The Effects of Augmented Reality Technology on Learning Achievement of First-Year University Students in China

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ABSTRACT
This study examined the impact of Augmented Reality (AR) technology on learning achievement among first-year university students in safety education contexts within a Chinese higher education setting. The research employed a one-group pretest-posttest pre-experimental design involving 30 first-year university students during the first semester of the 2025 academic year. Participants were systematically selected through cluster sampling methodology from a public university in China. Research instruments comprised specially designed AR technology-enhanced lesson plans focused on safety education content and a validated learning achievement assessment instrument with established psychometric properties, including demonstrated reliability and validity measures. Data analysis procedures employed both descriptive statistical analyses (means and standard deviations) and inferential statistical methods (paired samples t-test) to examine differences between pre-intervention and post-intervention learning achievement outcomes. Results demonstrated that students' learning achievement following AR-enhanced instructional delivery was statistically significantly higher compared to pre-intervention baseline levels ($p < .001$). The findings indicate that learning activities systematically incorporating Augmented Reality technology demonstrated substantial educational efficacy in enhancing students' learning achievement in safety education, suggesting practically meaningful and educationally significant improvements in learning outcomes. These empirical results contribute meaningfully to the expanding body of research evidence supporting the strategic integration of AR technology within higher education pedagogical frameworks and provide valuable implications for curriculum designers and educational practitioners seeking to enhance student learning outcomes through innovative technological interventions in safety education contexts.
Keywords: augmented reality technology, educational technology, learning achievement, safety education, higher education

INTRODUCTION
In the rapidly evolving landscape of higher education, the critical importance of campus safety and effective safety management has become increasingly apparent. A secure campus environment that facilitates normal educational activities and harmonious interpersonal interactions serves as the foundation for all forms of quality education and institutional administration. This imperative is particularly pronounced in the context of contemporary universities, where the rapid expansion of educational institutions has introduced multifaceted challenges in campus safety management. The increasing enrollment of students, coupled with the complexities inherent in modern societal issues, has contributed to a notable rise in safety-related incidents on university campuses, thereby underscoring the urgent need for more effective safety education and comprehensive management strategies (Xiong et al., 2024).

Contemporary campus safety incidents, including fires, violence, and online fraud, have occurred with increasing frequency, posing serious threats to students' physical safety and psychological well-being while generating significant reputational consequences for educational institutions (Jiang & Xiao, 2024). These developments underscore the urgent need to address fundamental pedagogical challenges in campus safety education, which include persistently low student engagement, limited opportunities for practical skill application, and inadequate simulation of realistic risk scenarios (Xiong et al., 2024). Traditional lecture-based instructional approaches have demonstrated substantial limitations, with empirical evidence indicating that 68% of university students fail to demonstrate proper fire extinguisher operation following conventional safety training programs (Li et al., 2024).

The contemporary information age has intensified these challenges by introducing complex safety risks that extend beyond traditional campus boundaries to encompass digital environments. Traditional safety education methodologies have proven inadequate in preventing and mitigating these evolving safety risks effectively, necessitating comprehensive reform in educational approaches. Effective campus safety requires integrated strategies that combine systematic educational initiatives with administrative reforms, encompassing personal responsibility frameworks, enhanced regulatory guidelines, and optimized technological infrastructure (Dong, 2023).

Comprehensive safety education serves multiple critical functions through both individual and institutional dimensions. Well-designed programs enable students to develop enhanced self-protection capabilities, recognize dangerous situations, and contribute to measurable reductions in campus criminal activities while fostering legal awareness and ethical reasoning capabilities (Li et al., 2024). This integrated model extends beyond immediate security outcomes to encompass broader educational and developmental objectives, facilitating the establishment of sound value systems that contribute to cultivating civilized campus communities and ensuring that university students achieve comprehensive development within safe environments supporting their overall well-being and educational success.

