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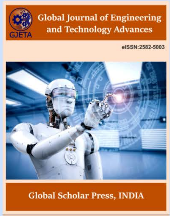

(Review Article)

Immersive reality and Artificial Intelligence: Transforming online learning through intelligent tutoring systems: A theoretical and methodological framework

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Abstract

Advances in immersive reality and artificial intelligence (AI) have opened new opportunities to transform online education. This article explores the integration of intelligent tutoring systems (ITS) and immersive technologies, particularly virtual reality (VR) and augmented reality (AR), in learning environments. The theoretical framework draws on concepts such as constructivism, cognitive load management, and collaborative learning to analyze the interactions between these technologies and their impacts on engagement and the personalization of educational pathways. A conceptual methodology based on Design-Based Research (DBR) is proposed, accompanied by a hypothetical scenario illustrating the use of VR and ITS in professional training. The article highlights the benefits, including improved practical skills and knowledge retention, while addressing challenges such as costs, technical complexity, and ethical issues. Finally, perspectives for future research and recommendations for equitable and sustainable adoption are discussed.

Keywords: Immersive Technologies; Intelligent Tutoring Systems; E-learning; Virtual Reality; Artificial Intelligence; Educational Technology

1. Introduction

The rise of immersive technologies and artificial intelligence (AI) has transformed educational methodologies. Intelligent Tutoring Systems (ITS) and immersive reality, particularly Virtual Reality (VR) and Augmented Reality (AR), offer innovative solutions to personalize learning pathways and enhance learner engagement. This article presents a theoretical and methodological exploration of the integration of these technologies into online educational environments.

2. Theoretical framework

2.1. Fundamental Definitions

2.1.1. Immersive Reality (VR/AR)

Immersive reality encompasses technologies such as Virtual Reality (VR) and Augmented Reality (AR), which immerse users in interactive and simulated environments. These environments recreate engaging experiences and promote active learning.

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These technologies are particularly effective in enhancing learner engagement, motivation, and knowledge retention. They also provide opportunities to explore otherwise inaccessible environments while fostering deeper empathy through immersive simulations [1].

In education, immersive reality is employed to simulate real or imagined contexts, enabling experiential learning and fostering the development of practical skills. These secure environments allow learners to practice, experiment, and gain insights without risk, thereby making educational experiences more enriching and accessible [2].

Building on these theoretical foundations, the proposed methodology demonstrates how immersive reality and ITS can be practically integrated into online learning.

2.2. Intelligent Tutoring Systems (ITS)

ITS are AI-based learning environments designed to deliver personalized instruction. Mousavinasab et al.[3] identify four key modules in an ITS: an expert knowledge module, a learner model, pedagogical strategies, and a user interface. These modules enable dynamic and personalized adaptation of educational content. These systems use advanced algorithms to analyze learners' performance and adjust educational materials accordingly.

Jdidou et al [4]emphasize that ITS can provide immediate feedback or recommend tailored resources, thus promoting efficient and individualized learning.

2.3. E-learning

E-learning refers to educational environments accessible through digital platforms. This learning mode offers increased flexibility and personalization, enabling students to take courses at their own pace and according to their preferences.

Chen et al. [5] highlight that AI-based tools facilitate the design of tailored curricula, improve knowledge retention, and address individual learner needs through adaptive systems.

In immersive environments, online learning is enriched by interactive experiences and simulations, which enhance learner engagement and strengthen active participation [6].

2.4. Links between Concepts

2.4.1. Introduction

The interactions between the three fundamental concepts immersive reality, Intelligent Tutoring Systems (ITS), and e-learning highlight their potential to transform educational environments when integrated cohesively.

2.4.2. Immersive Reality and E-Learning

Immersive reality enhances online learning by offering interactive experiences that stimulate engagement and cognitive immersion.

Lege et al. [7]explain that virtual reality provides learners with unique opportunities to interact with complex simulations, thereby improving their understanding and retention through experiential learning.

In online environments, this technology immerses learners in realistic scenarios, ranging from historical reenactments to laboratory simulations or professional training. Makransky et al. [8] also emphasize that immersive environments reduce the isolation often associated with online learning by strengthening virtual social presence.

2.4.3. Intelligent Tutoring Systems and E-Learning

ITS transform online learning by personalizing educational pathways and providing feedback tailored to learners' needs. Chen et al.[5] Explain that AI-driven ITS support adaptive instruction, enabling learners to receive personalized guidance based on their individual progress and challenges.

These systems integrate algorithms to monitor performance, predict needs, and recommend resources in real time. In the context of online learning, they address the lack of human supervision by providing automated yet personalized tracking [9].

