Pedagogical Agents in Education: A Survey of AI Integration and Applications

Abstract

Pedagogical agents, powered by advanced AI technologies such as large language models (LLMs) and natural language processing (NLP), are revolutionizing educational environments by offering personalized and interactive learning experiences. This survey explores the transformative potential of these agents in enhancing instructional methods, fostering student engagement, and promoting critical thinking through dynamic conversations. The integration of AI-driven methodologies allows pedagogical agents to tailor educational experiences to individual learner needs, optimizing educational outcomes. Despite their promise, the deployment of these agents faces technical challenges, including computational inefficiencies and biases in AI-generated content. Addressing these issues is crucial for improving user engagement and ensuring equitable access to educational technologies. Future research directions emphasize enhancing interaction capabilities and emotional intelligence, promoting diversity and inclusivity, and innovating learning and adaptation processes. By refining communication protocols and exploring adaptive frameworks, pedagogical agents can better support diverse educational contexts. This survey underscores the importance of multidisciplinary collaboration and ongoing research in advancing the development and application of AI technologies in education, paving the way for more effective and engaging learning experiences.

1 Introduction

1.1 Concept and Relevance of Pedagogical Agents

Pedagogical agents are a transformative element in educational environments, employing artificial intelligence to create interactive and personalized learning experiences. Utilizing advanced AI technologies, such as large language models (LLMs) and natural language processing (NLP), these agents enhance user engagement with educational content, offering tailored learning pathways that meet individual student needs [1]. Their significance lies in facilitating autonomous cooperation among communicative agents, thereby optimizing educational processes while reducing reliance on human input.

Incorporating pedagogical agents addresses the challenge of maintaining student engagement, particularly in computer-based learning environments where traditional methods may be ineffective [2]. These agents are crucial for fostering autonomous skill acquisition, allowing learners to develop competencies through interactive language-based interactions. This shift emphasizes the potential of pedagogical agents to transition educational practices from rote memorization to the cultivation of critical thinking and problem-solving skills [3].

Moreover, pedagogical agents enhance communication strategies in educational contexts, enabling students to navigate vast information and engage in meaningful dialogues [4]. By integrating advanced machine learning algorithms, these agents efficiently process large-scale data, providing insights and recommendations that enrich educational experiences [5]. Their ability to engage in

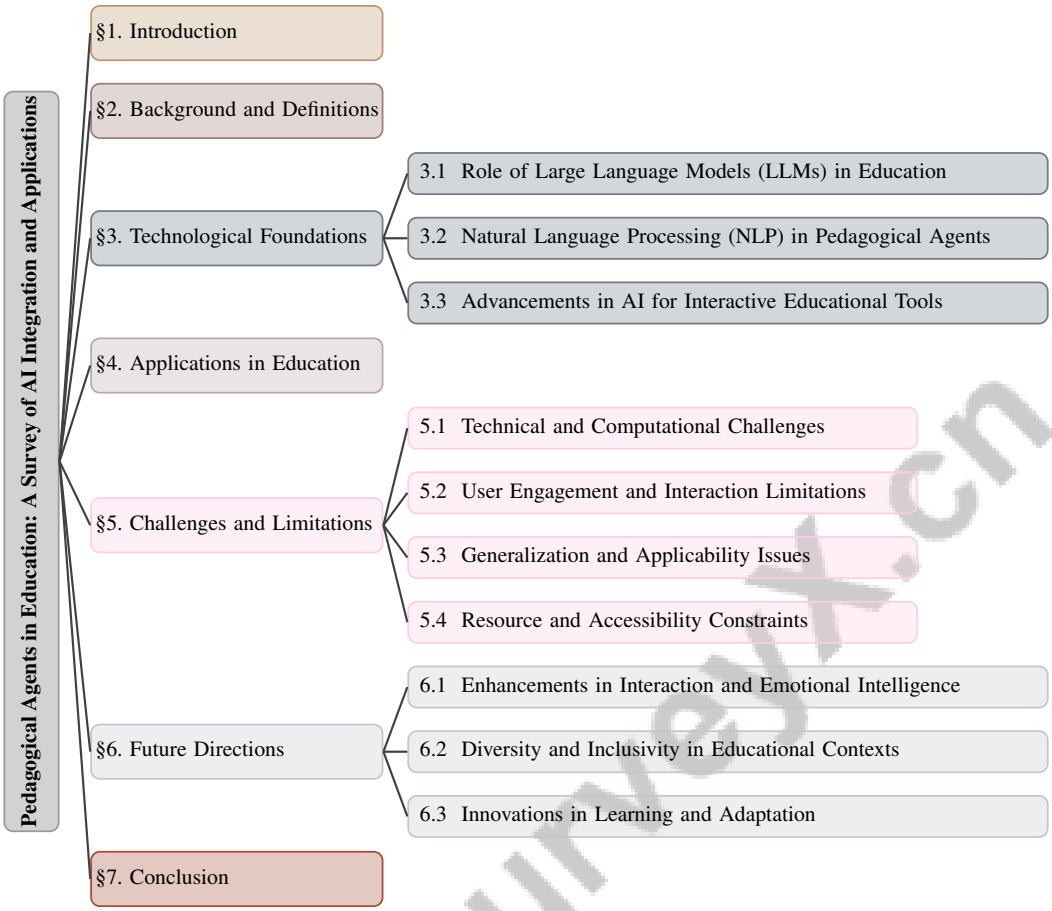

Figure 1: chapter structure

complex, goal-oriented dialogues exemplifies their role in fostering dynamic and interactive learning environments.

The evolution of pedagogical agents necessitates a comprehensive framework for understanding interactions with digital agents in educational settings. This framework is pivotal for analyzing how attributes such as emotional intelligence and interaction capabilities impact learning outcomes across diverse populations and contexts [6, 7]. Additionally, addressing sample efficiency in grounded language learning is essential for enhancing human-agent interactions, ensuring that pedagogical agents effectively support educational objectives.

