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Examining and Visualizing the Effects of Pedagogical Agents on Learning Outcomes

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ABSTRACT

While there has been a growing interest in the use of animated, interactive, and embodied agents in education, there is a lack of comprehensive understanding of their impact on learning outcomes. To comprehensively examine their impact on learning outcomes, this study utilized VOSviewer and CitNetExplorer for a bibliometric analysis, examining the research trends in the field of pedagogical agents for learning. The top 10 cited authors, sources, organizations, and countries in this field were identified. The findings indicate that animated, interactive, and embodied pedagogical agents may enhance learning outcomes. Furthermore, ethnicity and prior knowledge are significant factors in influencing learning outcomes. The integration of image, audio, visuals, and narration within these agents can positively impact learning outcomes, creating a more immersive and engaging learning experience. The ethical and social implications of pedagogical agents cannot be overlooked in the future research.

KEYWORDS

Animated Pedagogical Agent, CitNetExplorer, Embodied Pedagogical Agent, Interactive Pedagogical Agent, VOSviewer

INTRODUCTION

Pedagogical agents are computer-based characters or avatars designed to simulate human teachers for the purpose of delivering educational content and guidance (Zhao et al., 2023). They are often used in online and distance learning settings to provide personalized instruction and support. Pedagogical agents can be classified into interactive, animated, and embodied pedagogical agents based on their level of autonomy, interaction capabilities, and the type of content they deliver (Zhao et al., 2023). Animated pedagogical agents are computer-generated characters used in educational contexts to engage learners. They are designed to simulate human behavior and interact with learners through digital media, enhancing the learning experience (Hong et al., 2014). Embodied pedagogical agents, on the other hand, are physical robots or figurines that possess movement and interactivity, simulating human movement and speech. They aim to create a more immersive and engaging learning environment, particularly in areas like physical skills and spatial reasoning (Swiecki et al., 2019).

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Interactive agents engage students in conversation and provide immediate responses (Zhang et al., 2023). The design and implementation of pedagogical agents require a combination of educational theory, artificial intelligence techniques, and user-centered design principles to create effective and engaging learning experiences.

The study on the effects of animated and interactive pedagogical agents on learning outcomes is a groundbreaking exploration into the intersection of technology and education. It is crucial in our understanding of how to maximize the potential of digital tools in enhancing teaching and learning. The findings of this study have far-reaching implications for education systems worldwide, suggesting that the integration of animated and interactive agents can significantly improve student engagement and learning outcomes (Wei et al., 2024). This research also highlights the need for ongoing investigation into the most effective uses of these agents in various educational contexts, allowing for more personalized and impactful learning experiences. The study on animated and interactive pedagogical agents serves as a valuable resource for informing educational practices and policies, ultimately leading to more effective teaching and learning methods (Hong et al., 2014).

The research gap in the field of visualization and systematic analysis study on the effects of animated and interactive pedagogical agents on learning outcomes is wide and significant. While there has been a growing interest in the use of these agents in education, there is a lack of comprehensive understanding of their impact on learning outcomes (Gu et al., 2023). To date, much of the research in this area has focused on exploring the acceptability and engagement of students with these agents. However, there is a dearth of evidence regarding the type of pedagogical agents, such as animated, interactive and embodied pedagogical agents (Davis et al., 2021). Furthermore, it remains unclear whether ethnicity and prior knowledge, as well as pedagogical agents integrated with image, audios, visuals, and narration, influence learning outcomes (Zhao et al., 2023). Research should aim to bridge this gap by conducting rigorous visualization and systematic analyses to synthesize the existing evidence on the effects of animated and interactive pedagogical agents on learning outcomes. This will require a comprehensive search and analysis of publications using systematic and visualization methods.

This visualization and systematic analysis study, utilizing VOSviewer and CitNetExplorer, aims to explore the impact of pedagogical agents on learning outcomes. Through visualization capabilities of VOSviewer, we will create knowledge maps to identify key clusters and patterns within the research field (Huang et al., 2024). This will give us a comprehensive understanding of the field and highlight potential research gaps. CitNetExplorer, with its network analysis abilities, will help us trace the influence of individual studies and identify the most influential works (Yu & Yu, 2023). By combining both tools, we aim to gain a deeper understanding of the topic and its development over time. The results of this study will inform educators and researchers about effective uses of pedagogical agents in enhancing learning outcomes, leading to improved teaching practices and student learning experiences.

LITERATURE REVIEW

The Yearly Research Trend in Pedagogical Agents

The yearly research trend in pedagogical agents has shown a consistent increase in interest and activity (Gu et al., 2023). With the advancement of AI and machine learning technologies, the scope and potential of these agents are constantly being redefined. In recent years, there has been a particular focus on the use of pedagogical agents in online learning environments, as well as their ability to personalize and adapt to individual student needs. This trend is expected to continue, with an increasing emphasis on the role of agents in enhancing critical thinking, creativity, and collaboration among students (Morey, 2012). As the field matures, research is also likely to explore new applications for pedagogical agents in areas such as professional development, language learning, and distance

education (Lazzari et al., 2022). The future of pedagogical agents is promising, with the potential to revolutionize education through innovative uses of technology that enhance teaching and learning experiences.

Bibliometric Analyses of Studies on Pedagogical Agents

Bibliometric analyses of studies on pedagogical agents provide valuable insights into the research landscape of the field, including top cited authors, sources, organizations, and countries in research on animated or interactive pedagogical agents. Such analyses can identify the most influential studies, the evolution of research topics over time, and the extent to which different methodologies or theoretical frameworks are employed. They can also highlight gaps in the literature and identify areas where further research is needed (Martins et al., 2022). By quantitatively analyzing the published literature, bibliometric techniques provide a bird's-eye view of the field, enabling researchers to identify emerging trends and areas of opportunity. These analyses are crucial for understanding the state of the art in pedagogical agent research, identifying potential collaborations, and informing future research directions (Ki & Jeeheon, 2020).

