Stimulating Active Learning Through Learner-AI Interactions in Mixed Reality for Hybrid Intelligence

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Abstract

Generative artificial intelligence (AI) is transforming education by introducing both opportunities and challenges. As AI systems become more agentic, critical questions emerge regarding how educational institutions can prepare for and integrate these technologies to enhance learning and teaching in hybrid intelligence environments. This conceptual paper proposes a framework for designing and studying AI agents that stimulate active learning through learner-AI interactions. The framework is structured around three core components: human learning processes, AI learning processes, and a cross-learning loop that facilitates bidirectional interactions between learners and AI agents. To illustrate the framework's application, we present a case study involving learner-AI interactions in a mixed reality setting, highlighting how such interactions can promote active learning. Our findings provide a basis for understanding the integration of agentic AI in educational contexts and suggest directions for future research on hybrid intelligence.

Keywords

Emboded AI; Generative AI; Hybrid Intelligence; Higher Education [1]

1. Introduction

Over the past three years, rapid advancements in generative artificial intelligence (AI) have significantly reshaped educational practices and research. The increasing sophistication of AI systems, exemplified by advanced language models and interactive agents, has opened new avenues for enhancing teaching and learning [1, 2, 3]. As these systems transition toward more autonomous, or agentic, forms of operation, they raise important questions regarding the preparation of educational settings for their integration. This evolution calls for a reexamination of traditional pedagogical methods and highlights the potential of hybrid intelligence, in which human and machine capabilities work together to create more effective learning experiences.

The motivation for this conceptual paper arises from the need to address both the opportunities and challenges introduced by AI agents in educational contexts. On one hand, AI agents has the potential to support personalized and adaptive learning, enabling educators to move beyond traditional, one-size-fits-all approaches. On the other hand, integrating such technology into classrooms raises critical concerns about the design of learner-AI interactions, the reliability of AI-driven feedback, and the overall impact on human learning processes. Existing research in cognitive development [4, 5] and intelligent tutoring systems [6, 7] provides a strong foundation for understanding human learning and the potential role of technology therein. However, the rapid pace of technological change necessitates a new conceptual framework that explicitly addresses the interplay between human cognition and AI capabilities in real-world educational settings.

Joint Proceedings of LAK 2025 Workshops, co-located with the 15th International Conference on Learning Analytics and Knowledge (LAK 2025), Dublin, Ireland, March 03–07, 2025.

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To address this need, we propose a framework designed to study and guide the design of AI agents that stimulate active learning through structured learner-AI interactions. This framework comprises three key components. First, it incorporates established theories of human learning, which emphasize the importance of interaction, feedback, and adaptive challenge. Second, it integrates principles from AI learning, particularly those emerging from recent advances in machine learning and natural language processing. Third, it emphasizes the cross-learning loop—a dynamic process in which both human learners and AI systems learn from and adjust to each other through ongoing interactions. By clearly delineating these components, our framework offers a systematic approach to understanding how AI agents can be harnessed to promote active learning and improve educational outcomes.

The need for such a framework becomes even more evident when considering the current shift toward immersive learning environments, such as mixed reality settings. These environments offer unique opportunities for learner-AI collaboration by providing realistic and engaging contexts in which learning occurs [8]. Yet, the integration of AI agents in these settings is still in its early stages, and there remains a significant gap in our understanding of how to effectively design and implement such systems. Our proposed framework addresses this gap by offering a structured method for analyzing the interactions between human learners and AI agents. This, in turn, lays the groundwork for future empirical studies aimed at validating and refining the framework in diverse contexts.

A case study presented in this paper further illustrates the application of the framework in a mixed reality environment. In this study, we examine how structured learner-AI interactions can facilitate active learning by creating a continuous feedback loop between the human learner and the AI system. The case study demonstrates that when AI agents are designed in accordance with the principles outlined in our framework, they not only enhance the learning process but also contribute to the development of hybrid intelligence. The findings provide empirical support for the framework and highlight the practical benefits of integrating agentic AI into educational practices. They also point to the broader implications for educational design, suggesting that future interventions should consider both the cognitive processes of learners and the adaptive capabilities of AI.