Pedagogical agents integrate technology with educational practices, fostering interactive environments that promote active participation and deeper inquiry among students. By encouraging complex, divergent-thinking questions, these agents not only stimulate curiosity but also adapt to individual learning needs, addressing the diverse abilities and motivations present in modern classrooms [8, 7]. By promoting critical thinking and mitigating confirmation bias, these agents significantly enhance educational experiences and prepare students for future challenges.

1.2 Integration of AI Technologies

The integration of AI technologies, particularly LLMs and NLP, has substantially transformed educational environments by facilitating personalized and interactive learning experiences. Recent studies highlight a role-playing framework that automates cooperation among agents, showcasing the potential of AI technologies to enhance educational settings through seamless interaction and collaboration [1]. This integration is crucial for creating dynamic learning environments where AI agents autonomously support educational objectives.

Conversational agents, leveraging advanced NLP techniques, have demonstrated effectiveness in engaging diverse user groups, including older adults, underscoring the broad applicability of AI technologies in promoting educational engagement [4]. These agents utilize sophisticated language processing capabilities to facilitate meaningful dialogues, thereby enhancing educational experiences through tailored feedback and support.

The deployment of AI-driven educational tools is further strengthened by advancements in LLMs, which automate complex processes and enable large-scale applications in educational contexts. The integration of NLP techniques enhances task adaptation by merging natural language instructions with learning algorithms, optimizing educational outcomes. This synergy allows for zero-shot task adaptation, where agents learn to perform new tasks based solely on linguistic descriptions of differences from previously demonstrated tasks. Additionally, it facilitates the automation of pedagogical content generation, improving the efficiency of training programs aimed at fostering children's curiosity-driven questioning skills. Advanced frameworks for generating question-answer pairs from real-world examination data exemplify the potential of NLP in creating high-quality educational resources, while systematic evaluation methods for prompt engineering in LLMs refine the educational applications of these technologies [9, 10, 11, 12, 13]. However, challenges such as ensuring equitable access to AI technologies and addressing potential biases remain critical considerations. Addressing these challenges is essential to harness the full potential of AI in education, ensuring that these technologies support diverse learning needs while upholding ethical standards.

1.3 Objectives of the Paper

This survey provides a comprehensive analysis of AI-driven pedagogical agents, emphasizing their transformative potential in enhancing learning experiences, student engagement, and instructional methodologies. A primary objective is to address the integration of natural language interaction and the maintenance of conversational context within educational tools, which is vital for efficient information retrieval and user engagement. The paper proposes guidelines for the design and development of pedagogical agents, aiming to enhance learning outcomes through tailored interventions that promote deeper question-asking and emotional engagement among diverse learners [6, 14, 8, 7].

The survey investigates the development of action sequences that effectively integrate insights from both language models and grounded models of the environment. This integration enables agents to perform complex tasks in response to verbal commands, ensuring that generated actions are linguistically coherent and feasible within physical constraints. By framing this challenge as a probabilistic filtering problem, the research illustrates how to decode action sequences that maintain high probabilities under both language model and grounded model objectives, facilitating the execution of intricate, long-horizon tasks in robotic settings [15, 16, 17]. This capability is essential for developing pedagogical agents that autonomously support educational activities. The paper further explores the role of reinforcement learning in recommending effective interventions for students, addressing the limitations of existing recommender systems.

A key objective in advancing dialogue systems is to automate the discovery of subgoals, significantly enhancing the functionality of pedagogical agents. This enhancement allows agents to navigate and manage complex educational dialogues, facilitating more engaging and personalized learning experiences. For instance, leveraging LLMs can automate the generation of pedagogical content, such as question-answer pairs and keyphrases, essential for guiding students in their learning processes. Implementing such automated systems better supports innovative educational methods, like the 'learning-by-teaching' paradigm, where students actively engage with content through conversational interactions [10, 18, 12]. The survey also aims to develop scalable methods for training children in divergent question-asking, leveraging LLMs to foster curiosity and critical thinking.

By focusing on autonomous collaboration among agents, the paper seeks to optimize task completion without human intervention, thereby enhancing educational processes. The survey assesses user behavior and sentiment during interactions with dialogue agents, providing insights into their effectiveness across various educational contexts, particularly concerning emotional design and adaptability to different learner populations. Examining user engagement with conversational agents contributes to understanding the impact of emotional features and personalized interactions on learning outcomes [6, 18].

The paper proposes innovative frameworks for assessing the performance and impact of pedagogical agents, contributing to the development of reproducible evaluation techniques [5]. By exploring emerging technologies and methodologies, the survey aims to offer a comprehensive understanding of how AI technologies, particularly LLMs and NLP, can be leveraged to create dynamic and engaging educational experiences. This exploration is expected to pave the way for future research and development in AI-enhanced education.

1.4 Structure of the Survey

This survey is meticulously organized to comprehensively explore the integration of AI technologies, such as LLMs and NLP, into educational settings through pedagogical agents. The structure is designed to examine the diverse roles that animated pedagogical agents (APAs) play in enhancing educational experiences, while also addressing challenges in their emotional design and implementation, and outlining future research directions aimed at optimizing their effectiveness for various learner populations [6, 19, 8, 7].

The survey begins with an introduction outlining the concept and relevance of pedagogical agents, emphasizing their transformative potential in education. This section discusses the integration of AI technologies and sets forth the objectives of the paper, providing foundational understanding for subsequent sections.

Following the introduction, the background and definitions section offers a detailed overview of key concepts, including definitions of pedagogical agents, LLMs, NLP, and conversational agents. This section delves into the historical context and evolution of these technologies, providing a framework for understanding their current applications.

The technological foundations section explores the underpinnings of pedagogical agents, focusing on the role of LLMs and NLP in creating interactive educational tools. Recent advancements in AI that have enabled effective integration into educational environments are discussed, highlighting the innovative capabilities of modern AI-driven educational tools.

The applications in education section examines practical implementations of pedagogical agents, showcasing their ability to facilitate personalized learning experiences, enhance instructional methods, and improve student engagement and comprehension through dynamic conversations. This section draws on studies that highlight the effectiveness of multi-role chatbot learning environments and collaborative learning frameworks with AI integration.