Effects of Animated or Interactive Pedagogical Agents on Learning

The inconsistent findings regarding the effects of animated or interactive pedagogical agents on learning are perplexing but not surprising. The complex nature of learning and the wide range of factors that influence it make it difficult to pinpoint the exact impact of these agents (Lehman & Graesser, 2014). Some studies show positive effects on learning outcomes, suggesting that the interactivity and engagement they offer can enhance learning experiences (Moreno et al., 2001). Others report no significant benefits or even negative effects, possibly due to factors such as student age, subject matter, or the specific design and implementation of the agents (Nunes et al., 2016). To reconcile these findings, more rigorous research is needed, including well-designed experiments with larger sample sizes and better control groups. Exploring the mechanisms behind any observed effects could provide valuable insights into how these agents work and how they might be optimized for different learning contexts. While the jury is still out on the exact impact of animated or interactive pedagogical agents on learning, the potential benefits and challenges they present are worth further exploration (Aslan et al., 2023).

Effects of Embodied Pedagogical Agents on Learning

Embodied pedagogical agents, characterized by their physical form and ability to engage learners interactively, hold promise for enhancing learning experiences (Laubscher, 2016). However, research findings on their effects are inconsistent. Some studies report positive impacts on learning outcomes, particularly in areas like spatial reasoning and physical skills (Carlotto & Jaques, 2016). Others find no significant benefits or even negative effects (Lawson & Mayer, 2022). The inconsistencies may stem from variations in agent design, learner characteristics, and learning contexts. More rigorous research is needed to understand the specific factors that influence the effectiveness of embodied agents in different settings (Schouten et al., 2023). While the jury is still out on the exact impact of embodied pedagogical agents on learning, their potential for enhancing engagement and immersion in learning environments warrants further exploration (Zuo et al., 2022).

Ethnicity, Prior Knowledge, Image, Audios, Visuals, and Narration

The impact of ethnicity, prior knowledge, visuals, audio, and narration on learning is intricate and diverse. Each factor exerts varying effects on individuals, influenced by their unique experiences, backgrounds, and learning styles. For instance, ethnicity can shape individuals' learning preferences and perspectives (Zhao et al., 2023). Some ethnic groups may prefer visual learning due to cultural norms or educational backgrounds, while others may prefer auditory or kinesthetic methods. Prior knowledge can either enhance or hinder learning, depending on its alignment with new information.

When prior knowledge aligns with new information, it can facilitate comprehension and retention (Gilbert, 2009). However, when prior knowledge conflicts with new information, it can create cognitive dissonance and hinder learning (Flemban, 2018). Visuals and audios can be powerful tools for learning, but their effectiveness depends on their clarity and context (Aslan et al., 2023). Narration can provide valuable context and explanation, but poor quality can be distracting. Therefore, understanding the influence of these factors is crucial for optimizing learning outcomes and engaging diverse learners effectively.

Images and visuals can be powerful tools for learning, providing explicit learning materials (Wu et al., 2022). They can enhance comprehension and retention by making information more accessible and engaging. However, the use of images and visuals can also have limitations. For instance, if the visuals lack context or clarity, they can confuse learners and lead to misunderstandings. Audio elements, such as narration and sound effects, can provide valuable context and explanation, aiding in the comprehension of complex concepts (Choi & Lee, 2005). However, if the audio quality is poor or the narration lacks coherence, it can become a distraction rather than a help to learning (Ki et al., 2020). The inconsistent effects of these factors highlight the importance of individualized learning approaches that take into account the unique needs and preferences of learners (Dai et al., 2024). Educators and instructional designers should consider how ethnicity, prior knowledge, images, audios, visuals, and narration intersect to influence learning outcomes (Zhao et al., 2023). By creating inclusive learning environments that cater to diverse learners, we can better support their needs and help them achieve their full learning potential.

Research Questions

Considering the previous inconsistent findings and the significance in research regarding the effect of pedagogical agents on learning outcomes, we propose the following research questions. By addressing these research questions, we aim to provide a more comprehensive understanding of the pedagogical agents in learning, leading to the development of more effective and inclusive educational practices.

RQ1. What is the research trend in pedagogical agents?
RQ2. What are the top cited authors, sources, organizations, and countries in research on animated or interactive pedagogical agents?
RQ3. Can animated or interactive pedagogical agents enhance learning outcomes?
RQ4. Can embodied pedagogical agents enhance learning outcomes?
RQ5. Can ethnicity and prior knowledge, as well as pedagogical agents integrated with image, audios, visuals, and narration, influence learning outcomes?

METHODS

Research Design

The research design of this systematic analysis and visualization study aims to comprehensively investigate the effects of pedagogical agents on learning outcomes. It involves a rigorous search and selection of relevant studies, followed by a meticulous analysis of the data collected. VOSviewer and CitNetExplorer will be employed to visually represent the findings, identifying patterns, trends, and relationships between different variables. This approach aims to provide a comprehensive understanding of the impact of pedagogical agents on learning, enabling researchers and practitioners to make informed decisions about their use in educational settings.

VOSviewer and CitNetExplorer

A systematic analysis and bibliometric analysis is a comprehensive process that aims to synthesize and analyze the existing research on a particular topic. It requires a methodical approach to ensure all

relevant studies are included and the analysis is rigorous. The use of VOSviewer and CitNetExplorer, two leading bibliometric tools, further enhances this process by providing visual representations of the literature and quantifying patterns within it. Initially, the research question and scope were clearly defined. This laid the foundation for the literature search, which involved using Web of Science to identify relevant studies. The next step was screening and selecting studies based on their relevance to the research questions. Once the studies were selected, data was extracted from each one, focusing on key details like study characteristics, outcomes, and study quality.

CitNetExplorer is an exceptionally effective tool for exploring and analyzing citation networks (Yu et al., 2023). Its user-friendly interface allows researchers to seamlessly import data from various databases, such as Web of Science, and manipulate it to identify patterns and trends in their field of study. The interactive visualizations provided by the tool enable researchers to quickly identify clusters and key players within the network, making the analysis process more intuitive and efficient. Furthermore, CitNetExplorer's quantitative analysis capabilities enable researchers to measure and compare citation counts, collaboration patterns, and other key metrics, providing valuable insights into the research landscape. To sum up, the effectiveness of CitNetExplorer lies in its user-friendliness, interactive visualizations, and quantitative analysis capabilities, which collectively empower researchers to gain a deeper understanding of their citation networks (Yu & Peng, 2023).

