and fairness provide another difficulty because the AI's objectivity is directly impacted by the caliber of the alignment processes and training data. In addition to perpetuating bad language or magnifying existing human biases, biased data used to train deep learning models might promote detrimental preconceptions pertaining to gender, sexual orientation, political beliefs, or religion. Concerns about copyright violations also arise because GenAI models occasionally produce outputs that imitate or reproduce previously published works without the consent or payment

of the original authors, which is against the law. Lastly, GenAI has serious environmental issues with GenAI. Large neural networks, which are frequently the foundation of these systems, demand a significant amount of processing power, leaving a negative carbon footprint and consuming a lot of electricity.

On the other hand, it has been demonstrated that pedagogical agents (PAs) provide a number of benefits in learning environments. By giving students individualized, interactive experiences, they lower anxiety, boost user engagement, and enhance learning outcomes [55]. Additionally, it has been discovered that PAs significantly affect students' motivation, self-efficacy, and information acquisition [56]. The beneficial impacts of pedagogical agents in training [61], [23] and learning settings [59], [57], [60], [58] are also highlighted in studies. Nevertheless, there are several restrictions on its use in spite of these advantages. For instance, PAs can occasionally divert students' attention, causing them to pay more attention to the agent than the material being covered. Furthermore, some users may experience pain or disorientation when using PAs in virtual reality (VR) environments.

- Motivation & Engagement: By providing an interactive, human-like presence, PAs are intended to encourage a feeling of emotional involvement with students. This can boost motivation, reduce anxiety, and enhance general student participation, especially in challenging areas [55]. When students receive personalized, real-time feedback from an agent that simulates human interaction, they are more likely to feel encouraged.
- Self-Efficacy and Knowledge Gain: It has been demonstrated that PAs have a major effect on students' self-efficacy, increasing their confidence in their capacity to achieve academic success [56]. Because PAs are interactive, they provide prompt feedback and direction, which can make it easier for students to overcome obstacles.
- Effectiveness of Training and Learning: Research indicates that by offering ongoing assistance, PAs enhance training and learning experiences [61], [23]. By assisting students with assignments and providing them with individualized explanations and support, they aid in their learning [59], [57], [58], [60].

However, PAs also have their limitations:

- Distraction Risk: One of the main drawbacks of PAs is that students could lose attention on the subject in favor of the avatar or interaction itself. This can disrupt the learning process and lead to a lower degree of engagement with the instructional materials.
- VR-related Problems: Students may feel physically uncomfortable such as lightheaded or nauseous, when using PAs on VR devices, especially if they use them for a long amount of time. This may reduce the PA's overall efficacy, particularly for children, who might be sensitive to virtual reality settings.

While PAs offer interactive, emotionally supportive experiences, their limitations in content adaptation and potential for distraction highlight the need for complementary technologies to enhance their effectiveness.

Although GenAI and PAs have their own limits, combining GenAI and PAs has the potential to overcome many of these issues and greatly improve the teaching process. Students may gain from an ideal learning environment by combining the PA's human-like contact and motivational assistance with GenAI's capacity to provide individualized content and handle administrative duties. For example, GenAI may create dynamic material based on real-time data and student progress, including customized courses, tests, and comments. A

PA that serves as an engaging tutor or guide can convey this content, creating the appearance of a personal instructor while preserving the effectiveness of AI-driven customisation. Students can benefit from both individualized content and emotional support thanks to this collaboration, which makes their academic path efficient and interesting.

Additionally, by integrating GenAI with PAs, educators may be able to monitor student progress in real time and offer customized interventions. PAs may provide timely help and motivational support when GenAI pinpoints areas where students struggle, improving the educational process. Teachers would have more time to devote to higher-level teaching tasks like promoting creativity, creating teamwork, and attending to the complex needs of their students with this integrated approach.

Furthermore, teachers' administrative workloads can be significantly reduced by integrating GenAI with PAs, allowing them to concentrate on creating engaging, interactive classes. In order to effectively manage big classrooms, teachers would have access to a system that could track progress, highlight areas that needed assistance, and dynamically modify the curriculum based on the needs of each individual student. One of the studies related to merging these technologies is [35], which showed how promising it is to use AI-generated PAs in education and the great effect it plays on students' performance. Also, in [54], the author explored the learner's interaction in educational games using GenAI agents in HCI interaction. One of the findings of that study was that students can have a positive experience with GenAI agents when they are deeply engaged and immersed in their role.

In a nutshell, a bright future for education is presented by the combination of generative AI with pedagogical agents. Although each technology has unique advantages—GenAI offering adaptive, data-driven material, and PAs succeeding in human-like engagement and motivation—when combined, they offer a more comprehensive approach to learning that takes into account both the cognitive and emotional components of education. Combining the greatest aspects of GenAI and PAs could result in a more interesting, effective, and individualized learning environment that would eventually improve student results and assist teachers in their work.

6. Future Research Directions

Integrating Pedagogical Agents with Generative AI for Personalized Learning could present a promising direction for future research direction. Personalized and adaptable learning environments could be advanced through a combination of generative AI and pedagogical agents. The creation of highly responsive, context-aware pedagogical agents that employ generative AI to customize learning experiences in real-time, maximizing both cognitive and emotional engagement, could be a future research avenue in this field. Some of the key aspects for exploration are Personalized Learning Pathways; Emotionally Intelligent Agents, Culturally Responsive Pedagogy, Automated Assessment and Feedback, Collaborative Learning with AI, Long-term Learning Analytics and Adaptation, and Ethical Considerations and Bias Mitigation.

By tackling these research challenges, generative AI and pedagogical agents could be combined to produce highly engaging, personalized, and adaptive learning environments that would transform education for a range of student populations.

7. Conclusion

The integration of Pedagogical Agents (PAs) and GenAI in education holds transformative potential, particularly for students in K-12 education. PAs, enhanced by advances in GenAI, have evolved from static, pre-programmed tools into dynamic, adaptive systems capable of engaging students in personalized and interactive learning experiences. GenAI empowers PAs to provide real-time feedback, adapt to individual learning styles, and create customized content that aligns with students' needs and interests. For K-12 students, these technologies foster engagement, improve comprehension, and promote self-directed learning. PAs can act as virtual tutors, mentors, or collaborators, helping to bridge gaps in understanding and offering scalable support in diverse educational contexts. The conversational abilities of GenAI allow students to interact naturally with these agents, building confidence and creating a more inclusive learning environment. While students can experiment with new forms of expression and inquiry, teachers can use these tools to improve the way the curriculum is delivered. For these technologies to be used to their full potential responsibly, issues like data privacy, equity of access, and the requirement for teacher training must be addressed. By using the full potential of PAs and GenAI, teachers may design individualized, rich, and captivating learning experiences that equip students for a world that is changing quickly while making sure that the moral and practical consequences are handled with care. GenAI, however, still needs to be used with extra caution to ensure using it with safe and responsible practices. In this paper, we discussed PA and GenAI from different perspectives, including definition, how they apply to STEM and NON-STEM education, user interaction, engagement, and personalization. Additionally, we explored different studies that combined both technologies and showed a significant impact on student performance. Our goal for this paper is that it will be considered as a guide to scholars and practitioners who are interested in the field of GenAI and PA in K-12 education.

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