2.4.4. Integration of ITS into Immersive Environments

The integration of Intelligent Tutoring Systems (ITS) into immersive environments opens new pedagogical possibilities. Estrada et al [2] explain that the synergy between ITS and immersive environments fosters a more engaging and contextualized learning experience, while enhancing practical skills and theoretical understanding.

In these environments, ITS can guide learners by adapting tasks based on their performance and providing interactive explanations in visual or auditory forms. For example, in an immersive laboratory simulation, an ITS can detect errors made by the learner and provide step-by-step guidance to correct them.

2.4.5. Synthesis of Interactions

The intersection of immersive reality, ITS, and e-learning represents a shift towards more interactive, personalized, and immersive educational environments. Research indicates that this combination:

- **Enhances engagement**: by combining the sensory stimulation of VR with the personalization of ITS [6].
- **Improves learning outcomes**: through real-time adaptive feedback and safe practical experiences [3].
- **Reduces inequalities**: by making complex training accessible to a broad and diverse audience [10].

2.5. Underlying Educational Theories

2.5.1. Introduction

Intelligent Tutoring Systems (ITS) and immersive environments rely on robust theoretical frameworks to structure and optimize learning experiences. This section explores the key educational theories that support their integration and use in e-learning contexts.

2.5.2. Constructivism and Active Learning

Constructivism, derived from the works of Piaget and Vygotsky, posits that learning is an active process in which learners build their own knowledge through experiences. Makransky et al. [8] argue that immersive learning environments align with the principles of constructivism by promoting active participation and personalized feedback.

Intelligent Tutoring Systems (ITS), particularly when integrated into immersive environments, apply this paradigm by offering interactive scenarios and adaptive feedback. These approaches encourage learners to actively engage in the educational process, thereby enhancing their engagement and understanding.

2.5.3. Experiential Learning

Learning is often more effective when it is based on concrete experiences followed by critical reflection. Immersive environments allow learners to directly interact with realistic situations, fostering rich experiential learning. For instance, in a VR laboratory simulation, learners can experiment with complex procedures while receiving interactive feedback from an Intelligent Tutoring System (ITS).

Estrada et al. [2] emphasize that experiential learning is amplified in immersive environments, where learners can safely experiment and reflect on their actions. These environments provide unique opportunities to practice, test ideas, and develop skills without risks, thereby enhancing understanding and knowledge retention.

2.5.4. Cognitive Load Theory

Managing cognitive load plays a central role in learning environments. ITS, through their personalization tools, optimize this management by tailoring content and instructions to the learner's skill level, making the educational experience more effective and engaging.

Korhonen et al. [10] explain that integrating AI into immersive environments optimizes cognitive load by dynamically adjusting tasks to learners' abilities. By combining Virtual Reality (VR) and ITS, educational systems structure information in a way that avoids cognitive overload while maintaining learners' interest and engagement.

2.5.5. Collaborative Learning and Social Presence

Collaborative learning is enhanced by immersive environments, which promote social presence and interactions among learners. Makransky et al. [8] introduce the Theory of Immersive Collaborative Learning (TICOL), highlighting the importance of social presence and body ownership in immersive contexts. According to them, these elements play a key role in enhancing both learner engagement and knowledge sharing.

2.5.6. Synthesis of Theoretical Contributions

These theories provide a solid framework for understanding and developing educational systems that integrate immersive reality and ITS. They demonstrate that:

- **Constructivism and experiential learning** support the concept of learning based on action and reflection.
- **Managing cognitive load** is essential to ensure an optimal educational experience.
- **Social interactions and collaboration** enhance engagement and knowledge retention in immersive environments.

2.6. Identified Benefits and Challenges

2.6.1. Introduction

The integration of immersive reality and Intelligent Tutoring Systems (ITS) into learning environments offers numerous benefits while also raising specific challenges. This section examines these aspects based on recent research.

2.6.2. Identified Benefits

Enhancing Engagement and Retention

Immersive environments significantly boost learner engagement by making educational content interactive and immersive. Marougkas et al. [6] note that immersion improves content retention and learner engagement, particularly when gamification is used as a personalization strategy.

By combining ITS with immersive reality, learners receive real-time personalized feedback, which enhances their motivation and understanding of concepts [2].

Personalized Learning

ITS enable the personalization of learning pathways based on learners' needs and performance. Bezanson et al. [9] highlight that AI-driven ITS provide tailored guidance, improving learning efficiency while addressing the diverse needs of learners.