Augmented Reality (AR) technology has fundamentally transformed pedagogical approaches by providing intuitive, real-time interactive learning experiences that transcend the limitations of traditional instructional methodologies. AR technology enhances practical skill development by enabling students to engage in immersive virtual environments that simulate real-world scenarios, particularly benefiting fire safety education contexts. This technological innovation allows students to practice evacuation procedures and emergency response protocols without exposure to actual hazards or risks that might occur during conventional hands-on training exercises. The implementation of AR technology in safety education offers significant pedagogical advantages through its user-friendly interface and versatile application in learning management systems. This innovative approach effectively stimulates student engagement and facilitates enhanced comprehension of essential safety concepts, thereby contributing to improved learning outcomes and knowledge retention. The interactive nature of AR-based instruction promotes active participation and deeper understanding of complex safety procedures, making it particularly valuable for developing critical emergency response competencies among students (Md Shamsudin et al., 2023).

Despite the promising potential of Augmented Reality (AR) technology in educational contexts, several significant barriers impede its widespread implementation in higher education settings. The primary challenges include the substantial financial investment required for AR equipment procurement and the insufficient digital competencies among educators regarding AR technology utilization (Barroso Osuna et al., 2019; Perifanou et al., 2022). These technological and human resource constraints represent fundamental obstacles to effective AR integration in academic environments.

Furthermore, educational institutions face considerable difficulties in developing appropriate content frameworks and establishing comprehensive guidelines for implementing AR technology within complex curricular structures. Current approaches to AR integration often prioritize learner-centered pedagogical methodologies over systematic technological implementation strategies, creating a disconnect between educational objectives and technological capabilities (De Lima et al., 2022). This emphasis on learner-centered approaches, while pedagogically sound, may inadvertently overlook the technical infrastructure and instructional design considerations essential for successful AR deployment in educational settings.

This study investigates the impact of Augmented Reality (AR) technology on the learning achievement of first-year university students in safety education contexts, contributing to the ongoing scholarly discourse on enhancing educational outcomes through innovative pedagogical technologies. By integrating virtual content with real-world environments, AR technology enables realistic emergency scenario simulations, including fire safety protocols, hazard recognition, and emergency response procedures, allowing students to practice critical safety competencies within controlled learning environments while improving situational awareness and emergency preparedness skills.

AR technology enhances learning achievement by fostering student engagement, promoting knowledge retention, and developing critical thinking capabilities essential for effective safety decision-making. The study's findings will provide valuable empirical insights into the utilization of AR technology for creating academically enriching and pedagogically effective learning environments in higher education safety education programs.

LITERATURE REVIEW

This section presents a comprehensive examination of scholarly literature pertaining to the implementation of Augmented Reality (AR) technology in educational contexts and its effects on student learning achievement. The review encompasses theoretical foundations of AR-enhanced learning, empirical evidence of educational efficacy, current applications in safety education, and implementation challenges within higher education settings. The literature synthesis provides the conceptual framework for investigating AR technology's impact on learning outcomes among university students in safety education contexts.

Importance of Safety Curriculum

University students occupy a critical developmental position as they transition from academic environments to broader societal roles, making comprehensive safety education particularly vital for their successful integration into society. Safety education serves as a fundamental requirement for adapting to social development, ensuring personal security, and promoting holistic growth while establishing appropriate safety consciousness and enhancing self-protection competencies (Li et al., 2024). This educational foundation enables students to effectively prevent and respond to diverse safety risks, contribute to institutional stability, and develop the crisis response capabilities essential for academic achievement and personal development.

Contemporary safety education encompasses both traditional safety concerns and emerging digital-age challenges, including cyber threats and psychological vulnerabilities that students encounter in the information era. Beyond safeguarding physical health, comprehensive safety programs cultivate students' civic responsibility, legal awareness, and ethical values, preparing them to function as conscientious and resilient members of society (Jiang & Xiao, 2024). Network security education has become an indispensable component of this comprehensive approach, helping students recognize digital environment risks, enhance cybersecurity awareness, and develop necessary skills to prevent and respond to online threats while fostering responsible internet use and critical thinking abilities (Wang, 2019).

Current Safety Courses and Programs in Universities

Contemporary safety education programs in universities have evolved into comprehensive educational systems that strategically integrate multiple disciplinary areas, including legal education, fire safety protocols, and cybersecurity training. These interdisciplinary programs are designed to ensure students acquire both theoretical foundations and practical competencies, enabling effective application of safety principles in real-world contexts. The emphasis on content relevance to students' daily experiences, as highlighted in "University Students Safety Education and Self-Protection," demonstrates that selecting safety education materials that resonate with students' immediate concerns significantly enhances learning engagement and interest (Guo et al., 2021).