By presenting a detailed conceptual framework and supporting it with empirical evidence from a mixed reality case study, this paper contributes to the ongoing discussion about the role of advanced AI technologies in education. Our work offers practical guidelines for educators and researchers interested in the integration of agentic AI, while also setting the stage for further exploration of how these systems can be optimized to support active learning. In the sections that follow, we detail the theoretical underpinnings of the framework, describe the methodology of the case study, and discuss the implications of our findings for future research and practice in educational technology and learning sciences.

2. Research Background

2.1. Generative AI in Education

Generative artificial intelligence has emerged as a transformative technology in education, attracting considerable attention for its potential to enrich both learning and teaching practices. Early studies concentrated on the capabilities of AI systems to generate coherent text and creative content illustrating how models such as GPT-3 and GPT-4 can support creative and adaptive learning tasks [1], [9]. Subsequent research has examined the role of these systems in enhancing personalized learning, adaptive feedback, and scaffolding, drawing on foundations established by earlier studies in intelligent tutoring systems and computer-assisted instruction [6, 10].

Recent advancements have extended the application of generative AI beyond content creation to interactive learning environments. Scholars have explored the potential of these systems to serve as conversational agents that engage learners in meaningful dialogue, thus reinforcing active engagement and cognitive development. The integration of generative AI in educational contexts aligns with constructivist perspectives that emphasize learner autonomy and social interaction as key drivers of knowledge construction [5, 11]. In this light, AI-driven interactions are not merely about delivering information but are intended to foster reflective thinking and problem-solving through iterative dialogue and feedback.

Empirical investigations have highlighted the practical benefits of incorporating generative AI into learning activities. For instance, several studies have demonstrated that AI agents can offer real-time, contextually relevant responses [1]. These systems have been shown to tailor instructional support to individual needs, thereby promoting a more personalized learning experience. However, the literature also points to significant challenges, such as ensuring the accuracy and relevance of AI-generated content, addressing ethical concerns related to data privacy, and mitigating potential biases inherent in training datasets [12].

Despite these challenges, the body of research indicates that generative AI holds promise for transforming educational practices. Studies have underscored the importance of developing comprehensive frameworks that integrate technical, pedagogical, and ethical considerations to guide the deployment of AI in educational settings. This emerging literature provides a critical basis for understanding how learner-AI interactions can be structured to promote active learning and enhance educational outcomes. As the field continues to evolve, further research is needed to empirically validate these approaches and address the unresolved issues that accompany the use of generative AI in education.

2.2. Mixed Reality in Learning and Teaching

Virtual reality (VR) has long been recognized as a transformative technology in education, offering immersive environments that facilitate experiential learning and enhance spatial cognition. Early studies demonstrated that VR environments provide learners with opportunities to explore abstract concepts in simulated, risk-free settings [8]. Building on the insights gained from VR research, mixed reality (MR) has emerged as a complementary technology that combines digital content with the physical world, thereby offering unique advantages for education. While VR immerses learners in entirely virtual environments, MR allows for the overlay of interactive digital elements onto real-world settings, creating hybrid spaces that promote contextualized learning. Early investigations into MR have shown that this technology can enhance spatial understanding and support hands-on learning by enabling students to manipulate digital objects within their immediate physical environment [13]. These capabilities have proven particularly useful for visualizing complex concepts and fostering experiential learning that traditional classroom settings may not support.

Empirical studies have demonstrated that both VR and MR contribute to active and collaborative learning by encouraging real-time interactions among learners and instructors. Mixed reality, in particular, has been shown to facilitate adaptive learning experiences by tailoring instructional content to individual needs, a feature that aligns with constructivist theories emphasizing the importance of interaction and feedback in knowledge construction [11]. The integration of MR into educational practice has further extended the principles established by VR research, offering flexible environments where immersive digital elements enhance rather than replace the physical learning context.

3. LEAP Framework - Learning Enhancement through AI Partnership

This study adopts the design science paradigm common in Information Systems research, which treats the conceptual framework as an artifact designed to address specific challenges. Through a systematic review of related literature, theories and frameworks were selected based on their alignment with the design purpose of LEAP. These include the COPES model by Winne and Hadwin [4], Human-AI Shared Regulation of Learning model by Järvelä, Nguyen, and Hadwin [14], and learning analytics framework by Ifenthaler and Widanapathirana [15]. Figure 1 presents the LEAP framework for Learning Enhancement through AI Partnership, which is organized around four

