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Revolutionizing Education Scientometric: The Convergence of AI, Augmented Reality, and Virtual Reality for Immersive Learning

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ABSTRACT

Exploring the transformative impact of converging Artificial Intelligence (AI), Augmented Reality (AR), and Virtual Reality (VR) technologies on immersive learning environments. Using PRISMA methodology and comprehensive bibliometric analysis, we examined publication trends, keyword relationships, and collaboration networks across this rapidly evolving interdisciplinary field. Our findings reveal exponential growth in research output since 2020, with distinct thematic clusters forming around educational applications, immersive technologies, AI methodologies, and specialized domains including healthcare training. The analysis identifies key implementation challenges including technical limitations, ethical considerations, and accessibility barriers. This research demonstrates how AI-enhanced immersive environments create personalized, adaptive learning experiences that significantly improve engagement and knowledge retention across diverse educational contexts including medical simulation, architectural visualization, and language acquisition. The confluence of these technologies represents a paradigm shift in educational delivery, enabling experiential learning opportunities previously constrained by physical, safety, or resource limitations.

Keywords: User Experience, Digital Twin, Education; Medical, Technology, Metaverse

INTRODUCTION

Massive utilization of Augmented Reality (AR) and Virtual Reality (VR) shown in its diversification and significant growth in recent years (Gupta, 2023). In industrial setting, key players in different sectors shown keen interest in utilizing AR and VR in various setting such as gamming, retails, healthcare, and industrial design. Recently, ByteDance's Pico enterprise-focused headset and HTC's partnership with Siemens highlight the growing importance of VR in enterprise applications such as training, education (Gupta, 2023), and industrial design (Munde, 2024). Furthermore, Sony's new VR R&D centre in Singapore demonstrates a commitment to advancing

VR technologies through focused research and development efforts (Yeo & Shum, 2024). The global expansion and recent technology advancement in both technologies projected 27.1% CAGR from 2024 to 2035, this evaluation underscores the rapid growth expected in the VR market, driven by technological advancements, increased adoption across various sectors, and enhanced user experiences (Gupta, 2023). This suggests that VR is becoming more integrated into professional environments beyond entertainment.

Collaboration in learning environments extends beyond mere co-existence in digital space. It requires meaningful interaction(Ahmad et al., 2020; Vergara et al., 2019; Voreopoulou et al., 2024), shared understanding (Järvelä et al., 2023; Mahendru et al., 2024), and the ability to engage with content in ways that mirror or even enhance face-to-face experiences (Abu Khousa et al., 2023). Traditional digital platforms often fall short in creating truly collaborative environments where students can manipulate objects together, share perspectives, and experience learning as a communal activity. The integration of AI, AR, and VR technologies offers promising solutions to these limitations by creating immersive (Abadia et al., 2024; Agbo et al., 2023), interactive spaces where collaboration transcends physical constraints (Acevedo-Valle et al., 2018).

Current digital education platforms suffer from significant user interface and experience issues for both educators and learners. These interfaces often lack intuitive design (Abadia et al., 2024), accessibility features (Adnan et al., 2020; Asish et al., 2024), and seamless integration capabilities (Aji et al., 2024), creating frustrating experiences for teachers delivering content and students engaging with materials. Such platforms frequently present monotonous content delivery methods that fail to captivate learners' attention or accommodate diverse learning styles. Additionally, digital barriers such as screen fatigue and the impersonal nature of camera-mediated interactions create psychological distance between participants (Zisis et al., 2021). These screens serve as both literal and figurative barriers to authentic connection, hindering effective knowledge transfer and collaboration. Together, these factors contribute to diminished engagement (Ferguson & van Oostendorp, 2020; Freeman & Hibbs, 2024; Herodotou et al., 2019), reduced knowledge retention, and an overall demotivating educational experience that fails to leverage the full potential of digital learning environments.

AI, AR, and VR convergence transforms sectors through immersive simulations and intelligent tutoring. Many literature note how this integration advances digital inclusion in education via automated, adaptive environments (Cersosimo, 2023; Salazar et al., 2021). They highlight that these systems modernize learning by making it more engaging, personalized, and data-driven, while addressing scalability and regulatory challenges.