The real strength of VOSviewer and CitNetExplorer lies in the bibliometric analysis phase. These tools allow for the visualization of bibliographic data in the form of networks and clusters. This visualization provides a clear understanding of the relationships between different studies and their impact within the field. By using indicators like citation counts and keyword co-occurrence analysis, patterns within the literature can be easily identified. Finally, the results were interpreted and synthesized to draw conclusions about the state of the literature. Gaps and limitations in the current evidence base were highlighted, leading to recommendations for future research. The entire process was documented in a report that included tables, figures, and references to support the conclusions drawn.

Data Analysis

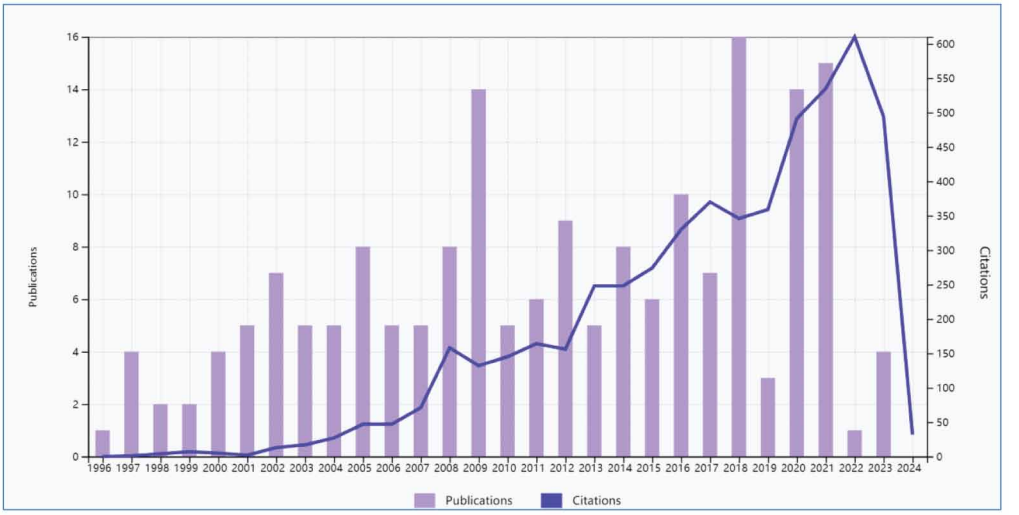
Data analysis using VOSviewer and CitNetExplorer is a powerful combination for visualizing and understanding complex networks of research. VOSviewer, a visualization tool, excels at mapping the structure of large datasets, such as bibliometric data, by creating interactive maps of keywords, authors, or institutions. These maps reveal patterns and trends in the data, showing relationships and clusters of information (Yu, 2022). CitNetExplorer, on the other hand, specializes in citation network analysis. It allows researchers to explore the connections between documents, authors, and journals, based on citation data. This tool provides insights into the influence and impact of specific works within a given field. Combined, these two tools offer a comprehensive analysis of research data (Yu et al., 2023). VOSviewer's mapping capabilities identify key areas of research, while CitNetExplorer's citation analysis reveals the influence and flow of ideas. Together, they provide a deeper understanding of the research landscape, enabling researchers to identify emerging trends, influential works, and potential collaborations.

RESULTS

RQ1. What is the Research Trend in Pedagogical Agents?

To address our research question, we conducted a thorough search of Web of Science, retrieving a total of 184 relevant publications by using the search terms "animat* pedagog* agent*" OR "interact* pedagog* agent*" (within the Topic field), covering the period from 1637 to 2024 on February 3, 2024. These publications were highly cited, with a total of 3,634 citing articles, of which 3,524 were citations without self-citations. The overall number of times cited reached 5,333, out of which 4,876

Figure 1. The research trend of studies on animated and interactive pedagogical agents



were citations without self-citations. The average number of citations per publication was 28.98, indicating the significant impact and relevance of these research findings within the field.

As shown in Figure 1, the research on animated and interactive pedagogical agents started in the year 1996. After around a decade of fluctuation, there was a sharp increase in related publications in the year 2009. However, in the following year, there was a sudden downslide in related publications, possibly due to exhaustion of research topics or other reasons. The years 2010 to 2019 saw ups and downs in the number of related publications, with the peak reached in the year 2018. However, in the following year, the number of related publications suddenly dropped to the lowest level, possibly due to the impact of the COVID-19 pandemic. In the years 2020 and 2021, the research recovered to a higher level, while in 2022 and 2023, it reached a lower level. As of the data collection date, the year 2024 has not yet begun.

The implications of this paragraph are several folds. Firstly, it highlights the dynamic nature of research in this field, with periods of growth and decline corresponding to changes in research focus, new technologies, and external events. The sharp increase in publications in 2009 and subsequent drop may reflect a shift in research focus or a response to new technological advancements or funding opportunities. Secondly, the impact of the COVID-19 pandemic on research is clearly visible in the sudden drop in related publications in 2020. This highlights the potential impact of external events on research output and the need for researchers to be adaptable in their approach and responsive to changes in the environment. Finally, the recovery of research in 2020 and 2021 demonstrates the resilience of the field and the adaptability of researchers to new challenges. It also suggests that there may be opportunities for further growth and development in this area, particularly as new technologies and methodologies emerge.

The relationship between AI and pedagogical agents in education is pivotal (Abdelghani et al., 2023). AI provides the intelligence and technology backbone, enabling agents to deliver highly personalized and adaptive learning experiences. These agents can sense and respond to students' unique needs, offering tailored feedback and guidance (Daniels & Lee, 2022). AI's predictive analytics help agents anticipate student challenges, ensuring timely interventions. This integration not only enhances learning outcomes but also supports teachers in making informed decisions about teaching strategies. Together, AI and pedagogical agents create a dynamic, responsive, and effective learning environment that caters to the diverse needs of students (Zhang et al., 2023).