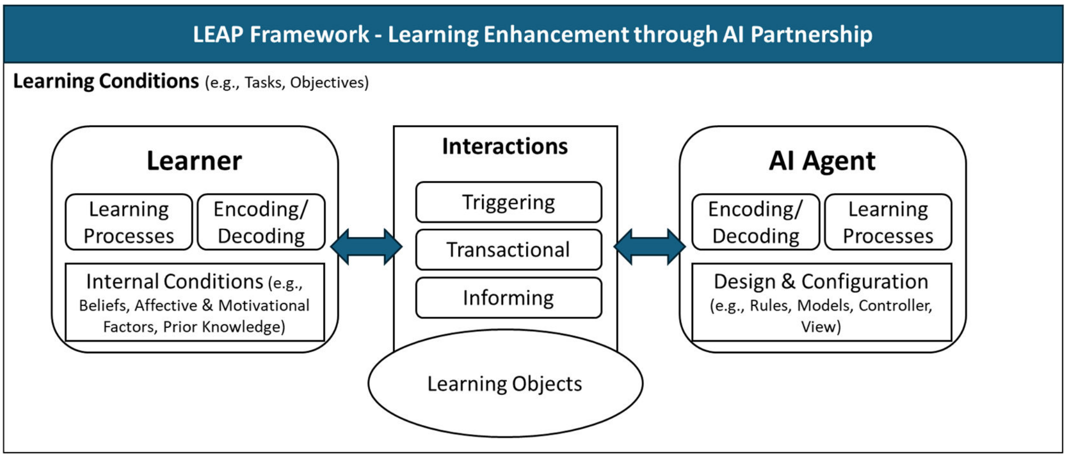

Figure 1: LEAP Framework - Learning Enhancement through AI Partnership

principal entities: Learning Conditions, Learner, AI Agent, and Interactions between the Learner and the AI Agent. Each of these entities plays a critical role in shaping the learning experience.

Learning Conditions refer to the foundational elements that shape the learning environment, including the design of learning tasks and the formulation of clear learning objectives. These conditions are pivotal, as they establish the context in which both human and AI learning processes operate. A well-designed set of learning conditions ensures that instructional goals are met and that the learning environment supports engagement and effective knowledge transfer.

Both the Learner and the AI Agent are characterized by shared components that reflect their roles in the learning process. Central to these components are the processes of encoding and decoding information. Encoding involves the deliberate presentation of information, while decoding pertains to the interpretation of the content received. For human learners, internal conditions such as cognitive capacity, prior knowledge, and metacognitive strategies regulate these processes. In contrast, the AI Agent's encoding and decoding are governed by its design and configuration, including algorithms, data inputs, and learning parameters. The recent advancements in reinforcement learning have enabled AI agents to dynamically adapt and learn from interactions, thus progressively enhancing their instructional capabilities.

The interactions between the Learner and the AI Agent are categorized into three distinct types: informing, transactional, and triggering interactions. Informing interactions represent one-directional communication where information is transmitted from the AI to the learner. Transactional interactions involve bi-directional communication that allows for feedback and clarification, promoting a dialogic exchange of ideas. Triggering interactions are specifically designed to initiate or reinforce learning processes, encouraging learners to reflect, question, and engage more deeply with the material. This categorization highlights the critical importance of interaction design in fostering active learning and adaptive support.

4. Illustrative Case Study – Kai

For illustration, Kai, the embodied generative AI agent, was designed as an expert on ethics in generative AI. Kai was developed to engage in real-time conversations with learners, thereby facilitating active learning around complex ethical issues in AI. As shown in Figure 2, Kai is integrated within a mixed reality learning environment alongside other learning objects. This setting not only enhances the visual and interactive appeal of the learning experience but also situates Kai within a context where digital and physical elements coexist to support learning.

