Development of Augmented Reality on Mathematics for Grade 2 Students at Zigong Vocational and Technical School in China

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The Asian Conference on Education 2024
Official Conference Proceedings

Abstract
This study explored the effectiveness of Augmented Reality (AR) technology in enhancing mathematics education, focusing on four topics: Geometry, Analytic Geometry and Functions, Calculus, and Algebra. The objectives were to develop AR-based learning materials, evaluate their impact on student achievement, and assess student satisfaction. The study involved the creation of interactive AR applications with 3D models and dynamic simulations to simplify abstract mathematical concepts. Research instruments included a 50-item pre-test and post-test, an AR media quality evaluation form, and a satisfaction questionnaire, validated by nine experts in content, media, and measurement. The AR applications were tested on 30 students, and their learning outcomes were analyzed using paired-sample t-tests. Results showed a statistically significant improvement in student performance, with mean scores increasing from 24.43 in the pre-test to 33.33 in the post-test ($p < .001$). The satisfaction survey revealed that the overall approval was at a "Very good" level (mean = 4.49, S.D. = 0.51), with students particularly appreciating the clarity, interactivity, and user-friendly design of the AR materials. The applications effectively improved spatial reasoning, comprehension of mathematical relationships, and problem-solving skills. This study concludes that AR significantly enhances learning outcomes and student engagement, addressing challenges in traditional teaching methods. These findings support the broader integration of AR into mathematics education to improve comprehension, motivation, and academic performance. Future research should focus on expanding AR applications across diverse educational levels and subjects.

Keywords: Learning Achievement, AR, Augmented Reality, Mathematics, 3D Model

Introduction

The 21st century marks a transformative era in education, driven by the rapid evolution of digital technology and innovative teaching tools (Li & Zhou, 2023). Despite these advancements, traditional methods of teaching mathematics still present significant challenges. Many students struggle with abstract concepts, such as geometry and algebra, due to the limitations of conventional teaching tools that rely heavily on static images and textual explanations. This often results in low engagement, reduced motivation, and gaps in conceptual understanding, particularly for complex topics requiring spatial reasoning. The lack of interactivity and real-world application further exacerbates these challenges, leaving educators seeking alternative approaches to enhance learning outcomes.

In response to these challenges, augmented reality (AR) has emerged as a promising educational technology, offering immersive and interactive experiences that bridge the gap between theoretical concepts and practical understanding (Ren et al., 2023). AR enables students to visualize mathematical problems in three dimensions, making abstract concepts tangible and easier to comprehend. Furthermore, AR integrates seamlessly with diverse learning platforms, including smartphone applications and traditional print materials, thus enhancing accessibility and reducing costs (Wang, 2021). By incorporating 3D models and interactive simulations through tools such as 3ds Max, Unity 3D, and Vuforia, AR fosters a dynamic learning environment where students can actively engage with mathematical content and develop problem-solving skills in an intuitive manner (Liang, 2023).

Recognizing the potential of AR to transform mathematics education, this study focuses on addressing the challenges faced by students at Zigong Vocational and Technical School in China. The integration of AR technology into the mathematics curriculum is intended to not only improve students' engagement and comprehension but also to provide a more personalized and innovative learning experience. This research aims to explore the effectiveness of AR by comparing students' performance through pre-test and post-test evaluations and analyzing their satisfaction with this technology. By tackling the limitations of traditional teaching methods and leveraging the advantages of AR, this study seeks to contribute to the development of more effective and engaging educational practices, particularly in mathematics.

Literature Review

Augmented Reality (AR) in Education

Augmented Reality (AR) has become a pivotal tool in modern education, offering immersive and interactive learning experiences that bridge the gap between theoretical concepts and practical understanding. By overlaying digital information onto the real world, AR enhances student engagement and facilitates deeper comprehension across various subjects. Recent studies have demonstrated that AR can significantly improve learning outcomes by providing contextualized and experiential learning opportunities. For instance, a systematic review by Tene and colleagues (2024) synthesized current knowledge on integrating immersive technologies, including AR, in STEM education, highlighting their positive impact on student performance and engagement.