In addressing challenges and limitations, the survey explores technical and computational difficulties, user engagement issues, and resource constraints. It also discusses the complexities of integrating diverse knowledge bases into conversational interfaces, exemplified by systems like UKP-ATHENA [20], which aim to overcome traditional limitations of search engines.

The future directions section identifies potential advancements in interaction capabilities and emotional intelligence of pedagogical agents, emphasizing the importance of diversity and inclusivity in educational contexts. It explores innovations in learning processes and adaptive capabilities, drawing on frameworks that enhance user understanding by addressing one-sided narratives [21].

In conclusion, this paper synthesizes key insights from discussions on the transformative role of AI technologies in education, particularly through AI-powered chatbots and advanced question-answer generation frameworks. It highlights the significant impact these innovations have on enhancing learner engagement, motivation, and inquiry-based learning in computer science education. The findings underscore the necessity for continued research and development in this rapidly evolving field, as well as the importance of developing systematic evaluation methodologies for AI-driven educational tools. This ongoing exploration is vital for optimizing AI's potential to support diverse learning needs and improve educational outcomes [10, 9, 19]. This structured approach ensures a thorough examination of pedagogical agents and their role in modern education, providing valuable insights for educators, researchers, and policymakers.The following sections are organized as shown in Figure 1.

2 Background and Definitions

2.1 Key Concepts and Definitions

Pedagogical agents are advanced AI systems enhancing education through natural language interactions, utilizing large language models (LLMs) and natural language processing (NLP) to offer adaptive learning experiences [12, 22]. Operating in multi-agent environments, these agents employ emergent communication and grounded compositional language to support autonomous skill acquisition and behavioral diversity, improving educational outcomes [23]. Dialogue agents, crucial to pedagogical agents, manage interactions through finite-state, frame-based, and agent-based systems [24], with persona detection tailoring interactions based on user profiles for contextually relevant responses [25]. Target-guided open-domain conversation directs dialogues towards specific educational goals using semantic knowledge relations [26].

Collaborative learning environments, such as multi-role chatbot frameworks, illustrate how pedagogical agents facilitate dynamic learning experiences by promoting engagement and supporting diverse educational objectives [19]. Integrating explainable AI (XAI) elements enhances transparency and user trust [27], while exploring agent enthusiasm informs the balance between engagement and cognitive load [28]. Challenges in predicting conversational dynamics in multi-party settings are addressed by benchmarks modeling turn-taking behaviors, crucial for effective interaction management [29]. Systems like ArguMentor demonstrate the capacity of pedagogical agents to expose learners to varied perspectives and enhance critical thinking [21].

Reinforcement learning and multi-armed bandit approaches are vital for understanding intervention recommendation frameworks used by pedagogical agents to optimize educational outcomes [30]. Grounded Decoding (GD) merges token probabilities from LLMs and grounded models to generate feasible action sequences, enhancing interaction capabilities [16]. These concepts underscore the transformative potential of pedagogical agents in educational environments, highlighting their role in fostering intelligent, interactive systems [7].

2.2 Historical Context and Evolution

The evolution of pedagogical agents and AI technologies in education has been shaped by advancements in computational capabilities and psychological insights. Early AI-driven educational efforts faced challenges in maintaining engagement and facilitating meaningful dialogue, especially with diverse groups like older adults [4]. This highlighted the need for sophisticated dialogue systems that adapt to diverse learners' needs. Technological advancements in parallel processing and distributed computing have enabled the development of efficient algorithms, facilitating AI systems that process extensive data and deliver personalized learning at scale [5]. The shift from rule-based to dynamic AI-driven models marks a significant milestone in educational technology evolution.

The advent of LLMs has further enhanced pedagogical agents, allowing greater autonomy and adaptability. These models have been crucial in developing multi-role chatbots that provide comprehensive support, addressing limitations of traditional single-role systems and enhancing engagement in educational contexts, especially in computer science [29, 19, 31, 18]. This evolution reflects a trend towards AI systems that learn from minimal demonstrations and adapt to new tasks, enhancing their educational utility.

Historically, AI integration in education has also been driven by the need for explainability and transparency to foster trust and understanding among users. Emphasizing explainability in pedagogical agent design has significantly enhanced their effectiveness, particularly in fostering curiosity-driven question-asking skills and tailoring interventions to diverse learning needs [14, 8, 6, 18, 12].

Critiques of imitation-based language learning methods, inadequate for capturing functional language aspects, have spurred the development of sophisticated AI systems for complex tasks across environments. Recent advancements, such as AI-powered multi-role chatbots in computer science education and the ArguMentor platform, enhance critical thinking by presenting counter-arguments and facilitating deeper engagement [19, 21]. The ongoing evolution of AI technologies in education reflects a continuous effort to enhance learning experiences and address learners' multifaceted needs, paving the way for future innovations.

In recent years, the integration of advanced technologies in educational settings has transformed traditional pedagogical approaches, leading to the emergence of innovative learning tools. Figure 2 illustrates the technological foundations in education, highlighting the roles of Large Language Models (LLMs), Natural Language Processing (NLP), and advancements in AI for interactive educational tools. This figure categorizes the contributions of these technologies into adaptive educational tools, procedural generation, meaningful dialogues, engagement and motivation, multi-agent systems, and dialogue systems. Such categorizations emphasize the significant impact these technologies have on creating personalized and engaging learning experiences, thereby reshaping how educators and learners interact within the educational landscape.