RQ2: What are the Top Cited Authors, Sources, Organizations, and Countries in Research on Animated or Interactive Pedagogical Agents?

To answer this question, we embarked on an extensive literature review. We scoured the Web of Science Core Collection and narrowed down the search results to 139 publications that matched the keywords "animat* pedagog* agent*" OR "interact* pedagog* agent*" (Topic). These publications were then imported into VOSviewer, a powerful visualization tool, to conduct a comprehensive analysis. We focused on two main types of analysis: co-authorship and co-citation. For the co-authorship analysis, we considered organizations and countries as separate units of analysis. The full counting method was employed to ensure accurate representation of co-authorships. The co-citation analysis allowed us to identify the most influential authors, organizations, countries, and sources in the field. The results of our analysis are summarized in Table 1, which lists the top ten cited authors, organizations, countries, and sources based on citations. These findings provide valuable insights into the key players and trends in the field of animated and interactive pedagogical agents. They also serve as a roadmap for future research, highlighting potential areas of collaboration and innovation.

To visualize the research hotspots, we obtained 298 results from Web of Science Core Collection for: "pedagogic* agent*" (Topic) and educat* (Topic) on March 17, 2024. We selected co-occurrence as the type of analysis, author keywords as the unit of analysis, and full counting as the counting method. The minimum number of occurrences of a keyword was set at 2. Of the 807 keywords, 160 met the threshold. For each of them, we calculated the total link strength of the co-occurrence links with other keywords. Those with the strongest total link strength were selected, leading to the map generated by VOSviewer below (Figure 2).

The effectiveness of CitNetExplorer is further demonstrated in Figure 2, which visualizes the top occurrences in the field of pedagogical agents through author keywords. The larger size of each node signifies its stronger total link strength, indicating the significance and centrality of those keywords within the citation network. The top keywords, represented by the larger nodes, include "pedagogical agent(s)", "intelligent tutoring system", "education", "learning", "e-learning", "educational technology", "motivation", "human-computer interface", and "online learning". This visualization clearly illustrates the key concepts and themes that dominate the research in this area, making it easier for researchers to identify trends, gaps, and potential areas for further exploration. The ability to quickly identify and analyze these patterns is a testament to the power and effectivenesss of CitNetExplorer as a citation network analysis tool.

RQ3: Can Animated or Interactive Pedagogical Agents Enhance Learning Outcomes?

After removing one early-access publication to avoid technical issue, we obtained 138 results from Web of Science Core Collection for: "animat* pedagog* agent*" OR "interact* pedagog* agent*" (Topic) on February 3, 2024. We entered the publication entries into CitNetExplorer for a clustering analysis, which divided the publications into two groups. Group 1 included 116 publications, while Group 2 involved 23 publications. Table 2 summarized the key information for the clustering analysis including number of publications, number of citation links, number of publications with $\geq$ 10 citations, and Number of publications in 100 most cited publication. We also included pioneer studies, publications with the highest citation scores, the most recent publication, the topics of discussion, and overall conclusions of both clusters.

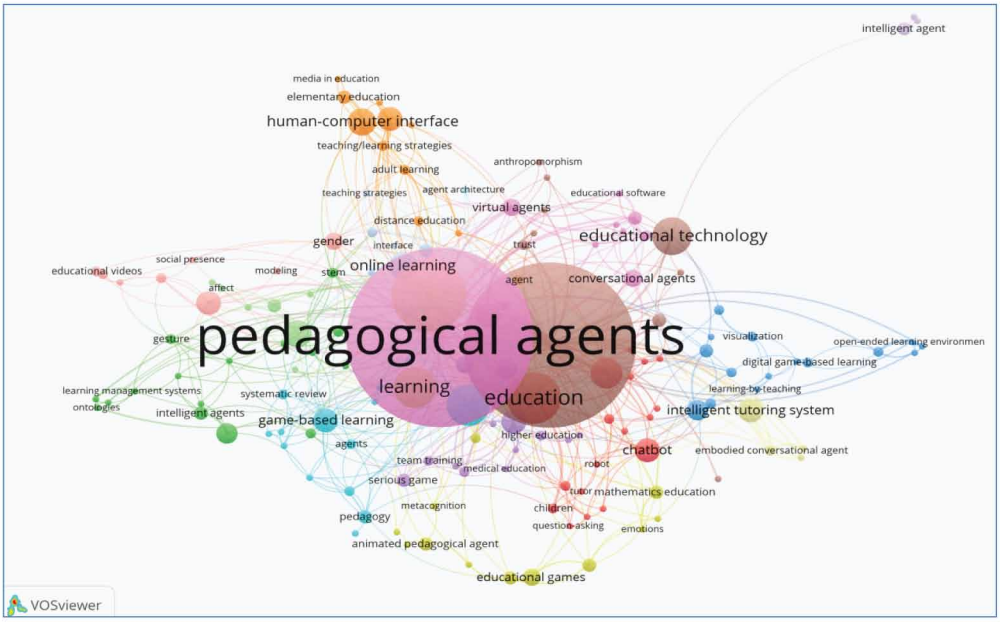
The animated nature of these pedagogical agents offers a unique opportunity to enhance tutorial communication and create more engaging learning environments (Woo, 2009). By leveraging different appeals, such as humor or fear, these agents can capture students' attention and promote a positive learning experience. However, it's crucial to consider the potential impact of these appeals on participants' mood and satisfaction. Strategically using humor and fear appeals can enhance the agents' effectiveness in maintaining student engagement and motivation (Buttussi & Chittaro, 2020).