In an immersive context, this personalization is amplified by the adaptability of scenarios, which dynamically adjust to learners' actions [8].

Development of Practical Skills

Immersive simulations allow learners to practice technical or behavioral skills in safe environments. For instance, in virtual reality training, learners can solve complex problems while receiving precise guidance from ITS [10].

2.6.3. Identified Challenges

High Costs and Accessibility

The deployment of immersive technologies and AI in educational contexts can be expensive, both in terms of acquiring equipment and maintaining systems. Mohammadrezaei et al. [11]highlight challenges associated with Extended Reality (XR), including the high costs of equipment, privacy concerns, and the lack of standardized guidelines.

This financial constraint often limits the adoption of such technologies in low-resource educational contexts.

Technical Complexity and Training

Implementing solutions that combine VR and ITS requires advanced technical skills for designing, integrating, and maintaining these systems. Additionally, teachers must be trained to effectively use these tools. Bezanson et al. [9] note that the lack of teacher training is a major obstacle to the effective implementation of immersive learning technologies.

Ethical and Privacy Concerns

The use of AI and immersive environments raises ethical challenges, particularly regarding data privacy and algorithmic bias. Dong et al. [12] emphasize issues such as privacy-preserving federated learning and the seamless integration of recommendation systems powered by large language models (LLMs) into AR/VR environments.

2.6.4. Synthesis

The benefits of integrating immersive reality and ITS into educational environments include enhanced personalization, improved knowledge retention, and the development of practical skills. However, their implementation requires overcoming technical, financial, and ethical challenges. These aspects must be addressed to ensure the successful and sustainable adoption of these technologies.

The theoretical principles discussed above lay the groundwork for innovative applications of immersive reality and ITS in education. These theoretical principles directly inform the proposed methodology, guiding the integration of immersive reality and ITS in practical applications.

3. Conceptual Methodology

3.1. Introduction

The proposed conceptual methodology aims to demonstrate how immersive reality technologies and Intelligent Tutoring Systems (ITS) can be integrated to enhance e-learning. The adopted approach is based on principles of iterative and collaborative research, tailored to dynamic digital environments.

3.2. Overall Methodological Approach

The proposed methodology is grounded in the framework of Design-Based Research (DBR), a methodological approach aimed at designing, testing, and refining educational solutions in real-world contexts. As highlighted by Estrada et al.[2], DBR provides an iterative cycle that involves analyzing problems, developing solutions, and validating their effectiveness through real-world testing.

This approach is particularly well-suited to emerging educational environments, as it promotes the integration of feedback from users (teachers and students) while adapting tools to identified needs [10].

3.2.1. DBR Steps for an Immersive System

Educational Context Analysis

- Identify the specific needs of learners and the educational objectives. For instance, a professional training program in VR might focus on mastering complex procedures or enhancing technical skills [13].

Initial Design

With the educational context thoroughly analyzed, the next step involves designing a prototype that addresses the identified needs and objectives. Develop a prototype of an immersive system integrating intelligent tutoring systems (ITS). This prototype includes modules such as a learner model to personalize learning paths and an immersive user interface [3].

Pilot Implementation

Test the system in a real or simulated educational environment. This involves evaluating learner engagement, pedagogical relevance, and system functionalities [9]. The findings from the pilot implementation inform the refinement process, ensuring the system evolves to meet user needs effectively.

Continuous Refinement

Collect qualitative and quantitative data from users. Feedback is used to adjust system components, such as optimizing adaptive algorithms or enriching immersive scenarios [10].

3.2.2. Advantages of DBR in This Context

- **Flexibility**: Facilitates the rapid adaptation of educational tools in response to user feedback, ensuring solutions remain dynamic and responsive to evolving needs [2].
- **Collaboration**: Promotes active collaboration among researchers, developers, and educators, fostering the co-creation of innovative and contextually relevant educational solutions [10].
- **Practical Outcomes:** Guarantees that the developed solutions are directly aligned with the needs of end-users and effectively applicable in real-world educational settings [13].

3.2.3. Structure and Modules of an Immersive ITS

Immersive ITS rely on four main modules:

- **Learner Model:** Analyzes learners' performance, preferences, and specific needs to deliver a personalized learning experience [3].
- **Pedagogical Model:** Designs educational strategies tailored to the content and learning context, ensuring instructional relevance and effectiveness [4].
- **Expert Model:** Integrates domain-specific expertise to provide accurate and guided learning pathways [3].
- **Immersive User Interface:** Employs immersive technologies, such as virtual and augmented reality, to create interactive, engaging, and impactful learning environments [2].