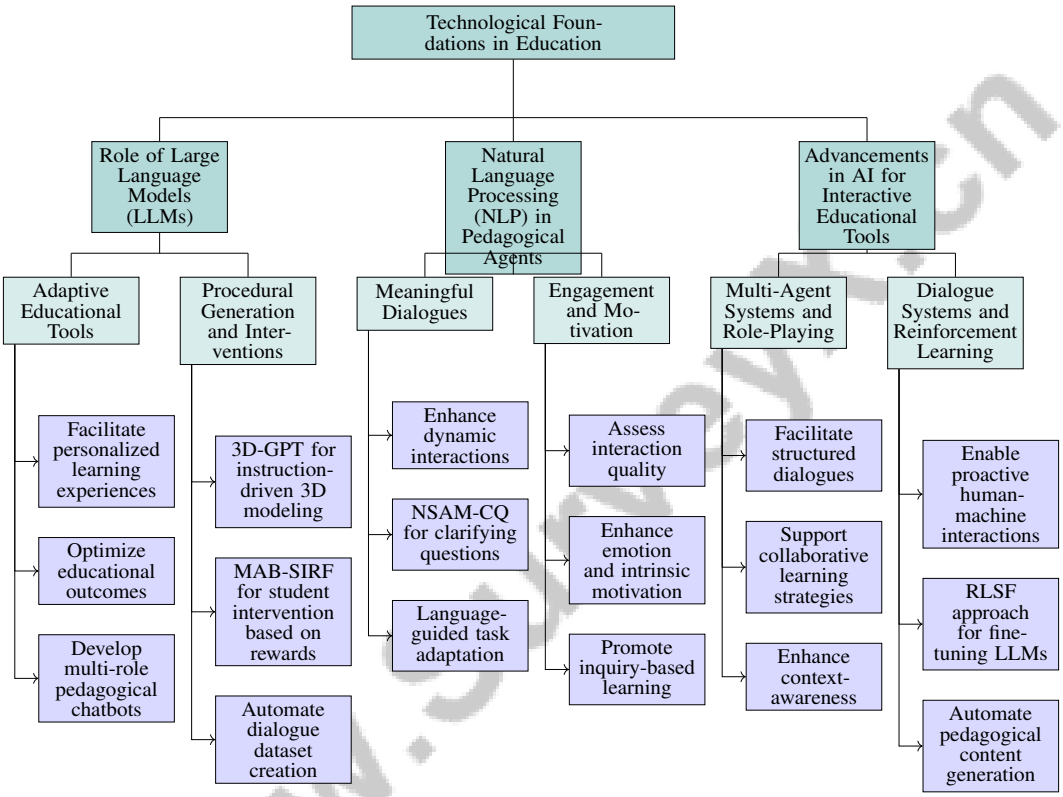

Figure 2: This figure illustrates the technological foundations in education, highlighting the roles of Large Language Models (LLMs), Natural Language Processing (NLP), and advancements in AI for interactive educational tools. It categorizes the contributions of these technologies into adaptive educational tools, procedural generation, meaningful dialogues, engagement and motivation, multi-agent systems, and dialogue systems, emphasizing their impact on personalized and engaging learning experiences.

3 Technological Foundations

3.1 Role of Large Language Models (LLMs) in Education

Large Language Models (LLMs) are instrumental in creating adaptive educational tools that facilitate personalized and contextually relevant learning experiences, thus optimizing educational outcomes. By integrating LLMs, educational systems can develop multi-role pedagogical chatbots that cater to diverse learner needs, exemplified by frameworks like the Subgoal Discovery Network (SDN), which decompose complex tasks into manageable subgoals [7, 32]. In multi-agent systems, LLMs enhance collaborative learning strategies and facilitate autonomous task-solving through role-playing methodologies [1]. Techniques such as Grounded Decoding further align educational tools with real-world contexts by integrating semantic reasoning with physical grounding [16].

As shown in Figure 3, this figure illustrates the role of Large Language Models (LLMs) in education, highlighting their use in adaptive educational tools, procedural generation tasks, and AI integration within educational frameworks. Each category showcases specific methods and frameworks, such as Subgoal Discovery, 3D-GPT Modeling, and Multi-role Chatbots, demonstrating the diverse applications and innovations enabled by LLMs in enhancing learning experiences. LLMs also support procedural generation tasks, as demonstrated by the 3D-GPT method, which enables instruction-driven 3D modeling by breaking down tasks into procedural steps [33]. Additionally, the Multi-Armed Bandit Student Intervention Recommendation Framework (MAB-SIRF) exemplifies LLMs' role in tailoring interventions to individual student needs based on cumulative rewards, thereby improving learning outcomes [30]. LLMs automate dialogue dataset creation, crucial for enhancing educational interactions' diversity and quality, and generate cues for teaching divergent question-asking, promoting critical thinking and engagement [12].

The integration of AI technologies, such as multi-role chatbots and collaborative AI systems, marks a significant advancement in educational frameworks, equipping students with essential skills for future challenges. Multi-role chatbots in computer science education, for example, serve functions like instruction, peer support, and career advising, promoting inquiry-based learning. Collaborative Learning with AI Speakers (CLAIS) fosters environments where human and AI participants work together, reshaping pedagogical knowledge and practices [10, 34, 19].

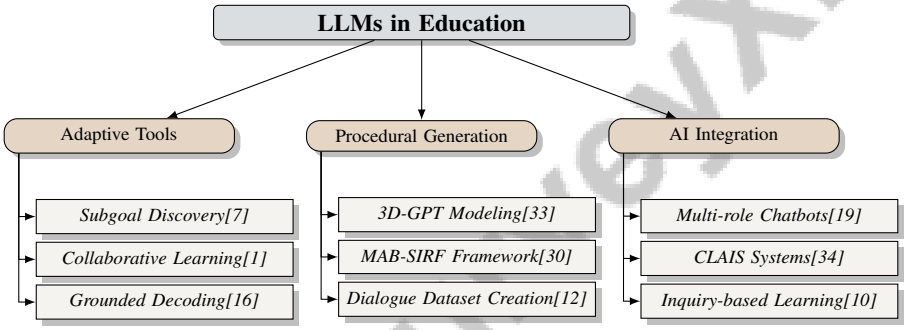

Figure 3: This figure illustrates the role of Large Language Models (LLMs) in education, highlighting their use in adaptive educational tools, procedural generation tasks, and AI integration within educational frameworks. Each category showcases specific methods and frameworks, such as Subgoal Discovery, 3D-GPT Modeling, and Multi-role Chatbots, demonstrating the diverse applications and innovations enabled by LLMs in enhancing learning experiences.