This technological convergence is emerging as a key driver in immersive learning, supported by extensive literature documenting both benefits and challenges. Research shows that combining AI's adaptive capabilities with AR/VR environments enhances engagement and retention while creating personalized, interactive educational systems. These applications span various domains including medical training (Ahmadvand et al., 2018; Alamer, 2023; Al-Hor et al., 2024; Al-Shouli et al., 2024), higher education (Abbas et al., 2024; Abdelkader et al., 2022; Agbo et al., 2023; Ai, 2024; Al Ghawail & Ben Yahia, 2024), and architectural design(Aboushal & Gharib, 2020; AbuKhousa et al., 2023; Adekitan & Shobayo, 2020). The following sections examine applications across these domains, discuss technical aspects, and identify implementation challenges.

Understanding the applications of AI, AR, and VR in the current landscape requires examining how these technologies intersect and complement each other to create effective immersive learning experiences. A comprehensive scientometric analysis reveals the evolution, patterns, and relationships within this emerging field. Through this systematic approach, researchers can identify temporal patterns in the development of these technologies in educational contexts, revealing how research priorities have evolved, and which approaches have gained prominence over time. By mapping the intellectual landscape, this methodology identifies underdeveloped research areas and potential knowledge gaps warranting further investigation, thereby directing future research efforts toward promising or neglected domains. Additionally, the analysis reveals complex interconnections between publications through citation networks, demonstrating how ideas influence subsequent research while illuminating collaborative relationships between researchers and their affiliated institutions across geographical and disciplinary boundaries.

METHODOLOGY

This scientometric analysis employs the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to examine the role of artificial intelligence (AI), augmented reality (AR), and virtual reality (VR) in creating immersive learning experiences for students (Sahabudin et al., 2024). The methodology ensures transparency, rigor, and reproducibility in identifying, screening, and synthesizing relevant studies.

Database Selection

To ensure comprehensive coverage of interdisciplinary research, we conducted a thorough evaluation of available academic databases and selected Scopus as our primary data source. Scopus was chosen for its exceptional breadth and depth in multidisciplinary coverage, particularly its robust indexing of research at the intersection of artificial intelligence, extended reality technologies (AR/VR), and educational sciences. This database offers superior coverage of both established journals and emerging publication venues, ensuring we captured both foundational research and cutting-edge developments in immersive learning technologies. Additionally, Scopus provides comprehensive metadata and citation tracking capabilities that facilitated our bibliometric analysis. The database's advanced search features allowed us to implement our complex search strings effectively, identifying relevant studies across multiple disciplines including computer science, education, psychology, and healthcare. This methodological choice was crucial for ensuring that our analysis captured the full spectrum of research addressing how AI-enhanced immersive technologies are being implemented and evaluated across diverse learning contexts.

Search Strategy

The search strategy was developed using the PICO framework (Population, Intervention, Comparison, Outcome) and refined with synonyms derived from standardized Medical Subject Headings (MeSH) and related terms as shown in Table 1 (Azzeri et al., 2022; Sahabudin et al., 2024). The keywords and search strings are outlined below:

Table 1: Keywords Search Strategy Using PRISMA PICO Approach

Item	Main Keywords	Synonyms	Search Strategy	Search Strings
Population	Students	Learners, K-12 education, higher education, STEM education	("students" OR "learners" OR "K-12 education" OR "higher education" OR "STEM education")	TITLE-ABS-KEY ("students" OR "learners" OR "K-12 education" OR "higher education" OR "STEM education") AND ("artificial intelligence" OR "machine learning" OR "augmented reality" OR "virtual reality" OR "immersive technologies") AND ("learning outcomes" OR "engagement" OR "motivation" OR "academic performance" OR "skill acquisition")
Intervention	Artificial Intelligence, Augmented Reality, Virtual Reality	Machine learning, deep learning, immersive technologies, 3D simulations	("artificial intelligence" OR "machine learning" OR "augmented reality" OR "virtual reality" OR "immersive technologies")	
Comparison	Traditional teaching methods	Conventional learning methods, non-digital learning	("learning outcomes" OR "engagement" OR "motivation" OR "academic performance" OR "skill acquisition")	
Outcome	Learning outcomes, engagement, motivation	Academic performance, skill acquisition, user experience	("learning outcomes" OR "engagement" OR "motivation" OR "academic performance" OR "skill acquisition")	

Inclusion Criteria

Studies were included based on the following criteria:

The inclusion criteria for this systematic literature review were carefully established to ensure comprehensive yet focused coverage of relevant research. Studies were selected based on a publication timeframe spanning from 1980 to 2024, providing a broad historical perspective while capturing the most recent developments in AI and AR/VR technologies. This temporal range was particularly important as it encompasses both the foundational research that established these fields and the recent technological breakthroughs that have accelerated their educational applications. The 2024 cutoff was deliberately chosen because publication data for 2025 remains incomplete, which would potentially introduce sampling bias into our analysis. Additionally, language restrictions limited inclusion to peer-reviewed articles published in English, ensuring accessibility for the review team and maintaining consistency in quality assessment.

The methodological scope was defined to include diverse research approaches, specifically empirical studies that provide evidence-based insights, systematic reviews that synthesize existing knowledge, meta-analyses that offer statistical integration of findings across multiple studies, and case studies that provide detailed contextual examinations of implementation. This methodological diversity was essential to capture both quantitative outcomes and qualitative insights regarding the implementation of these technologies. Finally, content relevance was strictly evaluated, with inclusion limited to studies that explicitly address the application of AI, AR, and VR technologies for enhancing student learning experiences. This criterion ensured that all included research directly contributed to answering our central research questions regarding the effectiveness and implementation of immersive learning technologies in educational contexts (Azzeri et al., 2022).

Exclusion Criteria

The following types of studies were excluded:

1. **Non-English Articles**: Due to language constraints of the review team.
2. **Review Articles**: To avoid redundancy with the aims of this SLR.
3. **Articles Published in 2025**: As the year is not yet complete, these were excluded to maintain temporal consistency.
4. **Non-Peer-Reviewed Articles**: Conference abstracts, editorials, and opinion pieces were excluded for lack of methodological rigor.

Data Extraction Framework

A systematic and comprehensive data extraction framework was implemented to capture essential variables, including:

1. **Study Design**: Experimental, quasi-experimental, or qualitative.
2. **Population**: Characteristics of the student population (e.g., age, educational level).
3. **Intervention**: Specific AI, AR, or VR technologies used.
4. **Outcomes**: Learning outcomes, engagement, motivation, and other metrics.
5. **Geographical Context**: Regional focus of the study.

Geographical Scope

An inclusive analysis of studies from geographically diverse regions was conducted to develop a comprehensive understanding of how AI and AR/VR are applied globally. However, no geographical constraints were imposed during the initial search to ensure broad coverage.

PRISMA Flow Diagram

The PRISMA flow diagram provides a systematic overview of how studies were identified, screened, and included in this scientometric.