Higher education institutions emphasize the integration of theoretical knowledge with experiential learning through organized activities such as emergency drills and crisis simulations, which enhance students' capacity for effective emergency response. The incorporation of expertise from legal professionals, public security personnel, and fire safety specialists adds specialized knowledge to training programs, making complex safety concepts more accessible and comprehensible to students. Continuous evaluation and iterative improvement of these programs remain essential, enabling institutions to assess program effectiveness and implement necessary modifications to maintain educational relevance and impact while creating safer and more stable campus environments that prepare students to navigate potential risks in both academic and personal contexts.

Learning Achievement

Learning achievement represents a complex and multifaceted construct that encompasses the degree to which students have acquired knowledge, skills, habits, and attitudes through systematic educational processes. This comprehensive concept refers to performance outcomes that indicate the extent to which specific educational goals have been accomplished, serving as a valuable measure of student quality and educational effectiveness (Tauhid, 2021). Learning achievement is characterized as the extent to which individual learners have successfully attained knowledge and competencies within specific domains of study, frequently indicated by evaluative metrics such as grades or scores that encapsulate academic effectiveness (Amin, 2020).

As a multifaceted construct, learning achievement includes cognitive goals across various subject areas, encompassing critical thinking abilities and domain-specific knowledge that reflect students' capabilities after receiving educational experiences (Steinmayr et al., n.d.). This achievement integrates numerous components that significantly impact academic success, including socio-economic status, emotional intelligence, intrinsic motivation, learning methodologies, and cognitive competencies, each of which plays an instrumental role in determining educational outcomes as substantiated by empirical research findings.

Cognitive abilities constitute fundamental prerequisites for attaining learning achievement in educational settings, encompassing a wide range of mental processes including memory integration and verbal comprehension. These cognitive faculties facilitate systematic knowledge accumulation over time and enable effective integration of various learning episodes, both of which are indispensable components for achieving academic success (Esposito & Bauer, 2022).

Measuring learning achievement constitutes a complex endeavour that requires comprehensive assessment frameworks integrating multiple methodologies to ensure accurate evaluation of student learning and educational effectiveness. This measurement process is pivotal for developing instructional strategies, assessing pedagogical effectiveness, and maintaining accountability within educational systems. A strategic approach to assessment encompasses three complementary methodologies, each serving distinct but interconnected functions in the evaluation process. Formative assessment occurs throughout the instructional process, providing continuous feedback that proves invaluable to both students and instructors. These assessments play crucial roles in monitoring student progress toward established learning objectives while facilitating necessary instructional adjustments that optimize learning outcomes. The implementation of effective formative assessment methodologies significantly influences student motivation and engagement, with constructive feedback substantially enhancing students' intrinsic motivation for improved academic performance (Harris & Jones, 2021; Wu, 2024). Summative assessment serves as the definitive mechanism for gauging the degree to which learners have successfully met educational objectives and learning outcomes established at the beginning of courses or instructional units. This assessment form provides comprehensive perspectives on student performance and frequently serves as the foundation for decisions regarding student advancement and graduation eligibility (Alemann, 2022).

The strategic implementation of these integrated assessment approaches enables educators to make informed decisions about instructional strategies, student advancement, and program effectiveness. Effective measurement ultimately depends on careful consideration of methodological factors that ensure reliable, valid, and meaningful evaluation practices supporting educational success and continuous improvement in learning outcomes.

Augmented Reality and Learning Achievement Enhancement

Augmented Reality (AR) has emerged as a transformative educational innovation that facilitates immersive and interactive learning experiences, demonstrating measurable improvements in students' academic performance across diverse educational contexts and institutional levels. The pedagogical effectiveness of AR technology is fundamentally grounded in constructivist learning theory, which emphasizes knowledge construction through authentic, experiential learning opportunities. By enabling learners to acquire knowledge through multimodal content delivery systems, AR creates sophisticated learning environments that seamlessly integrate physical and virtual components, thereby facilitating enhanced understanding and superior knowledge retention compared to traditional instructional approaches (Garzón, 2021).