3.2 Natural Language Processing (NLP) in Pedagogical Agents

Method Name	Interactive Capabilities	Task Adaptation	Educational Enhancement
CN[18]	Meaningful Dialogues	New Tasks	Improving Educational Experiences
NSAM-CQ[35]	Clarifying Dialogs Only	Learn And Adapt	Improve User Satisfaction
MRL[19]	Facilitate Interaction Quality	Learn And Adapt	Improve Student Engagement

Table 1: Comparison of NLP Methods in Pedagogical Agents: This table outlines the interactive capabilities, task adaptation, and educational enhancement features of various NLP methods used in pedagogical agents. The methods include CN, NSAM-CQ, and MRL, each contributing uniquely to improving educational experiences through enhanced dialogue and adaptability.

Natural Language Processing (NLP) is crucial for enabling pedagogical agents to conduct meaningful dialogues and deliver tailored educational experiences. By processing linguistic input, NLP enhances dynamic interactions that deepen students' subject comprehension [18]. Sophisticated models, such as the Neural Self-Attentive Model for Clarifying Questions (NSAM-CQ), determine when to ask clarifying questions, thus maintaining conversational flow and ensuring learners receive accurate information [35].

NLP also facilitates agents' learning and adaptation to new tasks through language-guided task adaptation, as demonstrated by the LARVA method, which utilizes linguistic descriptions to comprehend task differences [11, 36]. In educational contexts, NLP techniques assess interaction quality and enhance chatbot functionality, fostering engaging, contextually relevant conversations [19]. Systems

like UKP-ATHENA and BLAB illustrate NLP's role in processing user queries and generating dynamic responses, enhancing the educational experience [20, 37].

Furthermore, insights from the language game paradigm and multi-agent reinforcement learning (MARL) can lead to breakthroughs in understanding language emergence, essential for refining pedagogical agents' functionality [38]. Research indicates that NLP can enhance emotion and intrinsic motivation in learners, improving educational engagement [28]. Thus, NLP is integral to developing pedagogical agents, providing the linguistic capabilities necessary for effective communication, task adaptation, and interactive learning experiences. AI-powered, multi-role chatbots enhance educational agents' functionality, promoting active participation and motivation through inquiry-based learning approaches [19, 18]. Table 1 provides a comparative analysis of different NLP methods employed in pedagogical agents, highlighting their interactive capabilities, task adaptation, and contributions to educational enhancement.

3.3 Advancements in AI for Interactive Educational Tools

Recent advancements in AI have significantly enhanced educational tools' effectiveness, fostering dynamic and interactive learning environments. Integrating large language models (LLMs) with multi-agent systems, as exemplified by the 3D-GPT method, facilitates complex, multi-step educational tasks and enriches the learning experience [33]. The Subgoal Discovery Network (SDN) method improves dialogue policy learning efficiency by automatically discovering subgoals, crucial for managing complex interactions and providing structured pathways for learners [32].

In multi-agent systems, role-playing frameworks enhance educational tools' effectiveness by facilitating structured dialogues among agents, supporting collaborative learning strategies [1]. AI advancements, such as dynamic memory updates, enhance context-awareness and long-term memory, sustaining contextual continuity during interactions and significantly enhancing learner engagement. Applications like Curiosity Notebook utilize conversational agents to facilitate a 'learning-by-teaching' approach, while AI-powered chatbots fulfill multiple roles, catering to learners' psychological needs and fostering inquiry-based learning [12, 10, 18, 19].

The emergence of advanced dialogue systems utilizing decentralized learning illustrates AI's transformative potential in enabling proactive human-machine interactions. Systems developed in the DuConv dataset allow conversational agents to initiate discussions and maintain engagement, moving beyond passive response patterns. Innovations like the Dynamic Knowledge Routing Network enhance conversation smoothness and relevance, while frameworks like Machines Talking To Machines (M2M) facilitate rapid development of goal-oriented dialogue agents [15, 39, 26, 40]. These systems enhance educational tools' interactivity, creating more engaging learning environments.

Advancements in reinforcement learning methods, such as the RLSF approach, demonstrate significant improvements in fine-tuning LLMs, highlighting AI technologies' transformative potential in enhancing educational experiences by personalizing learning content [10, 19, 12]. Integrating AI-powered multi-role chatbots in computer science education has improved learner engagement by addressing psychological needs through roles such as instructor, peer support, and emotional support. Using LLMs to automate pedagogical content generation has proven effective in training children's curiosity-driven question-asking skills, fostering deeper inquiry and learning. Innovative frameworks for generating high-quality question-answer pairs from real-world examination data exemplify AI's role in streamlining educational content creation [19, 30, 8, 41, 12].

These advancements contribute to a more engaging, efficient, and personalized learning experience, paving the way for future innovations in AI-enhanced education. By harnessing advanced technologies such as AI-powered multi-role chatbots, large language models, and reinforcement learning algorithms, educational tools effectively address learners' varied needs, promoting an engaging and supportive learning environment that encourages exploration, inquiry, and the development of critical skills such as curiosity-driven question asking.

4 Applications in Education

The integration of advanced technologies in education has significantly transformed traditional pedagogical approaches, leading to innovative strategies that enhance learning experiences. Central to this transformation are pedagogical agents, which facilitate personalized learning tailored to

diverse learner needs. This section explores how these agents contribute to personalized educational experiences and their impact on educational outcomes.

4.1 Facilitating Personalized Learning Experiences

Pedagogical agents are pivotal in crafting tailored educational experiences that optimize learning outcomes through advanced AI methodologies. For instance, the Kids Ask method aligns cues with children's interests, enabling targeted interactions [12]. Dialogue agents further personalize learning by integrating emotional context into interactions, enhancing engagement [4]. Neeko exemplifies this by allowing user interaction with multiple characters, fostering dynamic learning pathways [2].