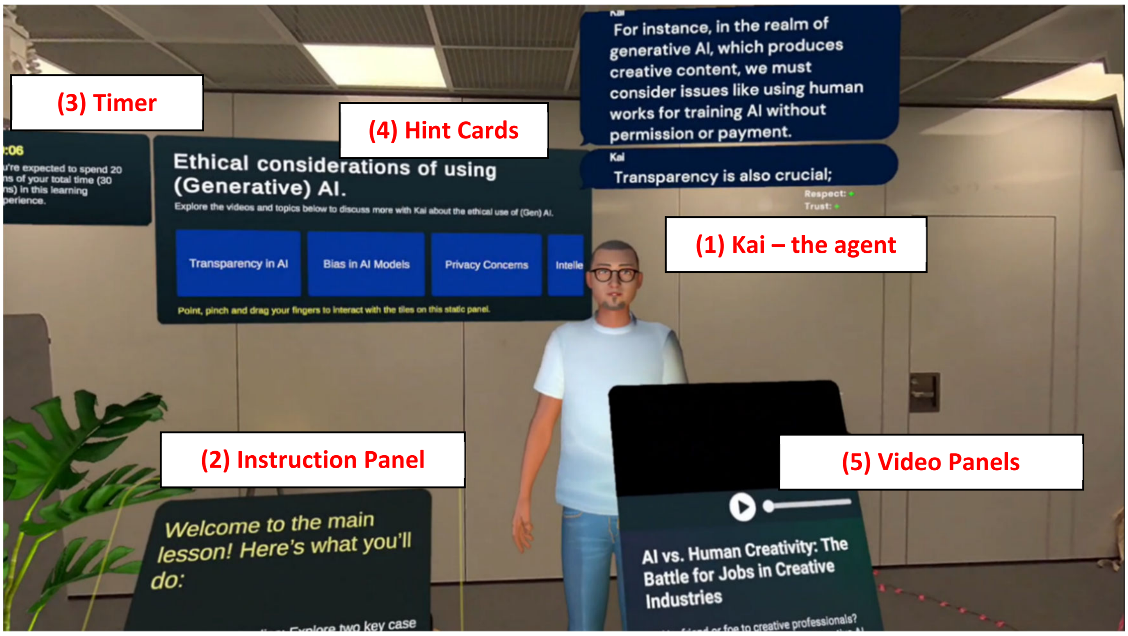

Figure 2: Kai - An Embodied Generative Artificial Intelligence (GenAI) in Mixed Reality for Stimulating Active Learning

Kai was engineered with a dual focus in line with the LEAP framework. First, as an expert on AI ethics, Kai is configured to provide clear and concise answers to learners' inquiries, ensuring that its responses are both accurate and accessible. Second, Kai is designed to facilitate transactional interactions by posing relevant follow-up questions that encourage learners to reflect on and discuss ethical considerations. This bi-directional communication is essential for creating a dynamic learning process where both the learner and the AI agent contribute to the conversation.

Preliminary findings from our pilot study indicate that participants who perceived Kai as more anthropomorphic and who experienced the conversation as natural reported higher levels of engagement. These results suggest that the human-like qualities of the AI agent, combined with the mixed reality environment, can significantly enhance the quality of learner-AI interactions. The design and configuration of Kai, therefore, not only demonstrates the practical application of the LEAP framework but also highlights the potential for embodied AI agents to transform educational experiences by promoting active and sustained learning.

5. Conclusion

The proposed LEAP framework provides a comprehensive structure that addresses both the pedagogical and technical dimensions of integrating AI in education. For researchers and learning scientists, the framework offers a clear set of components to consider when designing AI systems aimed at stimulating learning. For educational technology designers and computer scientists, it serves as a guideline for advancing AI development tailored for educational contexts. By outlining these key elements, LEAP bridges the gap between theoretical research and practical application, facilitating the study of human-AI interactions and promoting the design of educational systems.

Future research should focus on a comprehensive evaluation and refinement of the LEAP framework across a variety of learning contexts. Empirical studies conducted in diverse educational settings can provide insights into the framework's adaptability and effectiveness. By systematically applying and testing LEAP in different contexts, researchers can identify key factors that enhance learner-AI interactions and further optimize the design and configuration of AI agents to support active learning. Additionally, such investigations can inform modifications to the framework that address unique challenges and opportunities within specific learning environments, ultimately contributing to a more robust and generalizable model for integrating AI into education.

Acknowledgements

This research has been funded by the Research Council of Finland (formerly known as Academy of Finland) grant 350249 as well as Oulu University profiling project Profi7 Hybrid Intelligence 352788. The work was carried out with the support of LeaF Infrastructure, University of Oulu, Finland.

Declaration on Generative AI

During the preparation of this work, the author(s) used ChatGPT-4o in order to: Grammar and spelling check. After using these tool(s)/service(s), the author(s) reviewed and edited the content as needed and take(s) full responsibility for the publication's content.

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