Contemporary technological advancements in AR, encompassing significant developments in both hardware capabilities and software applications, have substantially enhanced the seamless integration of real and virtual learning environments. These innovations effectively reduce extraneous cognitive load while facilitating deeper comprehension of complex academic concepts and materials (Arena et al., 2022). This technological sophistication enables AR to establish educational contexts in which learners can engage with academic content through modalities and interactions that conventional pedagogical methodologies cannot replicate, thereby supporting both theoretical knowledge acquisition and practical skill development in ways that align with contemporary learning science principles.

Comprehensive meta-analytic research published in prestigious academic journals provides substantial empirical support demonstrating that AR technology significantly enhances learners' knowledge acquisition, conceptual comprehension, and practical competency development across diverse educational contexts and disciplinary domains. Garzón's (2021) seminal comprehensive review, encompassing over 25 years of AR research in educational settings, demonstrates that AR implementation consistently enhances student motivation and academic engagement while producing measurably favorable learning outcomes across multiple educational levels and subject areas.

Convergent evidence from multiple large-scale meta-analyses provides robust quantitative support for AR's educational efficacy, with studies published in premier educational technology journals, including Computers & Education and Educational Research Review, consistently reporting medium-to-high overall effect sizes on learning achievement outcomes (d = 0.68–0.90). These findings indicate that AR interventions produce educationally meaningful improvements that substantially exceed those typically observed with conventional instructional approaches (Chang et al., 2022; Garzón & Acevedo, 2019; Zhang et al., 2022).

Domain-specific research investigations have demonstrated particularly pronounced effectiveness within specialized professional fields, with Li et al. (2020) establishing that AR implementation substantially enhances learning outcomes in medical education contexts within health sciences curricula. Students engaged in AR-enhanced instruction demonstrated statistically significant superior performance in both accuracy measures and conceptual comprehension compared to counterparts receiving conventional pedagogical approaches, with particularly notable improvements observed in complex domains such as surgical training protocols and anatomical visualization studies. Furthermore, rigorous empirical data derived from randomized controlled trials provide additional substantiation that AR interventions enhance both theoretical knowledge acquisition and practical skill competencies, as demonstrated through nursing students' performance improvements in advanced cardiac life support instruction and assessment (Sun et al., 2024).

Critical Success Factors and Implementation Considerations
Empirical research has identified essential factors that significantly contribute to AR's educational efficacy, encompassing the pedagogical function of AR implementation, intervention duration, and subject matter characteristics that influence learning outcomes. These research findings consistently indicate that AR technology achieves maximum educational effectiveness when strategically designed for systematic content delivery and comprehensive skill enhancement rather than being employed merely for superficial attention capture or novelty effects (Chang et al., 2022; Garzón & Acevedo, 2019). Optimal implementation requires sophisticated instructional design frameworks that systematically align AR-enhanced activities with clearly defined learning objectives, ensure appropriate subject matter selection, and incorporate thorough consideration of learners' cognitive complexity levels and developmental readiness.

The comprehensive body of research evidence conclusively demonstrates that AR represents a highly promising educational technology for enhancing learning outcomes across both theoretical knowledge domains and practical skill applications. Its primary pedagogical strength resides in creating seamlessly integrated learning experiences that effectively combine physical and virtual educational environments, thereby enabling students to construct understanding and retain knowledge more effectively and efficiently than conventional instructional approaches can achieve. However, successful AR implementation depends critically on thoughtful and systematic instructional design processes that ensure AR-enhanced activities are meaningfully connected to specific educational goals while being appropriately matched to individual learner characteristics, cognitive capabilities, and specific content requirements within the educational context.

METHODOLOGY

Research Objective

To examine and compare the learning achievement outcomes of first-year university students in safety education before and after receiving instruction through Augmented Reality (AR) technology-enhanced learning management systems.

Research Hypothesis

First-year university students' learning achievement in safety education following instruction delivered through Augmented Reality (AR) technology-enhanced learning management will be significantly higher than their learning achievement before receiving the AR-enhanced instructional intervention.

Conceptual Framework

This research employs a one-group pretest-posttest pre-experimental design to examine the effects of Augmented Reality (AR) technology on learning achievement in safety education. The conceptual framework presented below serves as the theoretical foundation and methodological guide for conducting this investigation, illustrating the causal relationship between the independent variable (learning management using Augmented Reality technology) and the dependent variable (learning achievement) within the context of safety education for first-year university students.