These agents employ reinforcement learning to provide personalized intervention recommendations, adapting to individual student needs and curiosity traits, thus optimizing support based on real-time performance assessments [7, 30, 14, 8, 18]. They also leverage sequential learning frameworks, using past experiences to inform new tasks, as seen in technologies like ArguMentor, which promotes critical thinking through diverse perspectives [10, 30, 21]. These strategies highlight the importance of adapting educational content to learners' contexts, supporting continuous and personalized development.

Research shows that pedagogical agents enhance personalized learning by fostering diverse questioning strategies, promoting divergent-thinking questions linked to increased curiosity and deeper reasoning. Studies are exploring the integration of emotional recognition to optimize agent effectiveness across varied learner populations [6, 8].

As illustrated in Figure 4, the categorization of personalized learning strategies facilitated by pedagogical agents underscores the interplay of AI methodologies, learning strategies, and enhancement techniques. This visual representation further emphasizes the complexity and multifaceted nature of personalized learning experiences.

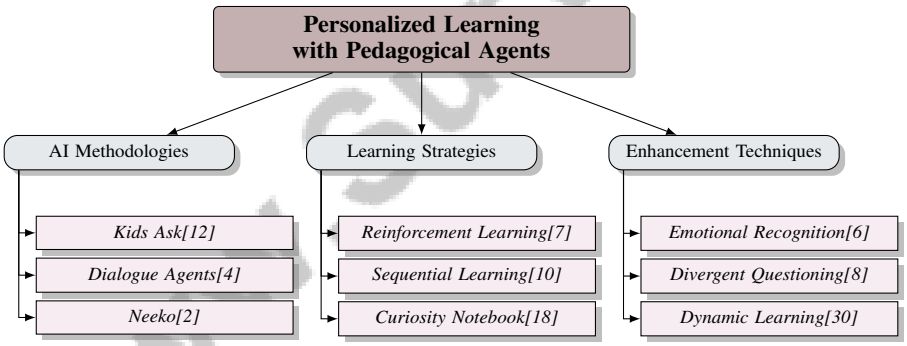

Figure 4: This figure illustrates the categorization of personalized learning strategies facilitated by pedagogical agents, highlighting AI methodologies, learning strategies, and enhancement techniques.

4.2 Enhancing Instructional Methods

Pedagogical agents enhance instructional methods by leveraging AI to provide personalized academic support and foster engaging learning environments. The multi-role chatbot method facilitates dynamic interactions tailored to individual instructional needs [19]. This approach allows agents to adopt various roles, enriching the learning experience with diverse perspectives and strategies.

Using advanced NLP techniques, these agents deliver contextually relevant feedback, enabling educators to tailor instruction to students' specific needs. This integration encourages students to ask complex, divergent-thinking questions, fostering curiosity and creating interactive learning environments [18, 8]. The enhancement of instructional effectiveness promotes active learning through meaningful dialogues and exploration of complex concepts.

Pedagogical agents also improve innovative teaching methodologies, such as flipped classrooms and collaborative learning frameworks, by offering personalized real-time support and feedback. This assistance fosters deeper engagement and critical thinking, encouraging students to ask complex

questions and enriching their learning experience [7, 14, 8, 6, 18]. By supporting these methodologies, pedagogical agents transform educational practices and enhance student outcomes.

The integration of pedagogical agents marks a transformative shift in educational technology, enhancing student engagement and learning outcomes through personalized interactions. Research indicates that these agents effectively encourage students to ask complex, divergent-thinking questions, stimulating curiosity and deeper reasoning. By tailoring approaches to individual learning styles, pedagogical agents create adaptive environments that significantly enhance teaching and learning processes [8, 7].

4.3 Improving Student Engagement and Comprehension

Pedagogical agents enhance student engagement and comprehension by fostering interactive and supportive learning environments. Utilizing advanced AI technologies, these agents create dynamic interactions that captivate learners and facilitate deeper content understanding. Positive instructor perceptions correlate with increased engagement, underscoring the importance of maintaining a positive interaction style [3]. By embodying these traits, pedagogical agents can significantly boost student engagement.

Integrating conversational agents into educational platforms provides real-time feedback and adaptive learning paths, crucial for maintaining student interest and promoting active participation. These agents analyze student responses and adjust instructional strategies to align with individual learning needs, enhancing comprehension and retention. Through tailored interactions, pedagogical agents cater to diverse learning styles, fostering deeper question-asking and curiosity. They effectively encourage students to formulate divergent-thinking questions, linked to greater academic success and intrinsic motivation [14, 8].

The ability of pedagogical agents to engage in meaningful dialogues enhances students' curiosity and question-asking skills, essential for deep learning. Research shows that these agents promote divergent-thinking questions, improving academic engagement and intrinsic motivation. Furthermore, agent enthusiasm positively influences students' emotional states, amplifying the learning experience [14, 28, 8, 18]. By creating supportive and interactive environments, these agents encourage exploration and critical thinking, ultimately leading to improved educational outcomes.

4.4 Dynamic Conversations and Social Interaction

Pedagogical agents utilize dynamic conversations to facilitate learning and enhance social interaction, creating engaging educational experiences that promote student involvement and comprehension. These agents employ advanced dialogue systems to manage interactions, incorporating understanding and generation of referring expressions, fostering meaningful exchanges and deeper content understanding [42].

Feature-oriented workflows, like the Awesum model, enhance learning by providing interactive visualizations that facilitate prompt evaluation and refinement. This capability allows learners to engage with educational material interactively, promoting critical thinking and active participation [9]. By enabling dynamic interactions with content, pedagogical agents support the development of social interaction skills and collaborative learning strategies.

Pedagogical agents' ability to adapt conversations based on real-time engagement assessments ensures interactions remain relevant and effective. Customizing dialogues to meet individual needs fosters personalized learning pathways, promoting curiosity-driven exploration and improving educational outcomes. This approach encourages deeper question-asking skills, particularly divergent-thinking questions associated with enhanced curiosity, while utilizing advanced NLP techniques to optimize content [31, 14, 8, 18, 12].