In China, the adoption of AR in educational settings has been gaining momentum. Li and Zhou (2023) explored the deep integration of information technology and regional teaching

in high school mathematics, emphasizing the role of AR in innovating teaching methods and enhancing student understanding. Similarly, Ren and colleagues (2023) investigated experiential teaching modes based on AR resources in solid geometry, finding that AR facilitated intuitive learning and improved spatial reasoning skills among students.

Internationally, the application of AR in education has been extensively studied. A study by Bacca and colleagues (2014) conducted a systematic review of AR trends in education, identifying its benefits in increasing motivation and facilitating learning. Additionally, Akçayır and colleagues (2016) examined AR in education, discussing current technologies and potential educational benefits.

AR in Mathematics Education

The integration of AR into mathematics education has shown promising results in addressing challenges associated with abstract concepts and student engagement. AR enables the visualization of complex mathematical ideas, making them more accessible and comprehensible. In China, Liang (2023) explored the application of AR technology in primary school teaching scenarios, demonstrating how AR can innovate classroom teaching models and empower smart classrooms.

Globally, AR has been utilized to enhance mathematics instruction. For example, a study by Dunleavy and colleagues (2009) investigated the impact of AR on student engagement and learning outcomes in mathematics, finding that AR activities increased student motivation and understanding of mathematical concepts. Similarly, Cai and colleagues (2019) examined the effects of AR-based learning environments on students' mathematical performance, reporting significant improvements in problem-solving skills and conceptual understanding.

Learning Outcomes and Student Achievement

The implementation of AR in educational contexts has been associated with improved learning outcomes and student achievement. AR provides interactive and engaging learning experiences that cater to diverse learning styles, thereby enhancing knowledge retention and application. In China, Wang (2021) conducted research on the design, development, and application of middle school mathematics teaching resources based on AR, highlighting its effectiveness in improving student performance and satisfaction.

International studies have also reported positive impacts of AR on learning outcomes. For instance, a study by Garzón and Acevedo (2019) conducted a meta-analysis of the impact of AR on students' learning gains, concluding that AR has a significant positive effect on learning outcomes across various educational levels and subjects. Additionally, Radu (2014) reviewed the effects of AR on learning performance, noting that AR applications can lead to increased motivation, improved spatial abilities, and enhanced collaboration among students.

In summary, both Chinese and international research underscore the potential of AR to transform education by enhancing engagement, facilitating understanding of complex concepts, and improving overall learning outcomes. The integration of AR into mathematics education offers promising avenues for addressing traditional learning challenges and fostering a more interactive and effective learning environment.

Methodology

Development of AR Content

The study involved the development of Augmented Reality (AR) content specifically designed to enhance learning in four key mathematical areas: Geometry, Analytic Geometry and Functions, Calculus, and Algebra. Each topic was carefully developed to include 3D models, interactive visualizations, and simulations aimed at improving students' comprehension of abstract mathematical concepts.

Development of Research Instruments

Three primary research instruments were developed for this study.

(1) Pre-test and Post-test Assessment
A 50-item test was designed to measure students' knowledge and learning outcomes before and after using AR. The test items were aligned with the mathematical concepts covered by the AR content.

(2) Evaluation of AR Media Quality
A structured evaluation form was developed to assess the quality of the AR content, including its usability, alignment with learning objectives, and effectiveness in promoting engagement and understanding.

(3) Satisfaction Survey
A questionnaire was designed to gauge students' satisfaction after using the AR-based learning materials. The questionnaire employed a 5-point Likert scale to measure various aspects of user experience.

To ensure the validity and reliability of these research instruments, they were reviewed and evaluated by a panel of nine experts comprising, Content Experts (3), to verify the accuracy and relevance of the AR content to the curriculum. Media Experts (3), to assess the technical quality and usability of the AR applications. Measurement and Evaluation Experts (3), to evaluate the appropriateness and clarity of the test items and survey questions.

The experts assessed the instruments based on their alignment with the learning objectives and their capacity to measure the intended outcomes. Revisions were made based on expert feedback before implementing the instruments in the study.