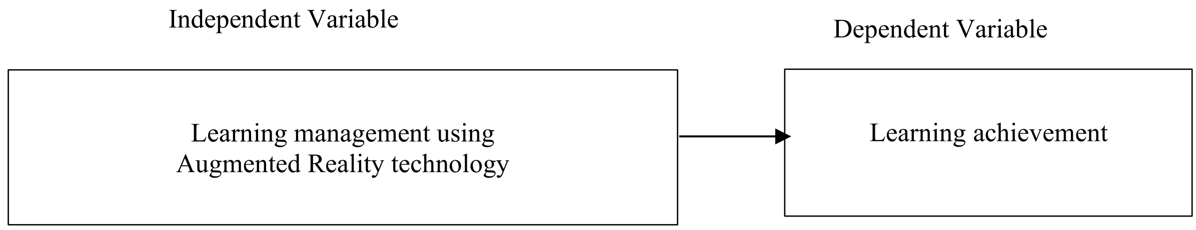

Figure 1 Conceptual framework illustrating the relationship between learning management using Augmented Reality technology and learning achievement enhancement among first-year university students in China

Research Methodology

Research Design

This study employed a pre-experimental research design utilizing a one-group pretest-posttest methodology to examine the effects of Augmented Reality technology on learning achievement among first-year university students in safety education (Best & Kahn, 2003). The pre-experimental design was selected as an appropriate methodological approach for investigating the preliminary effects of AR-enhanced instruction on student learning outcomes within the specified educational context.

Table 1: One-Group Pretest-Posttest Design

Pretest	Intervention	Posttest
O1	X	O2

Symbols used in experimental design.
O1 = Pretest measurement of learning achievement
O2 = Posttest measurement of learning achievement
X = Learning management using Augmented Reality technology intervention

Population and Sample

The target population for this study comprised first-year undergraduate students enrolled at a public university in China. This population was selected based on their developmental stage as beginning university students.
The study employed cluster sampling methodology to select 30 first-year undergraduate students from the Faculty of Arts at a public university in China. This non-probability sampling approach was chosen due to practical considerations related to classroom organization and the availability of intact academic groups within the faculty structure.

The selected participants were enrolled in safety-related courses during the first semester of the 2025 academic year, ensuring homogeneity in terms of educational level, subject matter exposure, and temporal context. All participants formed a single experimental group that received AR-enhanced instructional intervention, consistent with the one-group pretest-posttest research design employed in this investigation. The sample size of 30 students was determined based on practical constraints and represents a sufficient number for preliminary investigation of AR technology effects on learning achievement, while acknowledging that larger sample sizes would enhance the generalizability of findings in future research endeavours.

Research Instrument

This research utilized various instruments to measure the effectiveness of Augmented Reality technology learning management on students' learning achievement. The instruments are categorized into two main types: tools for learning management are Augmented Reality technology lesson plans, and instruments for data collection is Learning Achievement Test.

Instrument Development

Augmented Reality technology lesson plans

The development of AR-enhanced learning management materials followed a systematic six-step process designed to ensure both theoretical rigour and practical applicability:

1) Literature Review and Curriculum Analysis, The researcher analyzed curriculum objectives, safety-related learning outcomes, AR-based learning management literature, and safety education principles to develop four 2-hour lesson plans incorporating AR technology.

2) Instructional Design and Material Creation, Detailed lesson plans were developed, including teaching materials, interactive AR content, and assessment tools for each lesson, ensuring alignment with research objectives.

3) Expert Content Validation, Completed instruments were submitted to three experts: (a) an educational technology and AR applications specialist, (b) a safety education and risk management expert, and (c) a curriculum and instruction specialist.

4) Index of Item-Objective Congruence (IOC) Assessment, Experts evaluated the materials using IOC methodology, examining content accuracy, learning objective alignment, AR technology integration, activity design, and assessment methods.

5) Statistical Analysis and Pilot Testing, IOC values were calculated with acceptable thresholds of 0.67-1.0. Content was modified based on expert recommendations, followed by pilot testing with a representative sample to assess feasibility.

6) Final Refinement and Optimization, learning activities were revised based on expert feedback, time allocations adjusted, AR content integration enhanced, and assessment tools improved according to pilot study results.