Table 1. Top 10 cited authors, sources, organizations, and countries

N	Author	Citations	Link Strength	N	Author	Citations	Link Strength
1	Mayer, R.E.	212	2202	6	Johnson, W.L.	72	539
2	Moreno, R.	166	1915	7	Lester, J.C.	68	574
3	Baylor, A.L.	94	915	8	Craig, S.D.	62	695
4	Kim, Y.	73	612	9	Graesser, A.C.	54	358
5	Atkinson, R.K.	72	805	10	Sweller, J.	50	719
N	**Source**	**Citations**	**Link Strength**	**N**	**Source**	**Citations**	**Link Strength**
1	Journal of Educational Psychology	360	7466	6	Educational Psychological Review	86	2644
2	Computers in Human Behavior	189	5642	7	Applied Cognitive Psychology	84	2757
3	Computers & Education	189	4008	8	Educational technology research and development	82	2100
4	Learning and Instruction	133	4590	9	Journal of Computer Assisted Learning	81	1796
5	International Journal of Human-Computer Studies	92	1667	10	Contemporary Educational Psychology	77	1948
N	**Organization**	**Citations**	**Link Strength**	**N**	**Organization**	**Citations**	**Link Strength**
1	University Calif Santa Barbara	1028	5	6	Florida State University	220	0
2	University of New Mexico	714	2	7	Purdue University	111	4
3	University of Twente	585	0	8	Technische Universität Chemnitz	67	0
4	The University of Memphis	583	0	9	University of Southern California	58	0
5	Arizona State University	399	1	10	Universidade do Vale do Rio Dos Sinos	28	0
N	**Country**	**Citations**	**Link Strength**	**N**	**Country**	**Citations**	**Link Strength**
1	USA	3002	10	6	Germany	68	0
2	Netherlands	711	2	7	Brazil	61	0
3	South Korea	128	2	8	Spain	47	0
4	China	125	5	9	Italy	43	1
5	Australia	79	3	10	Canada	28	1

For instance, humor can lighten the learning atmosphere and make it more enjoyable, while fear Appeals can emphasize the importance of a particular topic or concept. With careful consideration of these factors, educational institutions can take advantage of the animated nature of these agents to deliver impactful and engaging tutorials that support meaningful learning (Shaw et al., 1999).

Figure 2. Visualizing keywords based on co-occurrences



The integration of interactive pedagogical agents in multimedia lessons is a transformative approach to meaningful learning (Wang et al., 2018). These agents, which primarily communicate through speech, have the potential to revolutionize the way students engage with content. Not only do they improve learning outcomes, but they also offer an opportunity for researchers in the field of information systems to gain valuable insights. The strategic use of different appeals, such as humor or fear, can further enhance the effectiveness of these agents in engaging and motivating students (Buttussi & Chittaro, 2020). For instance, humor can be employed to make learning more enjoyable and less dull, while fear Appeals can be used to emphasize the importance of a particular topic or concept. The integration of animated pedagogical agents in multimedia lessons represents a promising avenue for enhancing tutorial communication and learning environments (Craig et al., 2002). As research in this area continues to evolve, it is likely that even more innovative approaches will emerge, further improving the learning experiences of students worldwide.

RQ4: Can Embodied Pedagogical Agents Enhance Learning Outcomes?

Based on the clustering analysis, we identified the longest path within Cluster 1, which consists of seven publications (Figure 3). This path represents a trajectory of ideas and concepts that have been developed and refined over time. The path begins with the initial publication, which introduces the fundamental concepts and serves as a starting point for the cluster. Subsequent publications build upon these concepts, exploring their applications and extensions in greater detail. The path highlights the evolution of ideas within the field, tracing how they have developed and been refined over time. Understanding this path is valuable for comprehending the underlying themes and trajectories within Cluster 1, and it can inform future research by identifying key developments and gaps in the literature.

The Cohen (1988) study, which has been widely cited by six subsequent studies, provides a comprehensive overview of power analysis techniques. It offers practical tools for applied statisticians and covers set correlation and multivariate methods. Additionally, the study examines the impact of effect size, psychometric reliability, and dependent variables on research outcomes. Updated chapters

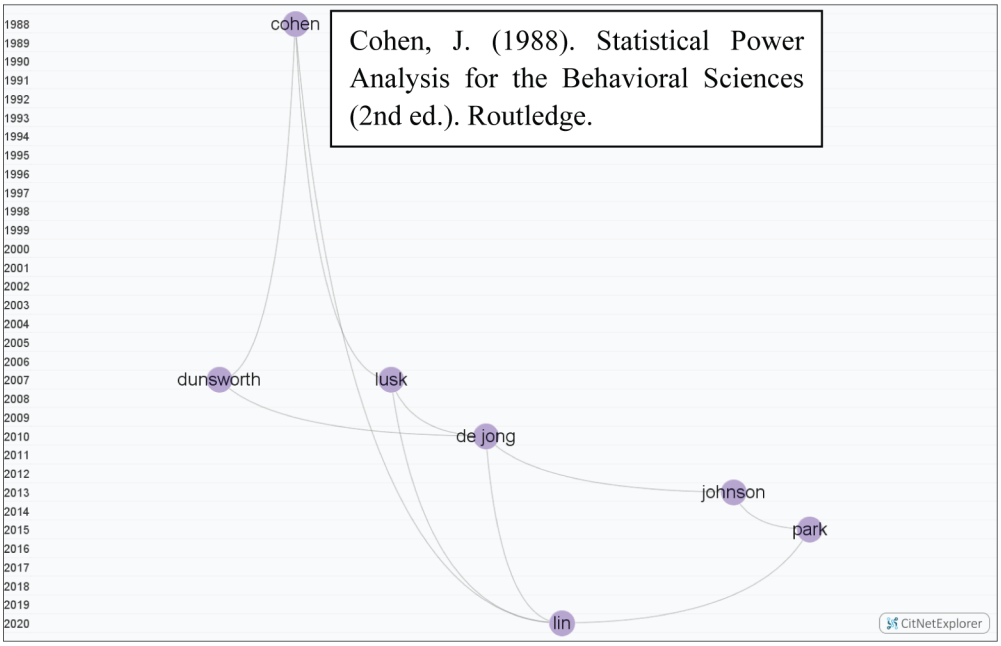
Table 2. Citation network information for two clusters