Dynamic conversations facilitated by pedagogical agents are essential for enhancing learning and social interaction. These agents emulate human teachers by providing instructional support and engaging students in the 'learning-by-teaching' paradigm, where they actively contribute to their learning process. Applications like Curiosity Notebook leverage conversational interventions to deepen student engagement with educational content. Research indicates that pedagogical agents effectively encourage students to ask complex, divergent-thinking questions, fostering curiosity and enhancing question-asking fluency. By personalizing interactions according to individual curiosity

traits, these agents equip learners to engage collaboratively and meaningfully with educational material [18, 8].

5 Challenges and Limitations

5.1 Technical and Computational Challenges

Integrating pedagogical agents into educational settings presents several technical and computational hurdles that impede their optimal functionality. A significant issue is conversation deviation and role confusion, necessitating robust dialogue management mechanisms [1]. Systems like Neeko, which rely on profile-based role embeddings, often suffer from imprecise role representations, leading to accumulated errors that reduce agent efficacy [2].

The inefficiency of algorithms when handling large datasets poses another challenge, increasing computation time and resource demands [5]. This inefficiency complicates human integration in the learning process and challenges the scalability of pedagogical agents. Moreover, the lack of real-time feedback for children's question formulations limits immediate corrective opportunities [12].

Benchmarks often overlook the emotional intensity of topics, affecting user engagement and sentiment [4]. This oversight complicates the development of agents capable of managing emotional expressions, impacting learning outcomes such as retention and performance [3]. Additionally, procedural content generation faces challenges like curve control and shading design, which hinder the creation of sophisticated educational tools. The complexity of interactions between users and digital agents, influenced by various social and cognitive processes, further complicates effective implementation, as traditional interaction models often fail to capture these nuances [7].

Addressing these challenges is crucial for enhancing pedagogical agents' support in diverse learning environments. Research highlights the role of these agents in promoting inquiry-based learning and fostering curiosity, with multi-role AI chatbots showing promise in meeting varied learner needs through personalized interventions [19, 8].

5.2 User Engagement and Interaction Limitations

Despite the potential of pedagogical agents to enhance educational experiences, they face limitations in user engagement and interaction that can compromise their effectiveness. A significant issue is AI-generated content bias, as seen in the ArguMentor system, which may produce responses inconsistent with expert human analysis, affecting educational quality and user trust [21].

Managing dynamic conversations in real-time is challenging, particularly as agents assume various roles—such as instructors, peers, and emotional supporters—while addressing learners' psychological needs. This complexity is compounded by the need to adapt to students' inputs and interventions, with advanced NLP techniques being employed to improve engagement and motivation [12, 10, 18, 19]. Agents must balance coherent dialogue maintenance with adapting to diverse user inputs and emotional cues. Misinterpretation of user emotions can lead to misunderstandings and reduced engagement, especially when agents fail to meet user expectations or learning goals.

The agents' limited capacity to provide real-time personalized feedback can hinder their support for individual learning needs. While they aim to deliver personalized experiences, their impact is often diminished by the lack of immediate feedback, particularly in complex problem-solving scenarios. Research shows that agents can enhance students' question-asking skills, promoting divergent-thinking questions that foster deeper reasoning and curiosity. However, without timely feedback, their potential to significantly influence student learning is constrained, especially given the superficial nature of question-asking in traditional classrooms. Immediate feedback mechanisms are essential to better support diverse learners and foster engagement in critical thinking tasks [14, 8].

Sustaining user engagement over time is further challenged by agents' reliance on pre-defined interaction scripts, which often fail to accommodate the dynamic nature of human communication. This limitation is evident in dialogue agents for older adults, where engagement varies with topic complexity and intimacy. Increased verbosity and self-disclosure occur with more challenging topics, suggesting that a flexible, context-aware approach could enhance user experience. Systems like ArguMentor highlight the importance of incorporating diverse perspectives and interactive features to foster deeper engagement and critical thinking, emphasizing the need for dialogue systems that adapt

to human conversation fluidity [4, 21]. This rigidity can result in mechanical or repetitive interactions, diminishing the perceived value of agents and reducing user motivation to engage with educational content.

Addressing these limitations requires ongoing research and development to enhance the adaptability, emotional intelligence, and personalization capabilities of pedagogical agents. By improving features such as role diversity in AI chatbots, as demonstrated in studies on multi-role pedagogical agents, educational technologies can better cater to varied learner needs. These advancements support inquiry-based learning and foster motivation through tailored interactions, such as those provided by Instructor, Peer, Career Advising, and Emotional Supporter Bots, enhancing engagement across different educational settings, including computer-based and VR environments. Utilizing NLP techniques for automating pedagogical content creation can streamline training programs that enhance students' curiosity-driven questioning skills. Collectively, these innovations contribute to more effective and engaging educational experiences that accommodate diverse learning environments [43, 19, 12].

5.3 Generalization and Applicability Issues

Pedagogical agents face significant challenges in generalization and applicability across diverse contexts. A critical issue is the portrayal of conversational agents, which may exhibit gender biases affecting user behavior and perceptions [44]. This bias impacts acceptance and effectiveness, necessitating strategies for equitable representation and interaction.

The complexity of robotic agents compared to virtual agents introduces challenges related to cost and accessibility, affecting their educational applicability [41]. Scalable solutions balancing technological sophistication with practical implementation constraints are needed.

The emergence of natural language in multi-agent cooperation presents challenges in maintaining consistency and interpretability across diverse tasks and environments [45]. Developing robust frameworks is essential for reliable agent interactions in varied educational scenarios.

Research often focuses on specific data types or models, limiting the generalizability of findings and the applicability of XAI methods across different domains [46]. Broader studies encompassing diverse datasets and models are needed to enhance the general applicability of pedagogical agents.

Reliance on specific datasets restricts conversational models' robustness across varied contexts [29]. Further exploration is required to develop adaptive models capable of handling diverse interaction scenarios effectively.

The simplified action space in current implementations may not generalize to complex real-world tasks without adaptation [47]. Sophisticated models accommodating real-world educational environment intricacies are necessary.

Specific domain applications, such as reinforcement learning symbolic frameworks, may not universally enhance general reasoning capabilities across tasks [48]. Versatile approaches applicable across a wide range of educational contexts are needed.