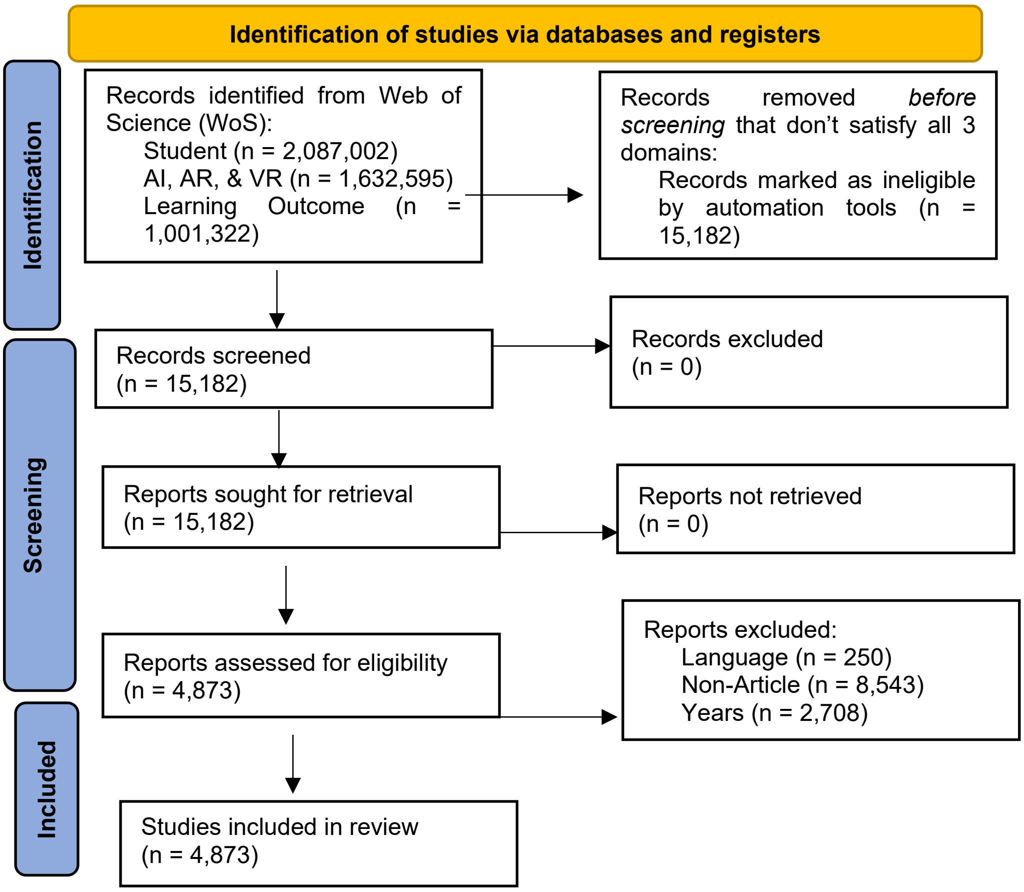


Figure 1: PRISMA Flow Diagram for Identification of Study Register

The scientometric article selection followed the PRISMA framework's process shown in Figure 1. In the **Identification** stage, we conducted comprehensive searches across multiple scholarly databases including Scopus and Web of Science to gather all potentially relevant records. This initial search yielded a substantial number of articles that matched our search criteria, providing a broad foundation for subsequent refinement. During the **Screening** stage, we methodically examined these records by first eliminating duplicates across databases, then applying our predetermined inclusion and exclusion criteria to titles and abstracts. This process substantially narrowed our dataset to articles specifically addressing AI, AR, and VR applications in educational contexts. The **Eligibility** assessment involved rigorous evaluation of full-text articles that passed the initial screening. Each article underwent thorough examination against our quality assessment criteria to verify methodological soundness and relevance to our research questions. Finally, the **Inclusion** stage finalized the corpus of studies that met all criteria and were synthesized in our review. This systematic approach ensured comprehensive coverage while maintaining methodological rigor throughout the selection process, resulting in a curated collection of high-quality studies that form the foundation of our analysis.

Data Analysis

The data was collected and exported in both .csv and .ris file formats to ensure compatibility with various analytical tools and preserve bibliographic information integrity. These structured data files were then subjected to comprehensive computational analysis using Python programming language and its specialized data science libraries, including pandas for data manipulation, matplotlib and seaborn for visualization generation, and scikit-learn for advanced statistical processing. Additionally, VOSviewer software was employed for its sophisticated bibliometric visualization capabilities, particularly its ability to generate network maps that effectively illustrate relationships between keywords, authors, and publications. This dual-tool approach allowed for both granular statistical examination and intuitive visual representation of complex bibliometric patterns across the literature corpus.

RESULT AND DISCUSSION

The bibliometric analysis in this section offers a multifaceted examination of the research landscape surrounding the convergence of AI, AR, and VR technologies in educational contexts. Through visualization and quantitative assessment, we explore publication trends, keyword relationships, prominent authors, and collaboration networks to understand the evolution and current state of this rapidly developing field. The analysis reveals not only the exponential growth in research interest but also identifies thematic clusters and intellectual communities that are shaping the direction of immersive learning technologies.