These modules operate synergistically, ensuring a seamless and personalized educational experience [3].

3.2.4. Hypothetical Case: Personalized Immersive Learning Scenario

A hypothetical scenario demonstrates the application of these modules, for instance:

- **Context**: Industrial maintenance training using virtual reality (VR).
- **Objective**: Train technicians to diagnose and repair complex equipment.
- **Scenario**: Learners are immersed in a virtual environment where they interact with simulated machinery.

Role of the Intelligent Tutoring System (ITS)

- Provide guided instructions for each step of the procedure.
- Analyze learners’ actions in real time.
- Adapt the difficulty levels dynamically based on their performance.

This scenario highlights how ITS and immersive reality technologies collaborate to enhance practical learning while ensuring a high level of personalization [10] .

3.2.5. Proposed Tools and Techniques

To implement this methodology, several tools and techniques are proposed:

Analytical Techniques

- Biometric Data Analysis: Using sensors to monitor cognitive load and learners' attention.
- Learning Analytics: Collecting and interpreting behavioral data to adjust learning pathways.

Adaptive Feedback

- Real-time feedback powered by machine learning algorithms.
- Interactive progress visualization to motivate learners.

AI Integration

- Voice recognition algorithms for natural interactions in VR environments.
- Bayesian networks to model learners’ knowledge and predict future needs.

These tools combine immersive technologies and personalization to address contemporary educational challenges [2], [12].

Addressing these challenges will not only overcome barriers but also unlock opportunities for future innovations, as discussed in the following perspectives.

3.2.6. Implications and Future Perspectives

Introduction

The integration of immersive reality and Intelligent Tutoring Systems (ITS) into educational environments opens new possibilities while raising significant implications. This section explores the potential contributions, challenges, and future directions for research and the implementation of these technologies.

3.2.7. Potential Contributions

Enhanced Personalization of Learning

ITS enables the real-time adaptation of educational pathways to meet learners' specific needs. This personalization, amplified by immersive reality, improves engagement and knowledge retention [9].

Broader Access to Complex Training

Immersive reality democratizes access to learning scenarios that would otherwise be expensive or hazardous to replicate in the real world. For instance, medical or industrial training can be simulated in VR at a lower cost [10].

Strengthening Practical and Emotional Skills

By simulating interactive and collaborative environments, these systems develop not only technical skills but also emotional and social competencies through immersive and contextual interactions [8].

3.2.8. Challenges and Limitations

Technological and Financial Constraints

The high costs of equipment (VR headsets, sensors) and the infrastructure required to integrate ITS may limit adoption, particularly in low-resource settings[11] .

Educator Training

Teachers need to be trained to leverage the capabilities of these technologies, which demands additional time and resources [9].

Ethical and Privacy Concerns

The use of AI in immersive environments raises issues related to data privacy and algorithmic bias. Solutions must adhere to high standards of security and ethics [12] .

3.2.9. Future Directions

Interdisciplinary Research

Collaboration between educational researchers, engineers, and AI experts is essential to overcome current limitations and develop innovative solutions.

Emerging Technologies

The integration of machine learning and extended reality (XR) with advanced emotional models opens new opportunities for even more immersive and personalized educational systems [14].

Accessibility and Equity

To ensure widespread adoption, it is crucial to develop more affordable and accessible solutions that are adaptable to diverse cultural contexts [11].

Synthesis

Intelligent Tutoring Systems (ITS) and immersive reality technologies represent a significant breakthrough in the field of education. However, their full potential can only be realized by addressing key technological, financial, and ethical challenges. Sustained, interdisciplinary research is essential to optimize their impact and ensure their sustainable integration into educational practices

4. Conclusion

This study emphasizes the potential of combining Intelligent Tutoring Systems (ITSs) with immersive reality to transform e-learning environments. These technologies, by integrating adaptive feedback and interactive simulations, address key challenges such as learner engagement and knowledge retention. Their application offers a promising avenue for creating more dynamic, personalized, and effective educational experiences.

However, challenges such as implementation costs, technical barriers, and ethical concerns must be addressed to fully realize their potential. Overcoming these obstacles will require interdisciplinary collaboration and continuous innovation.

Moving forward, my research will focus on two key areas. The first involves developing more accessible and cost-effective solutions for integrating ITSs and immersive environments into diverse educational settings. The second seeks to evaluate the long-term impact of these technologies on learner engagement, performance, and skill development. By pursuing these objectives, I aim to contribute to the advancement of educational technologies that are inclusive, effective, and adaptable to real-world needs.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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