Learning Achievement Test

The development of the learning achievement test followed a systematic eight-step process designed to ensure psychometric rigor and content validity:

1) The researcher analyzed learning objectives, content domains, and expected outcomes within safety education curricula. A comprehensive test specification table was constructed to ensure systematic content coverage, resulting in an initial instrument comprising 45 multiple-choice items addressing risk identification, safety protocols, and emergency response procedures.

2) Preliminary test items were developed according to the established test specification framework. Items were systematically designed to assess multiple cognitive levels consistent with Bloom's Taxonomy, with each question carefully aligned to specific learning objectives and knowledge domains within the safety education curriculum.

3) The preliminary instruments underwent comprehensive review and refinement under supervisory guidance to ensure adequate content coverage and technical accuracy. Following these revisions, the test items were submitted to a panel of three subject matter experts for content validation.

4) Three subject matter experts evaluated each test item using established criteria, including content accuracy, linguistic clarity, cognitive level appropriateness, and construct validity. Index of Item-Objective Congruence (IOC) values were calculated, with items achieving IOC scores between 0.8 and 1.0 retained for subsequent pilot testing.

5) A pilot study was conducted with 30 participants possessing characteristics similar to the target population but excluded from the primary study sample. This pilot phase was essential for establishing the instrument's psychometric properties and identifying necessary refinements.

6) Pilot test data underwent comprehensive statistical analysis examining item difficulty indices ($p = 0.20$-0.80), item discrimination indices ($r \geq 0.20$), and internal consistency reliability using Cronbach's alpha coefficient. This analysis ensured selection of items with appropriate difficulty levels and satisfactory discriminating power.

7) Based on psychometric analysis results, 20 multiple-choice questions and 4 short-answer questions meeting specified criteria were selected. The retained multiple-choice items demonstrated p-values between 0.32 and 0.55 and r-values ranging from 0.20 to 0.73. The final instrument achieved an overall reliability coefficient (Cronbach's alpha) of 0.80.

8) The final instrument version was refined based on statistical analysis findings and expert recommendations, ensuring the assessment tool possessed both adequate validity and reliability for measuring student learning achievement in safety education contexts within the primary investigation.

Data Collection

The data collection process involved three systematic steps designed to ensure accuracy and reliability in measuring the effects of Augmented Reality technology-enhanced learning management on students' learning achievement in safety education.

1) Pre-experimental Step: Institutional permission was obtained from the academic administration of the participating university, with relevant faculty members informed about the study objectives and procedures. Coordination meetings were conducted with instructors responsible for the experimental group to align lesson plans and establish standardized data collection procedures. The pretest was administered using the validated learning achievement test to establish baseline measurements for the experimental group. All pretest scores were systematically verified and documented to ensure data integrity and accuracy before proceeding to the intervention phase.

2) Experimental Step: The AR technology-enhanced learning management intervention was implemented with the experimental group across four 2-hour instructional sessions, following the systematically developed lesson plans. Student participation and responses were continuously documented throughout the implementation period to maintain comprehensive records of the educational process. Adherence to planned activities and time

allocations was monitored to ensure fidelity of implementation, while technical issues and implementation challenges were systematically recorded for subsequent analysis and methodology refinement.

3) Post-experimental Step: The posttest was administered using the identical learning achievement test to measure post-intervention learning outcomes under consistent assessment conditions maintained for the experimental group to ensure reliability measurement. All assessment data were systematically collected and verified for completeness and accuracy, with particular attention paid to maintaining the integrity of the measurement process. The collected data was then organized and prepared for subsequent statistical analysis, ensuring proper documentation and secure data storage protocols were followed throughout the process.

Data analysis

The data collected was analyzed using both descriptive and inferential statistical methods. Descriptive statistics, including means and standard deviations, were calculated to summarize the central tendencies and variability of the learning achievement scores. Inferential statistics employing paired samples t-tests were conducted to examine significant differences between pre- and post-intervention performance. All statistical analyses were performed using statistical analysis software to ensure computational accuracy and reliability of results. The significance level was set at $\alpha = .05$ for all statistical tests

The data were analyzed to compare the learning achievement of first-year university students in safety education before and after receiving AR technology-enhanced instruction, employing paired samples t-test analysis. The results of the statistical analysis are presented in Table 2.