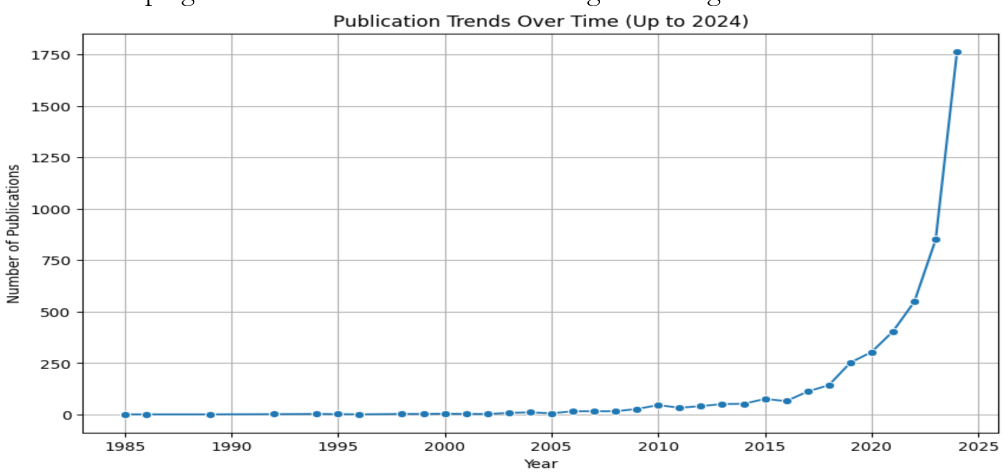


Figure 2: Publication over time from 1985 to 2024

The analysis of publication trends over time reveals a compelling narrative about the evolution of research in AI, AR/VR, and immersive learning. Bibliometric data in Figure 2 shows a remarkable trajectory, with publications steadily increasing through the 2010s before experiencing a dramatic upward inflection around 2020. This exponential growth pattern suggests not merely incremental advancement but rather a paradigm shift in research interest and investment. The surge coincides with several significant technological developments, including improvements in computational power, refinements in AR/VR hardware accessibility, and breakthroughs in machine learning algorithms that made practical applications more feasible across educational contexts.

Several factors likely contributed to this acceleration in research output. The COVID-19 pandemic served as a catalyst (Abalkheel, 2021; Abdelkader et al., 2022, 2022; Abumalloh et al., 2021; Al-Shouli et al., 2024), forcing educational institutions worldwide to rapidly adopt and investigate digital learning solutions (Cersosimo, 2023; Freeman & Hibbs, 2024; Salazar et al., 2021). This global shift created unprecedented demand for immersive technologies that could replicate or enhance traditional learning experiences in remote settings. Simultaneously, substantial increases in both public and private funding for educational technology research provided the necessary resources for expanded investigation (Bernardo et al., 2022; Ibáñez et al., 2020). Major technology companies also intensified their investments in educational applications of AR/VR during this period, further stimulating academic interest and creating opportunities for industry-academic partnerships. The trend continuously been explored during recent years could also contribute from the massive investment in technology related area such as 5G and 4.0 industrial revolution that shift the workforce from in-situ landscape to ex-situ implementation.

The implications of this publication trend extend beyond mere quantification of research volume. The exponential growth curve indicates that AI, AR/VR, and immersive learning have transitioned from niche interests to mainstream research priorities across multiple disciplines. Such priorities resulted in industry demand to streamline digital space for work related activities and users' immersive experiences. This demand supported by the recent trend of of companies that invested in overall AR and VR technologies. In future, maturity of this technology and combine with global market expansion may also affect working trend, this is due to the current hiring trends especially in first world countries where employers hiring remote workers in order not to only reduce costs (Mustajab, 2024), but also to provide all time and holistic services to satisfy market demand and expansion (Hackney et al., 2022), tapping into global talent pools (Abisheganaden et al., 2023), increase productivity, and provide better inclusivity. Therefore, as metaverse technology that employ AR and VR matured, it is in the realm of possibility that business and work progress in digital landscape where spatial barriers will be negligence. However, the rapid expansion both in research and applications in the technology has created a rich but somewhat fragmented knowledge landscape (Ferguson & van Oostendorp, 2020; Freeman & Hibbs, 2024; Li & Yang, 2023), with research clusters forming around specific applications (Abdrakhmanov, Tuimebayev, et al., 2024; Abdrakhmanov, Zhaxanova, et al., 2024; Abdullah et al., 2018), methodologies (Abdrakhmanov, Zhaxanova, et al., 2024; Adhikari et al., 2021; Aeckersberg et al., 2019), and theoretical frameworks (Adewale et al., 2024; Aiken et al., 2021; Al Amoudi et al., 2024). As these technologies continue to mature, the research community faces the challenge of synthesizing findings across disparate domains to develop comprehensive frameworks for effective implementation. The trend strongly signals the need for continued investment in addressing persistent technical challenges, exploring new application domains, and establishing evidence-based best practices for the pedagogical integration of these powerful technological convergences.