Cluster	Number of publications	Number of citation links	Number of publications with ≥ 10 citations	Number of publications in 100 most cited publication
1Brue	116	773	39	39
2Green	23	29	3	3
Item	**Year published**	**Number of Citations**	**First Author**	**Title**
Pioneer (Cluster 1)	1988	11	Cohen, J.	Statistical power analysis for the behavioral sciences
Highest Citation Score (Cluster 1)	2001	46	Moreno, R.	The Case for Social Agency in Computer-Based Teaching: Do Students Learn More Deeply When They Interact With Animated Pedagogical Agents?
Most Recent (Cluster 1)	2023	0	Dolata, M.	
Topic of Discussion (Cluster 1)	Interactive pedagogical agents			
Overall Conclusion (Cluster 1)	The integration of interactive pedagogical agents, communicating through speech, in multimedia lessons enhances meaningful learning. The interaction with digital agents positively influences learning outcomes, which informs research directions in information systems and provides guidance for developers of educational digital agents.			
Pioneer (Cluster 2)	1978	11	Vygotsky, L.S.	The development of higher psychological processes
Highest Citation Score (Cluster 2)	2000	41	Johnson, W.L.	Animated Pedagogical Agents: Face-to-Face Interaction in Interactive Learning Environments
Most Recent (Cluster 2)	2020	1	Buttussi, F.	Humor and Fear Appeals in Animated Pedagogical Agents: An Evaluation in Aviation Safety Education
Topic of Discussion (Cluster 2)	Animated pedagogical agents			
Overall Conclusion (Cluster 2)	The animated pedagogical agents hold great promise for enhancing tutorial communication and learning environments. Their application has generally positive effects on learning, regardless of the specific appeals used. However, the use of humor and fear appeals can influence participants' mood, their liking of the application, and their perception of the agent. Strategic use of these different appeals can further enhance the effectiveness of these agents in engaging and motivating students.			

include expanded tables for power and sample size calculations in multiple regression/correlation analysis, building upon Cohen's foundational work. Statistical Power Analysis is a valuable resource for enhancing analytical capabilities in applied statistics. The six studies citing this study focus on the impact of animated pedagogical agents on educational outcomes, utilizing the statistical theories and practices outlined in the Cohen (1988) study.

The findings from several studies suggest that using a pedagogical agent can enhance learning outcomes. It was found to be more engaging than learning without an agent. A conversational style of instruction in lessons led to better retention but also caused more anxiety. When delivered by a pedagogical agent, the conversational style increased mental effort, but without the agent, learners found it easier. This supports the use of a pedagogical agent for Chinese learners in this style. However,

Figure 3. The first longest path constructed from Cluster 1



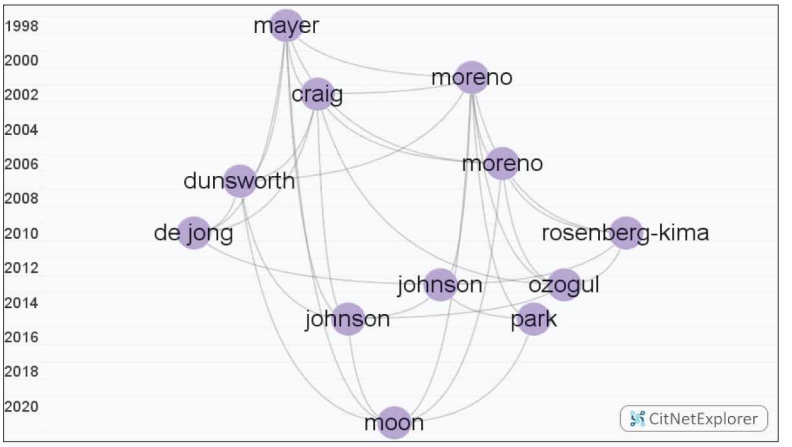
simpler designs, without an animated agent, can be beneficial under certain conditions, particularly when the material is not complex or advanced technology is unavailable (Lin et al., 2020). The presence of images didn't significantly affect cognitive load, interest, motivation, or achievement. But the type of narration made a difference. Human voice narration by a pedagogical agent reduced cognitive load and boosted situational interest. Personalized narration also improved motivation, regardless of whether it was by a pedagogical agent or on-screen text. No significant differences were found in recall or comprehension tests (Park, 2015).

Fully embodied agents lead to more accurate answers for near and far transfer items than voice-only conditions. Animated worked examples outperform static ones when subgoals are presented sequentially (Lusk & Atkinson, 2007). This suggests that an animated pedagogical agent can enhance learning outcomes in a science-focused environment (Dunsworth & Atkinson, 2007). However, the effect depends on learners' prior knowledge: low prior knowledge learners benefit more from visual signaling, while high prior knowledge learners don't. College-bound students with low prior knowledge benefit from an animated agent in instruction with multiple visual representations, but high prior knowledge learners don't (Johnson et al., 2013). To optimize learning, it's recommended to design systems that optimize working memory capacity and avoid cognitive overload (de Jong, 2010).

RQ5: Can Ethnicity and Prior Knowledge, as Well as Pedagogical Agents Integrated With Image, Audios, Visuals, and Narration, Influence Learning Outcomes?

We identified the second longest path within the first cluster, containing 12 publications (Figure 4). This path is led by Mayer (1998) and demonstrates a trajectory of ideas and concepts that have been developed over time. The path begins with Mayer's seminal work, which lays the foundation for the cluster's themes and serves as a starting point for further exploration. Subsequent publications build upon Mayer's work, extending its applications and refining its theoretical framework. This path highlights the evolution of ideas within the field, tracing how they have developed and been

Figure 4. The second longest path containing 12 publications



refined over time. Understanding this path is valuable for comprehending the underlying themes and trajectories within the first cluster, and it can inform future research by identifying key developments and gaps in the literature.

Ethnicity, prior knowledge, image, and narration exert an important influence on APA-assisted learning outcomes. In learning, students using same-ethnicity APAs produce lower retention, transfer, and program ratings compared to those with different-ethnicity APAs. This supports an interference hypothesis for students with same-ethnicity APAs (Moreno & Flowerday, 2006). Low prior knowledge learners gain more in APA signaling conditions, but high prior knowledge learners don't benefit from visual signaling (Johnson et al., 2013). Lower prior knowledge students score higher with visual signaling, matching higher prior knowledge students. Visual signaling effectiveness depends on learner characteristics, including prior domain knowledge (Johnson et al., 2015). Choice of animated agent boosts learner motivation (Ozogul et al., 2013). Images don't affect cognitive load, interest, or achievement, but narration matters. Human voice narration reduces cognitive load and boosts interest, while personalized narration improves motivation. No differences were found in recall or comprehension tests (Park, 2015).