Table 2: Comparative Analysis of Learning Achievement Among First-Year University Students in AR Technology-Enhanced Safety Education: Pre- and Post-Instruction Comparison

Learning Achievement	n	M	SD	$\bar{D}$	Sd	t	p	Effect Size
Before instruction	30	9.20	0.73	10.37	5.34	10.63*	.000	1.94
After instruction	30	19.57	5.58					

* $p < .05$

Analysis of the data presented in Table 2 revealed statistically significant differences in learning achievement outcomes ($t = 10.63$, $p < .001$). Examination of mean learning achievement scores in safety education among first-year university students who received AR technology-enhanced instruction demonstrated significantly higher post-instruction performance ($M = 19.57$, $SD = 5.58$) compared to pre-instruction baseline measurements ($M = 9.20$, $SD = 0.73$) at the $\alpha = .05$ significance level.

Effect size analysis using Cohen's d calculated with the change score standard deviation yielded a very large effect ($d = 1.94$), indicating that the AR technology intervention demonstrated substantial practical significance in enhancing students' learning achievement in safety education. According to Cohen's conventions, this effect size substantially exceeds the threshold for large effects ($d \geq 0.8$), suggesting that the observed improvements represent educationally meaningful gains attributable to the AR-enhanced instructional intervention.

CONCLUSIONS AND DISCUSSION

Conclusions

This study successfully demonstrated the educational efficacy of Augmented Reality technology in enhancing learning achievement within safety education contexts. The research findings confirm that systematic integration of AR-enhanced instructional methods produces measurable improvements in student learning outcomes. The intervention's success can be attributed to AR technology's unique capacity to create experiential learning environments that bridge the gap between theoretical knowledge and practical application. By enabling students to engage with safety scenarios through interactive simulations, the technology addressed fundamental limitations of conventional instructional methods while providing safe, controlled environments for skill development and knowledge acquisition. These empirical findings provide robust support for the research hypothesis and contribute valuable evidence to the growing literature on technology-enhanced learning in higher education. The results demonstrate that AR technology represents a viable and effective pedagogical tool for institutions seeking to improve safety education outcomes and enhance student preparedness for real-world emergencies.

Discussion

The implementation of Augmented Reality (AR) technology in safety education pedagogy significantly enhanced post-intervention learning achievement by fundamentally transforming abstract safety concepts into experiential learning opportunities. Learning management using AR technology was systematically integrated throughout various stages of the instructional process, including content presentation, scenario simulation, and facilitating interactions between learners and educational materials. In this research, AR technology was utilized across three key instructional phases: Step 1 (Introduction), Step 2 (AR-Enhanced Teaching), and Step 3 (Summary and Assessment). The second step comprised three critical components: 1) presenting safety-related content through interactive AR visualizations, 2) simulating real-world environments for hands-on practice, and 3) engaging students in active problem-solving tasks.

By integrating AR-enabled applications and devices throughout these instructional phases, this pedagogical approach enhanced university students' acquisition and application of safety competencies through multiple cognitive and behavioral mechanisms. AR technology enabled cognitive embodiment by visualizing complex safety procedures, such as fire extinguisher operation and hazard identification, through interactive three-dimensional simulations, thereby increasing knowledge retention through multisensory engagement. Concurrently, behavioral reinforcement created high-frequency skill refinement cycles where real-time feedback during AR training exercises provided corrective prompts for incorrect techniques, reducing operational errors through systematic protocol automation.

Contextual stress adaptation integrated time-pressured scenarios, notably three-minute multi-hazard decision-making exercises, which accelerated crisis response capabilities through simulated high-stress challenges. Finally, responsibility internalization through structured reflection activities and safety commitment documentation fostered personal accountability, evidenced by increased student expressions of safety ownership and engagement. This integrated framework of embodied learning, iterative practice, adaptive stress exposure, and ethical internalization collectively addressed the knowledge-application gap inherent in traditional safety instruction, shifting educational outcomes from theoretical recall to demonstrable competence in real-world safety management contexts.

The significant improvement in learning achievement following AR-enhanced instruction aligns with previous research demonstrating AR's educational efficacy across multiple domains. Li et al. (2020) demonstrated that AR-enhanced medical training improved anatomical understanding by 40% through three-dimensional visualizations, while Radu and Schneider (2019) documented AR's advantages in conveying abstract concepts such as electromagnetic field dynamics. The current findings extend these results to safety education, confirming AR technology's capacity to: (1) reduce cognitive load by transforming theoretical safety protocols into interactive simulations (Gong et al., 2024), and (2) enhance student engagement through immersive hazard-response scenarios, addressing traditional safety education's documented limitations in student participation and retention (Xiong et al., 2024).