Data Collection

The study was conducted with a sample group of 30 students from Zigong Vocational and Technical School. The AR content was implemented as part of their mathematics curriculum. The data collection process involved the following steps:

(1) Pre-test Administration
Students completed a pre-test to assess their initial knowledge and understanding of the mathematical topics before using the AR-based content.

(2) Implementation of AR Content
Students engaged with the AR materials over a specified period, during which they explored and interacted with the AR applications for the four topics.

(3) Post-test Administration
After completing the AR-based lessons, students took a post-test identical to the pre-test.

(4) Satisfaction Survey
Students completed a satisfaction questionnaire to provide feedback on their experience with the AR materials.

Data Analysis

The data collected from the pre-test and post-test assessments were analyzed using a paired-sample t-test to compare the mean scores and determine the effectiveness of the AR-based learning materials in improving students' academic performance. Additionally, descriptive statistics (mean and standard deviation) were used to analyze students' responses to the satisfaction survey, providing insights into their perceptions and experiences with the AR technology.

Result

Development of AR Technology

The developed AR applications provided interactive and engaging content for four key mathematical topics: Geometry, Analytic Geometry and Functions, Calculus, and Algebra. Each topic featured dynamic 3D models and interactive simulations tailored to enhance student comprehension. The AR interfaces were designed to be user-friendly, offering clear navigation menus and intuitive controls for effective learning experiences. These applications demonstrated the capability of AR to transform abstract mathematical concepts into tangible learning materials, fostering deeper understanding and engagement. As shown in Figure 1:

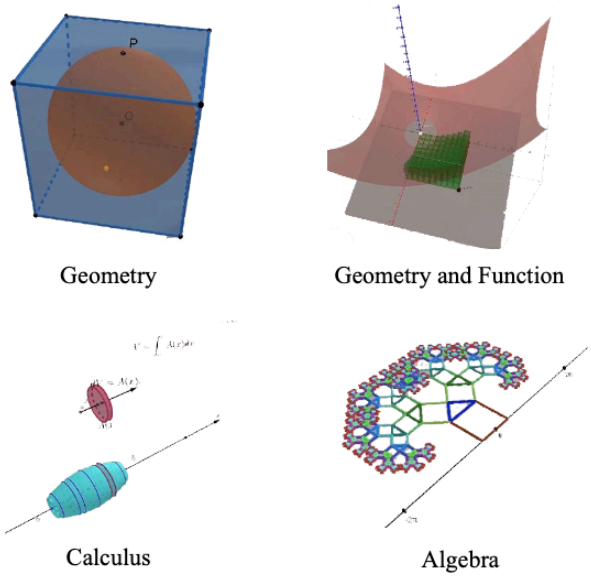

Figure 1: Example of AR Program

Comparative Analysis of Academic Performance

The effectiveness of AR in enhancing student achievement was evaluated by comparing pre-test and post-test results. The findings are summarized in Table 1:

Table 1: Comparison of Academic Performance Before and After Using AR

Test	n	Mean	S.D.	t-test	Sig. (2-tailed)
Pre-test	30	24.43	7.77	10.106	0.000**
Post-test	30	33.33	6.44		

**Statistical Significance at the .001 Level

The analysis revealed a statistically significant improvement in academic performance after students engaged with the AR materials ($p < 0.01$). The mean score increased from 24.43 in the pre-test to 33.33 in the post-test, with a t-test value of 10.106. This indicates that the use of AR technology substantially enhanced students' understanding and mastery of mathematical concepts.

Student Satisfaction With AR Learning

Student satisfaction was assessed using a structured questionnaire. Table 2 presents the results:

Table 2: Results of Analysis of Learner Satisfaction After Using AR

Statement	Mean	S.D.	Result Interpretation
1. The content of this course meets the purpose of AR learning	4.43	.50	Good
2. In line with the AR mathematics teaching theme content, the content is clear and correct.	4.56	.50	Very good
3. Use the language teaching correctly, use the appropriate language description.	4.40	.49	Good
4. The content structure is comprehensive, the original knowledge and the new knowledge link.	4.50	.50	Good
5. Difficulty teaching reasonable students can understand	4.20	.54	Good
6. Curriculum flexibility can meet the differences of students	4.33	.57	Good
7. AR teaching is easy to understand, and the graphic fonts are appropriate.	4.66	.47	Very good
8. The AR program is clear in use and simple in content expression.	4.80	.40	Very good
9. The teaching sound is appropriate.	4.53	.57	Very good
10. Course controls are easy to use and clearly described.	4.56	.50	Very good
11. The interaction with the students is reasonable and comfortable.	4.33	.54	Good
12. The graphics look and comfortable to use.	4.63	.49	Very good