The integration of auditory and visual information, particularly through spoken narration, can enhance multimedia learners' comprehension and align with dual-processing models of working memory. Multimedia learners integrate words and pictures best when words are presented auditorily, aligning with the dual-processing model of working memory (Mayer & Moreno, 1998). Spoken narration outperforms printed text in multimedia environments, with no difference between printed text and printed text with narration (Craig et al., 2002). Interactive agents enhance communication and learning (Moreno et al., 2001). Animated agents coordinate narration, gaze, and pointing to foster learning in a science-focused environment (Dunsworth & Atkinson, 2007). Matching agents by race/gender improves women's responses in engineering fields, but White male agents are more influential for Black female participants (Rosenberg-Kima et al., 2010). Cognitive capacity limits learning; optimal systems prevent overload (de Jong, 2010). Visual cognitive cues enhance learning comprehension, integrating pictorial info via visuospatial clues (Moon & Ryu, 2021). To facilitate reading easiness, the results are tabulated (Table 3).

Ethnicity and learners' background play significant roles in the effectiveness of pedagogical agents on learning outcomes (Zhao et al., 2023). Pedagogical agents, or virtual teachers, are digital characters designed to engage learners in educational content. They can vary widely in appearance,

Table 3. A summary of research question answers

N	Research question	Result
1	What is the research trend in pedagogical agents?	Figure 1
2	What are the top cited authors, sources, organizations, and countries in research on animated or interactive pedagogical agents?	Table 1
3	Can animated or interactive pedagogical agents enhance learning outcomes?	Yes
4	Can embodied pedagogical agents enhance learning outcomes?	Yes
5	Can ethnicity and prior knowledge, as well as pedagogical agents integrated with image, audios, visuals, and narration, influence learning outcomes?	Yes

personality, and interaction style, and their effectiveness can be influenced by the cultural and ethnic backgrounds of the learners.

Firstly, it is important to consider the cultural fit between the pedagogical agent and the learner. Agents that are culturally sensitive and resonate with the values, beliefs, and norms of specific ethnic groups are more likely to engage learners and promote learning (Zhao et al., 2023). For example, agents that incorporate cultural elements or use language and communication styles that are familiar to learners from specific ethnic backgrounds may be more effective in captivating their attention and fostering a positive learning environment. Secondly, learners' ethnic and cultural backgrounds can influence their preferences for certain types of agents (Zhou & Bickmore, 2021). Some learners may prefer agents that embody authoritative figures or experts, while others may prefer agents that are more relatable and approachable. Understanding these preferences can help designers create agents that are more aligned with the needs and preferences of diverse learner populations.

Moreover, the social and economic backgrounds of learners can also affect their interactions with pedagogical agents (Escorcia-Clavijo & Becerra-Patino, 2023). Learners from diverse ethnic groups may have different levels of access to technology and digital resources, which can limit their ability to fully engage with agents. Additionally, learners' prior educational experiences and literacy levels can influence their ability to understand and interpret the information presented by agents (Nguyen, 2023). It is important to consider these factors when designing agents to ensure that they are accessible and effective for all learners. By considering the ethnicity and learners' background in the design and evaluation of pedagogical agents, we can create more inclusive and effective educational experiences that promote learning outcomes across diverse populations.

DISCUSSION

Pedagogical agents are becoming increasingly important in the field of education, as they have the potential to revolutionize the way students learn. In this article, we explored the role of animated or interactive pedagogical agents, embodied pedagogical agents, ethnicity and prior knowledge, and the integration of image, audio, visuals, and narration in enhancing learning.

Animated, interactive, and embodied pedagogical agents can improve learning outcomes. There are several more reasons why they are such a valuable tool for enhancing learning. These agents are highly customizable, allowing educators to target specific learning needs and goals (Drasute et al., 2018). They can be designed to incorporate different learning styles, making them suitable for a wide range of students. Moreover, the interactive nature of these agents fosters critical thinking and problem-solving skills, preparing students for real-world challenges (Fabio et al., 2019). Research has shown that students who engage with interactive agents tend to exhibit more positive attitudes towards learning and are more likely to pursue further education. By incorporating these agents into

our educational system, we can create a more engaging, inclusive, and effective learning environment that benefits all students.

Embodied pedagogical agents offer several advantages for enhancing learning. They simulate real-world scenarios, providing students with a more authentic and immersive learning experience (R. E. Mayer & DaPra, 2012). By simulating real-world scenarios, students are able to explore and engage with concepts in a simulated environment, promoting critical thinking and problem-solving skills. This approach allows students to actively participate in the learning process, rather than passively receiving information. Embodied agents are designed to promote active participation and interaction (Chen et al., 2012). They engage students kinesthetically, encouraging them to explore and manipulate the simulated environment. This active engagement helps students to retain information better and promotes a deeper understanding of concepts. The integration of image, audio, visuals, and narration further enhances the learning experience. These multimedia elements make information more engaging and memorable, helping students to retain knowledge longer. By harnessing these technologies and approaches, we can create an educational system that better meets the needs of all students and promotes effective learning.

Ethnicity and prior knowledge are significant factors in the learning process (Zhao et al., 2023). To ensure effective engagement, pedagogical agents must take into account the cultural background and experiences of individual learners. Agents should be designed with cultural sensitivity, aiming to present information in a culturally relevant and meaningful way. This approach can help to reduce potential barriers to learning and foster a sense of belonging and respect among students of diverse ethnic backgrounds. Prior knowledge is also crucial. It allows students to build upon their existing knowledge, enabling them to make connections between new and familiar concepts (Flemban, 2018). By taking into account students' prior knowledge, agents can tailor the learning experience to their individual needs, promoting a more meaningful and relevant learning process. By considering ethnicity and prior knowledge, we can create pedagogical agents that are inclusive and responsive to the diverse needs of learners. This approach will foster a positive learning environment where all students feel empowered to reach their full potential.