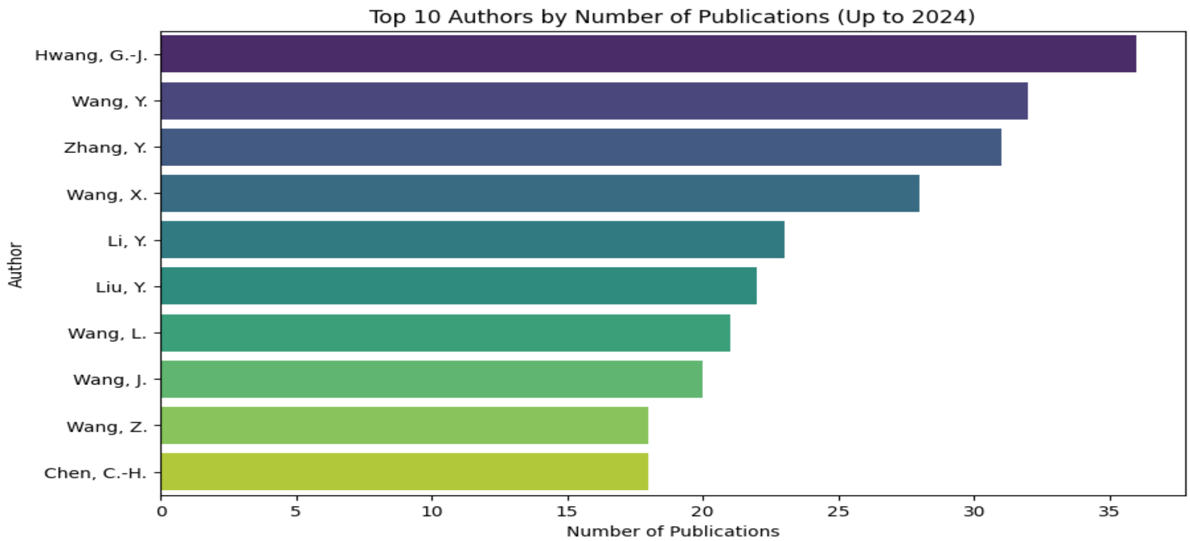


Figure 3: Author ranking based on number of publications

Our bibliometric analysis identified the most influential researchers in the field of AI, AR, and VR convergence for immersive learning. The publication output analysis reveals that Hwang, G.-J., Wang, Y., and Zhang, Y. stand as the most prolific contributors, having published extensively on topics related to immersive technologies in educational contexts compared to other authors in Figure 3. These researchers have not only produced a substantial volume of work but have also shaped core theoretical frameworks and methodological approaches that underpin current understanding of how these technologies can transform learning experiences.

The prominence of these authors is particularly significant as it indicates centres of expertise and intellectual leadership in this emerging interdisciplinary field. Hwang's work, for instance, has been instrumental in developing frameworks for adaptive learning environments that incorporate both AI analytics and immersive interfaces. Similarly, Wang and Zhang have contributed substantially to understanding how virtual environments can be optimized for different learning contexts, from STEM education to clinical training. Their collective contributions represent a concentration of knowledge that has accelerated development in this domain.