Small sample sizes and short-term focus in some studies limit findings' generalizability, emphasizing the need for comprehensive research considering long-term effects and diverse populations [43]. Addressing these challenges is essential for advancing pedagogical agents' development and application, ensuring effective support for diverse educational needs.

5.4 Resource and Accessibility Constraints

Deploying pedagogical agents, particularly multi-role chatbots, in educational contexts is often constrained by resource and accessibility limitations, impacting scalability and effectiveness across diverse settings. Implementing multi-role chatbots requires substantial computational resources and infrastructure, which may not be available in all educational institutions, posing a barrier to widespread adoption in under-resourced or rural areas [19].

Ethical considerations surrounding large language models (LLMs) and their frameworks complicate accessibility. Frameworks enabling agents to write and execute code introduce safety concerns, necessitating controlled evaluation environments to mitigate risks [27]. These safety measures can increase deployment complexity and cost, restricting access to advanced educational tools.

The need for controlled environments and robust infrastructure underscores the disparity in access to cutting-edge educational technologies, emphasizing the importance of scalable solutions adaptable to various resource levels. To integrate pedagogical agents into diverse contexts and ensure equitable access to innovative learning experiences, addressing constraints related to classroom question-asking practices is crucial. Research indicates children struggle to formulate deeper, meaningful questions. Leveraging advancements in NLP and personalizing interventions based on individual curiosity traits can enhance engagement and foster skills like divergent thinking, ultimately improving the educational experience [14, 12, 8].

6 Future Directions

The evolution of pedagogical agents in educational technology is set to significantly enhance interaction and emotional intelligence, crucial for creating engaging learning experiences. This section explores specific advancements poised to transform pedagogical practices and learner engagement.

6.1 Enhancements in Interaction and Emotional Intelligence

Future developments in pedagogical agents aim to refine interaction capabilities and emotional intelligence, crucial for effective educational contexts. Enhancing chatbot interactions and expanding roles to improve emotional intelligence are priorities [19]. Integrating complex actions and larger vocabularies will improve communication strategies, facilitating more human-like interactions and better learning outcomes [15].

Research will focus on enhancing automatic curricula and agents' perceptual capabilities, vital for interpreting learners' emotional cues and personalizing educational experiences [22]. Real-time feedback and studies on long-term effects on children's curiosity will be pivotal [12]. Additionally, understanding the impact of emotional tone across educational contexts will guide the design of emotionally responsive agents [3].

Improving NLP modules in platforms like BLAB will enhance user engagement and information access, supporting nuanced educational interactions [37].

6.2 Diversity and Inclusivity in Educational Contexts

Diversity and inclusivity are fundamental in designing pedagogical agents to ensure accessibility and effectiveness across varied learner demographics. Research should address gender biases in conversational agents to promote gender equality and minimize design biases [44]. Inclusive pedagogical agents must consider cultural, linguistic, and socioeconomic factors, integrating diverse perspectives to accommodate varied learner needs.

Research highlights the significance of emotional design in multimodal affective pedagogical agents, enhancing learning outcomes across populations [41, 6, 19]. Inclusive design principles can mitigate bias, fostering curiosity-driven question-asking and tailoring interventions for diverse learners [14, 12, 8]. This approach ensures educational technologies contribute to social equity and quality education access.

6.3 Innovations in Learning and Adaptation

Innovations in learning and adaptation are crucial for advancing pedagogical agents' capabilities, focusing on personalized educational experiences. Integrating multiple chatbot roles can enhance motivation and performance by addressing psychological needs [19]. Improving communication protocols will enhance adaptability, allowing agents to better understand human behaviors [49].

Proactive dialogue systems represent a promising innovation area, enhancing adaptability and engagement by anticipating learner needs [40]. Developing a task curriculum that encourages a generalized action set is essential for versatile pedagogical agents [27].

Refining experimental setups to mimic human language emergence conditions will lead to significant learning process innovations [38]. Applying collaborative learning frameworks like CLAIS to various contexts can enhance AI-driven tools' adaptability [34].

Exploring reinforcement learning techniques such as RLSF offers avenues for enhancing adaptive capabilities in reasoning tasks [48]. Improving dynamic knowledge routing networks' adaptability can indicate potential learning innovations [26].

Future work will focus on enhancing action space for better generalization and testing frameworks in real-world settings [47]. Integrating variable-size inputs and applying Graph Neural Networks may further enhance capabilities [23]. Refining prompting strategies for LLMs and expanding validation studies will enhance effectiveness and safety [50]. Exploring alternative learning methods to enhance frameworks like AutoFlow indicates potential innovations in adaptive capabilities [51].

7 Conclusion

This survey has delved into the profound influence of AI technologies, focusing on pedagogical agents within modern educational settings. By integrating large language models (LLMs) and natural language processing (NLP), these agents significantly enhance personalized learning, refine instructional strategies, and elevate student engagement through dynamic interactions. AI-driven methodologies enable the customization of educational experiences to align with individual learner requirements, thereby optimizing educational outcomes.

The research underscores the critical role of multidisciplinary collaboration in the creation and deployment of pedagogical agents, essential for adapting to new technologies and addressing challenges faced by individual researchers. Incorporating human-in-the-loop methods alongside advanced reinforcement learning techniques can notably enhance the efficacy and adaptability of dialog management systems, which are crucial elements of pedagogical agents.

Ongoing advancements in user-centered explainable AI (XAI) are vital for improving user understanding and interaction with AI systems. A focus on user-centered design ensures that pedagogical agents remain accessible and effective across diverse educational contexts. Additionally, innovations such as GroupDebate highlight the potential of AI technologies to improve cognitive consistency and reasoning accuracy in educational applications.

The application of collaborative learning frameworks like CLAIS has shown substantial improvements in participants' Intelligent-Technological, Pedagogical, And Content Knowledge (I-TPACK), further demonstrating the positive impact of AI technologies on educational practices. Preliminary insights from studies on LLM-based chatbots emphasize the necessity for continued exploration and development in this field to fully harness the benefits of AI in education.

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