The integration of various media elements within pedagogical agents, such as images, audio, visuals, and narration, can significantly enhance the learning process (Dunsworth & Atkinson, 2007). Images, for instance, can provide a visual representation of complex concepts, making them more accessible and comprehensible (Dunsworth & Atkinson, 2007). Audio and narration can further explain and clarify information, complementing the visuals and enhancing the overall learning experience (Kappagantula et al., 2020). The integration of these media elements can create a more immersive and engaging learning experience. By combining visuals, audio, and narration, agents can present information in a variety of ways, catering to different learning styles and preferences (Park, 2015). This approach can make the material more memorable and understandable, promoting a deeper level of comprehension and retention. By taking advantage of these multimedia elements, pedagogical agents can provide an enriching and comprehensive learning experience, catering to the diverse needs of learners. This approach can foster a more engaged and interactive learning environment, enabling students to fully comprehend and apply the material.

Pedagogical agents can be an innovative and engaging tool in the curriculum, providing personalized and interactive learning experiences for students (Zhang et al., 2023). To effectively use these agents, teachers should carefully plan their integration into the lesson plans, aligning them with learning objectives and outcomes. Agents can be designed to simulate real-world scenarios, fostering active learning and critical thinking skills (Bellingham, 2022). Additionally, they can be used to support collaborative learning, encouraging students to work together and share ideas (Zou et al., 2024). Teachers should monitor student progress and provide feedback, ensuring that agents are used effectively to support student learning (Daniels & Lee, 2022). By leveraging the capabilities of pedagogical agents, teachers can create engaging and effective curricula that meet the needs of diverse learners.

CONCLUSION

Major Findings

This study utilized VOSviewer and CitNetExplorer for a bibliometric analysis, examining the research trends in the field of pedagogical agents for learning. The top 10 cited authors, sources, organizations, and countries in this field were identified. The findings indicate that animated, interactive, and embodied pedagogical agents may enhance learning outcomes. Furthermore, ethnicity and prior knowledge are significant factors in influencing learning outcomes. The integration of image, audio, visuals, and narration within these agents can positively impact learning outcomes, creating a more immersive and engaging learning experience.

Limitations

While VOSviewer and CitNetExplorer are powerful tools for bibliometric analysis, they have some limitations. Firstly, they rely heavily on the quality and currency of the data sources, which may not always be comprehensive or up to date. Secondly, the analysis is quantitative and may not capture the nuances and contextual factors that are important in understanding research impact. Finally, VOSviewer and CitNetExplorer are not designed to analyze the content or methodology of individual studies, limiting their ability to provide a comprehensive understanding of research trends and impact.

Future Research Directions

The future of pedagogical agents in learning is indeed promising, but it also faces crucial challenges that need to be addressed. With the advancing AI technology, there are opportunities to craft more sophisticated and personalized learning experiences through these agents. However, to fully realize this potential, several key research directions must be pursued.

First, it is imperative to enhance the AI algorithm development to create more effective and trustworthy pedagogical agents. Huang et al. (2024) emphasize the need for this enhancement, highlighting the current limitations of many agents that rely on machine learning techniques. These techniques are often plagued by data biases and lack transparency, as pointed out by Pagano et al. (2023). To mitigate these issues, future research must prioritize the development of more transparent and robust algorithms. These algorithms should be able to handle diverse datasets while providing meaningful explanations for their decisions. This approach will not only improve the reliability of AI-powered agents but also foster trust and enhance the user experience.

Another crucial research area is the integration of human-agent collaboration in education. Adamo et al. (2021) argue that while AI-powered agents have the potential to provide valuable support in the learning process, they cannot fully replace human teachers. Therefore, future studies should focus on exploring ways for agents to work alongside teachers to enhance the overall learning experience. This might involve the development of new interfaces and collaboration tools that facilitate effective communication and cooperation between humans and AI agents. By bridging the gap between AI technology and human expertise, we can create a more personalized and engaging learning environment that benefits both students and teachers.

The future of pedagogical agents in learning is full of promise but also poses significant challenges. With the advancement of AI technology, the potential to create more sophisticated and personalized learning experiences through these agents is immense (Zhang et al., 2023). However, to achieve this, it is crucial to address multiple research areas.

Firstly, human-agent collaboration is a key aspect that requires further exploration (Adamo et al., 2021). While AI-powered agents can provide valuable support, they cannot fully replace human teachers. Future research should focus on how agents can work alongside teachers to enhance the learning experience. This collaboration might involve the development of new interfaces and tools that facilitate effective communication and cooperation between humans and AI agents.

Secondly, personalizing learning experiences is another crucial direction for research. By leveraging AI-powered agents, it is possible to tailor learning paths and material to individual students' unique needs and preferences. However, to create truly personalized experiences, a deep understanding of the complexities of learning processes and appreciation for individual differences among students is essential. Researchers should investigate innovative methods for collecting and analyzing data to inform the development of more personalized learning plans.

Moreover, the ethical and social implications of pedagogical agents cannot be overlooked (Roa et al., 2022). As these agents become more integrated into educational settings, it is important to ensure their use is equitable and respects the privacy and autonomy of students. Researchers have a responsibility to thoroughly investigate the potential unintended consequences of implementing these agents and provide guidance on their ethical and responsible use in education (Zou et al., 2024).

Finally, pedagogical agents in education provide managers with novel tools to enhance their skills and contexts (Ilic et al., 2023). One practical implication is the agents' ability to gather real-time student data, enabling managers to make informed decisions about resource allocation and curriculum design (Apoki & Crisan, 2022). Agents can also automate administrative tasks, freeing up managers' time for more strategic work. Furthermore, the agents' personalized learning approach helps managers cater to diverse student needs, improving overall learning outcomes. These practical implications not only improve educational efficiency but also enhance managers' skills in data analysis, decision-making, and strategic planning (Apoki et al., 2022).

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CONFLICTS OF INTEREST

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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