The observed large effect size ($d = 1.94$) substantially exceeds meta-analytic benchmarks for educational interventions, which typically range from $d = 0.4$ to 0.8, suggesting AR technology's exceptional utility for high-risk skill acquisition in educational settings. This finding aligns with Yang et al.'s (2024) research on fire drill simulations, where AR implementation increased correct emergency responses by 63%. These convergent findings suggest that AR technology represents a particularly promising pedagogical tool for safety education contexts where traditional instructional methods have demonstrated limited effectiveness in translating theoretical knowledge into practical competencies.

The Study Reached the Following Findings

This study yielded the following key findings regarding the implementation of Augmented Reality technology in safety education. 1) The AR-enhanced intervention produced statistically significant improvements in students' safety education learning achievement, with post-intervention performance substantially exceeding pre-intervention baseline levels. This advancement was accompanied by reduced variability in learning outcomes across the participant cohort, indicating more consistent educational benefits. 2)The magnitude of improvement achieved a very large practical effect size, substantially surpassing conventional benchmarks for educational interventions. This scale of efficacy suggests that AR technology fundamentally enhanced both cognitive processing during hazard assessment tasks and procedural execution during emergency response scenarios.3) Participants demonstrated consistent application of AR-acquired safety protocols in subsequent practical exercises, with reflective assessments revealing substantial shifts toward safety ownership and responsibility internalization. This transfer of learning indicates the intervention's effectiveness in bridging the gap between theoretical knowledge and practical implementation.

RECOMMENDATIONS

Recommendations for Implementation

Based on the findings and limitations of this study, the following integrated recommendations are proposed to advance the implementation of augmented reality technology in safety education contexts. 1) Educational practitioners should adopt a phased integration approach, beginning with pilot AR modules targeting high-risk scenarios such as laboratory chemical spills and emergency evacuation procedures. Initial implementation should utilize cost-effective mobile AR solutions before scaling advanced hardware systems to ensure financial sustainability and institutional feasibility. This approach should be coupled with a hybrid training model that strategically combines AR simulations for cognitive decision-making processes with traditional physical drills for psychomotor skill development, particularly for high-stakes procedures such as fire extinguisher operations. 2) Educators implementing this AR-enhanced learning management approach must develop comprehensive understanding of the instructional design process and acquire clear knowledge of teaching and learning management procedures. They should also develop competencies in learning environmental design and facilitation. Professional development is critical, and mandatory workshops should address scenario design for safety contexts, troubleshooting common AR tracking errors, and calibrating standardized assessment rubrics to ensure consistent evaluation of safety competencies across different educational settings.

Recommendations for Future Research

Based on the conclusions and discussion of the study, the researcher has several suggestions as follows: 1) Future research should conduct randomized controlled trials comparing AR-enhanced instruction with traditional safety education methods using validated assessment instruments, such as the National Safety Council's Safety Skills Inventory. Critical control variables should include prior safety training experience, spatial ability, and technology familiarity to ensure accurate attribution of observed effects to the AR intervention. 2)Longitudinal studies should track participants for 6-12 months post-training to measure: (a) retention of AR-acquired knowledge through assessments at three-month intervals, (b) real-world application rates through analysis of incident reports and safety performance metrics, and (c) correlations between AR training completion and reduced campus accident frequencies. 3) Research should investigate AR framework effectiveness across high-risk academic disciplines, including: (a) engineering laboratories for chemical exposure simulations, (b) medical campuses for biohazard response training, and (c) fieldwork-intensive programs for geological hazard identification. These studies would establish the generalizability of AR-enhanced safety education across diverse educational contexts and risk environments. 4) Economic evaluation studies should assess the financial feasibility and return on investment of AR implementation compared to traditional safety education methods, considering factors such as equipment costs, training expenses, and potential reduction in safety-related incidents and associated costs.

Declaration of Generative AI and AI-Assisted Technologies

During the preparation of this work, the authors used Claude AI to correct grammatical errors and improve readability. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Credit Authorship Contribution Statement

All authors have read and agreed to the published version of the manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

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