

USE OF AR/VR TECHNOLOGIES AND LEARNING SIMULATIONS IN TEACHING GEOGRAPHY: MODERN APPROACH AND ANALYSIS OF PEDAGOGICAL EFFECTIVENESS

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Abstract:

In today's digital era, augmented reality (AR) and virtual reality (VR) technologies are increasingly emerging as innovative tools that increase the effectiveness of the educational process. This article analyzes the scientific and methodological foundations, possibilities, and experimental results of using AR and VR technologies and educational simulations in teaching geography. The study compares the analysis of theoretical sources and the results of practical experiments, revealing the positive impact of AR and VR technologies on students' spatial thinking, cognitive activity, and motivation. The results show that lessons organized based on AR and VR provide 20–25% higher learning outcomes compared to traditional methods.

Keywords: Augmented reality, virtual reality, geography education, educational simulation, digital pedagogy, spatial thinking.

Introduction

Over the past decade, the digital transformation of education has fundamentally reshaped pedagogical approaches and instructional practices. Geography, as a discipline, requires students to understand complex spatial phenomena, natural processes, and the interactions between physical and human systems, which have traditionally been taught through theoretical explanations and two-dimensional instructional materials. The emergence of Augmented Reality (AR) and Virtual Reality (VR) technologies has significantly expanded these possibilities by enabling immersive and interactive visualization of geographical phenomena, thereby promoting experiential learning and enhancing students' conceptual understanding [1]. Furthermore, empirical studies have demonstrated that AR- and VR-supported instruction increases students' motivation and engagement while strengthening the effectiveness of visual learning, one of the fundamental principles of contemporary education [2]. Despite these advantages, the successful integration of these technologies into school geography education remains constrained by several factors, including insufficient methodological support, limited teacher competencies, and inadequate technological infrastructure [3]. A comprehensive



evaluation of both the opportunities and limitations of AR and VR is therefore essential for improving instructional quality and achieving desired educational outcomes.

In recent years, AR and VR technologies have attracted growing attention in educational research. However, systematic investigations focusing specifically on their application in geography education, their pedagogical effectiveness, and the practical challenges associated with classroom implementation remain limited. Consequently, there is a need for evidence-based research that evaluates the educational value of immersive technologies and establishes methodological recommendations for their effective integration into geography instruction.

The present study aims to identify the pedagogical conditions that facilitate the effective implementation of AR and VR technologies in geography education and to examine their impact on students' academic achievement through an experimental research design. By providing empirical evidence on learning outcomes and instructional effectiveness, this study seeks to contribute to the development of innovative, technology-enhanced approaches to geography teaching and learning.

METHODOLOGY

This study employed a mixed-method research design combining a systematic literature review with a quasi-experimental approach. The research was conducted in two consecutive phases.

1. Theoretical phase. A systematic review of the literature was carried out using the Scopus, Web of Science, and ScienceDirect databases. Peer-reviewed articles published between 2015 and 2026 were identified through a structured search strategy using keywords related to geography education, augmented reality, virtual reality, and immersive learning. A total of 78 publications were initially retrieved. After applying predefined inclusion and exclusion criteria, 25 high-quality studies were selected for detailed analysis. Each article was critically examined, and the findings were compared, verified, and synthesized to establish the current state of research and identify existing knowledge gaps.

2. Experimental phase. To evaluate the educational effectiveness of AR and VR technologies in geography instruction, a quasi-experimental pre-test–post-test control group design was employed. Two parallel Grade 7 geography classes were assigned as the experimental group and the control group, with 25 students in each group.

Students in the experimental group received instruction supported by AR/VR technologies, whereas the control group was taught using conventional teaching methods. The intervention incorporated Google Earth VR, ArcGIS 360, and the Merge Cube augmented reality platform as instructional tools. The experimental lessons focused on the topics “Natural Zones” and “Lithosphere”, selected because they involve complex spatial concepts that can benefit from immersive visualization.

The effectiveness of the intervention was evaluated by comparing the pre-test and post-test results of both groups. Students' academic achievement was analyzed using an independent-samples t-test, while learning motivation was assessed through a five-point Likert-scale



questionnaire [4]. Statistical analyses were conducted to determine whether the observed differences between the experimental and control groups were statistically significant.

RESEARCH RESULTS

Results of the Literature Review. The systematic literature review identified three major pedagogical advantages of integrating Augmented Reality (AR) and Virtual Reality (VR) technologies into geography education.

First, enhanced visualization and interactivity enable students to better understand complex geographical phenomena through immersive three-dimensional representations. Second, experiential learning promotes the development of spatial thinking by allowing learners to observe, explore, and simulate geographical processes in virtual environments. Third, increased motivation and emotional engagement encourages active participation in the learning process, resulting in improved learning experiences and knowledge retention [1,5].

Nevertheless, the reviewed studies consistently highlight several challenges associated with the implementation of AR and VR in school education, including technological limitations, insufficient infrastructure, and the need for appropriate pedagogical adaptation and teacher training [3].

Regarding students' motivation and classroom engagement, previous studies indicate that lessons supported by AR/VR applications significantly increase students' interest and active participation. For example, Thompson (2024) reported that 85% of students evaluated their VR learning experience as either interesting or very interesting, while overall classroom engagement increased by approximately 40% compared with traditional instruction [6].

Results of the Experimental Study. The findings of the quasi-experimental study further confirmed the positive educational impact of immersive technologies. Students in the experimental group achieved a mean post-test score of 88.1 ± 5.2 , whereas the control group obtained an average score of 72.4 ± 4.3 . The difference between the two groups was statistically significant ($p < 0.01$), demonstrating that AR/VR-supported instruction substantially improved students' academic achievement.