The overall mean satisfaction score was 4.49 (S.D. = 0.51), interpreted as “Very good.” Students highly appreciated the clarity, usability, and aesthetic design of the AR materials. Specific aspects such as content alignment with learning objectives and ease of understanding received particularly high scores.

Discussion

The findings of this study highlight the effectiveness of Augmented Reality (AR) technology in enhancing students' learning outcomes and satisfaction in mathematics education. The results demonstrate a statistically significant improvement in students' academic performance after using AR-based learning materials ($p<.001$). This aligns with prior research that emphasizes the potential of AR to simplify abstract mathematical concepts and promote deeper understanding through interactive and immersive experiences (Ren et al., 2023).

Academic Performance Improvement

The significant increase in post-test scores indicates that AR effectively facilitates students’ comprehension of complex mathematical topics, such as geometry, analytic geometry, calculus, and algebra. Previous studies have shown similar outcomes, where AR-enabled visualization and interaction improve problem-solving skills and conceptual understanding (Cai et al., 2019). Moreover, AR’s ability to provide real-time feedback and adaptive learning paths likely contributed to the observed improvements, as suggested by Wang (2021), who reported AR's effectiveness in tailoring learning to individual needs.

Student Satisfaction

The high level of satisfaction reported by students underscores the usability and engaging nature of AR materials. Key elements, such as clear content structure, interactive 3D models, and aesthetic graphics, were particularly well-received. This supports findings by Liang (2023), who noted that AR fosters positive attitudes toward learning by making abstract concepts more tangible and relatable. Additionally, the flexibility of AR to accommodate diverse learning styles likely enhanced student engagement, as observed in other studies (Garzón & Acevedo, 2019).

Alignment With Global Research

These results are consistent with global findings that emphasize the transformative potential of AR in education. For example, a meta-analysis by Garzón and Acevedo (2019) concluded that AR significantly enhances learning outcomes across various disciplines, particularly STEM fields. Similarly, research in South Korea highlighted the role of AR in reducing math anxiety by creating a non-threatening and interactive learning environment (Kim & Song, 2019).

Implications and Challenges

The findings suggest that integrating AR into mathematics curricula can address common challenges associated with traditional teaching methods, such as limited engagement and difficulty in understanding abstract concepts. However, implementing AR on a larger scale may require addressing challenges such as high development costs, the need for teacher training, and ensuring technological compatibility (Liang, 2023). Future studies could explore

strategies for overcoming these barriers to maximize the potential of AR in diverse educational contexts.

Conclusion

This study evaluated the effectiveness of Augmented Reality (AR) technology in enhancing mathematics education, focusing on four topics: Geometry, Analytic Geometry and Functions, Calculus, and Algebra. The developed AR applications featured interactive 3D models, dynamic visualizations, and user-friendly interfaces designed to make abstract concepts more accessible. Results indicated a statistically significant improvement in students' academic performance, with average scores increasing from 24.43 in the pre-test to 33.33 in the post-test ($p<.001$). Additionally, the student satisfaction survey revealed a high overall score of 4.22 (S.D.=0.51), with users particularly appreciating the clarity, interactivity, and aesthetic quality of the AR materials. Geometry applications improved spatial reasoning, while analytic geometry tools helped students better understand mathematical relationships. Calculus topics, including limits and derivatives, were simplified through interactive simulations, and algebra lessons enhanced problem-solving skills. The study concludes that AR is an effective tool for improving learning outcomes and engagement in mathematics, offering a promising solution to the challenges of traditional teaching methods. These findings support the integration of AR into educational practices to enhance comprehension, engagement, and overall student achievement.

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