The questionnaire results also revealed a high level of student satisfaction with immersive learning. Specifically, 91% of participants in the experimental group reported that AR/VR-based lessons helped them understand geographical concepts more effectively than conventional teaching methods. In addition, students demonstrated higher levels of classroom participation, learning motivation, and spatial reasoning skills throughout the intervention (Figure 1).



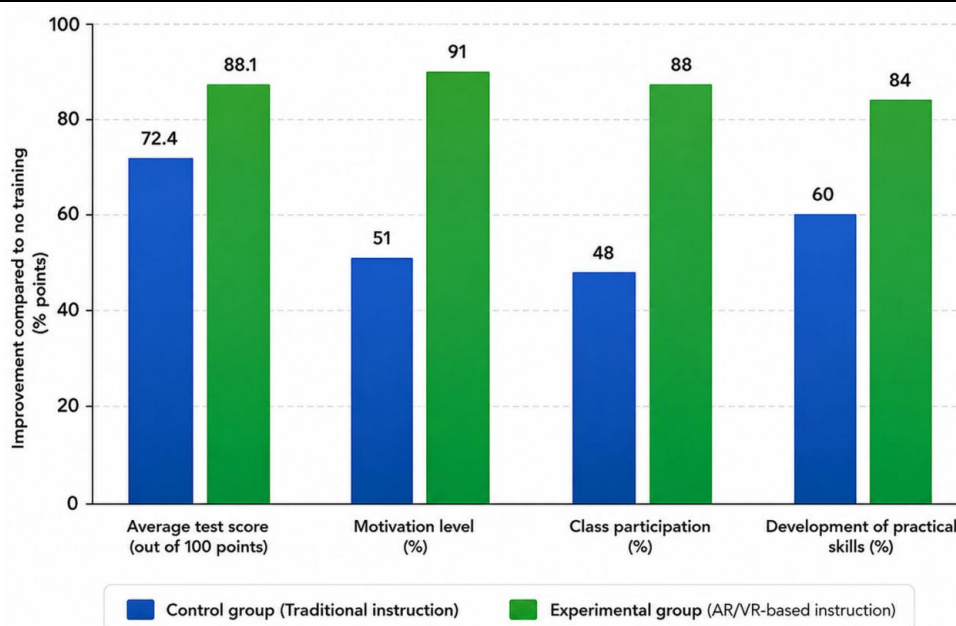


Figure 1. Comparison of the effectiveness of AR/VR-based instruction in geography education between the experimental and control groups.

Source: Compiled by the author based on the results of the experimental study.

DISCUSSION

The findings of this study demonstrate that Augmented Reality (AR) and Virtual Reality (VR) technologies provide substantial pedagogical benefits in geography education. These advantages are primarily associated with multisensory learning, immersive educational environments, and interactive learning experiences, all of which contribute to deeper conceptual understanding and greater student engagement. However, the results also indicate that the successful integration of AR and VR into school education depends on several critical factors.

First, technological infrastructure remains one of the major barriers to implementation. The high cost of VR headsets, compatible devices, and high-performance computers continues to limit the widespread adoption of immersive technologies, particularly in schools with limited financial resources.

Second, teacher preparedness plays a crucial role in the effective use of AR and VR. Previous research indicates that only approximately 30% of teachers possess sufficient knowledge and practical skills to integrate immersive technologies into their instructional practices effectively [7]. This finding highlights the need for continuous professional development and targeted teacher training programs.

Third, the quality and availability of educational content remain significant challenges. There is still a shortage of scientifically accurate, pedagogically sound, and curriculum-aligned AR/VR learning materials, particularly those adapted to local educational contexts and national



curricula [5]. Developing high-quality localized digital content is therefore essential for maximizing the educational potential of immersive technologies.

The present study also suggests that the effectiveness of AR and VR varies across different branches of geography. For example, immersive visualization appears to be particularly beneficial for physical geography, including topics such as landforms, geological processes, and climate systems, where complex spatial relationships can be represented more effectively in three-dimensional environments. In contrast, the educational benefits for human and economic geography may be comparatively less pronounced, although further empirical investigation is required.

Overall, the findings support previous studies demonstrating that AR and VR technologies enhance students' conceptual understanding and academic achievement [1,4]. By actively engaging learners in the construction of knowledge rather than passive information reception, immersive technologies align closely with the principles of constructivist learning theory, particularly the concept of learning through discovery, thereby fostering meaningful and student-centered learning experiences [2].

CONCLUSION

The findings of this study indicate that Augmented Reality (AR) and Virtual Reality (VR) technologies represent not merely supplementary instructional tools but transformative innovations capable of reshaping geography education. Their integration into the teaching process enhances students' spatial thinking, facilitates a deeper understanding of complex physical and human geographical phenomena, and promotes interdisciplinary learning. Consequently, the successful implementation of AR/VR-based instruction requires the development of dedicated educational modules, continuous professional development for teachers, and adequate technological infrastructure in both schools and higher education institutions.

The results further demonstrate that AR/VR technologies and educational simulations have considerable potential to improve the quality of geography education by fostering not only academic achievement but also inquiry-based learning, critical thinking, creativity, and problem-solving skills. However, to ensure their effective and sustainable integration into educational practice, several measures should be considered. These include:

- 1- developing affordable VR solutions suitable for school environments;
- 2- establishing specialized professional training programs to improve teachers' digital competencies;
- 3- creating collaborative frameworks for the development, localization, and dissemination of high-quality curriculum-aligned educational content.

Future research should investigate the long-term educational effects of AR and VR technologies, examine their effectiveness across different age groups and educational levels, and explore the potential of integrating immersive technologies with artificial intelligence (AI) to create more adaptive, personalized, and intelligent learning environments.



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