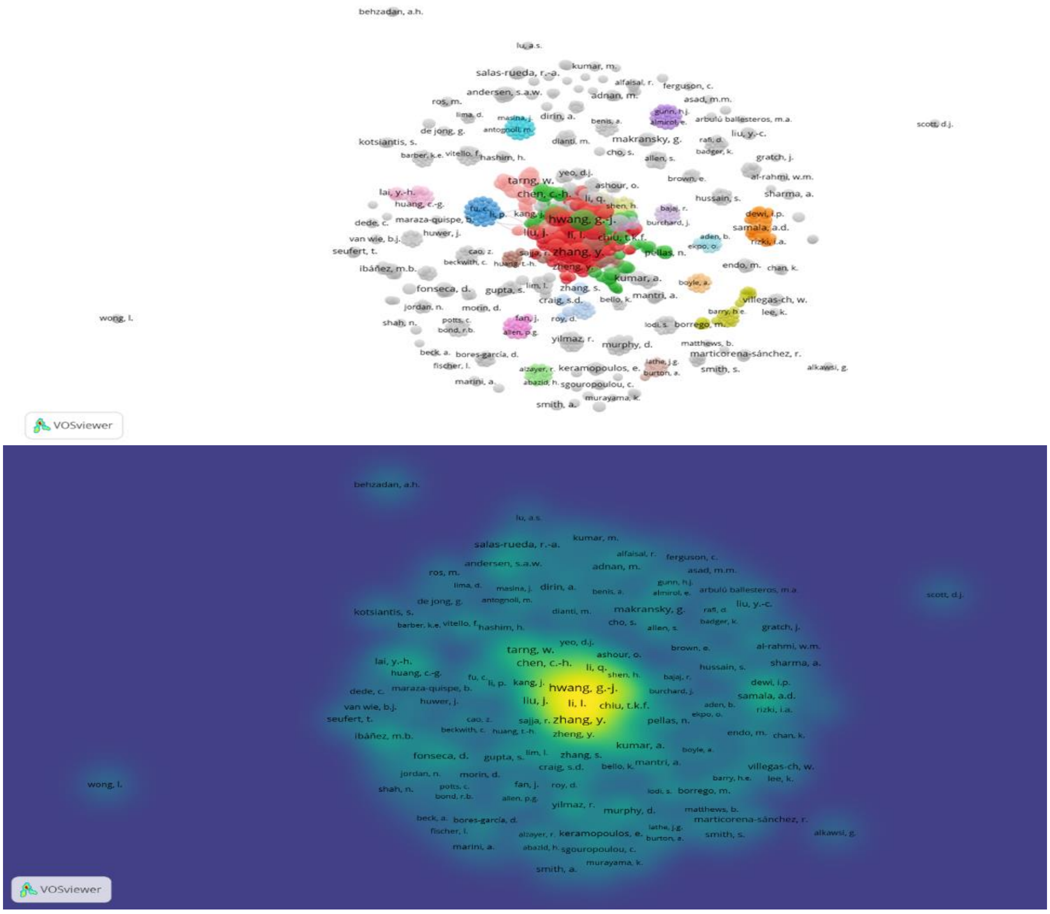


Figure 4 (a): Author Publication Network, 4 (b): Author Publications Density Visualization

Publication patterns among these leading researchers reveal several important trends. First, there is a tendency toward collaborative research, with most high-output authors participating in extensive co-authorship networks as shown in Figure 4(a). This reflects the interdisciplinary nature of the field, which requires expertise in computer science, educational psychology, and domain-specific knowledge. Second, these researchers typically maintain affiliations with institutions that have established research centres or laboratories dedicated to educational technology, providing the infrastructure necessary for sophisticated development and testing of immersive learning environments.

Understanding the institutional and geographical distribution of these productive authors provides valuable context for the development of the field (Refer Figure 4(b)). Many leading contributors are affiliated with universities in East Asia, Europe, and North America, suggesting both global interest in these technologies and potential regional variations in implementation approaches (Figure 5 and 6).

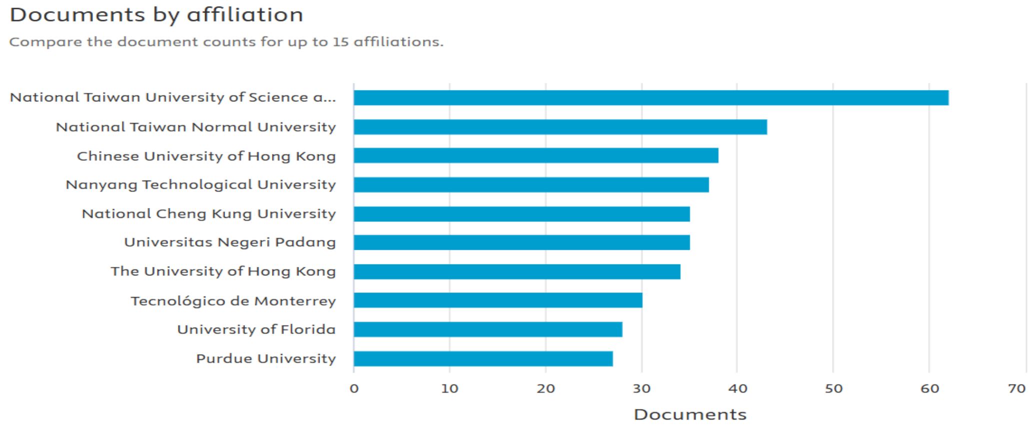


Figure 5: Publication based on Affiliations

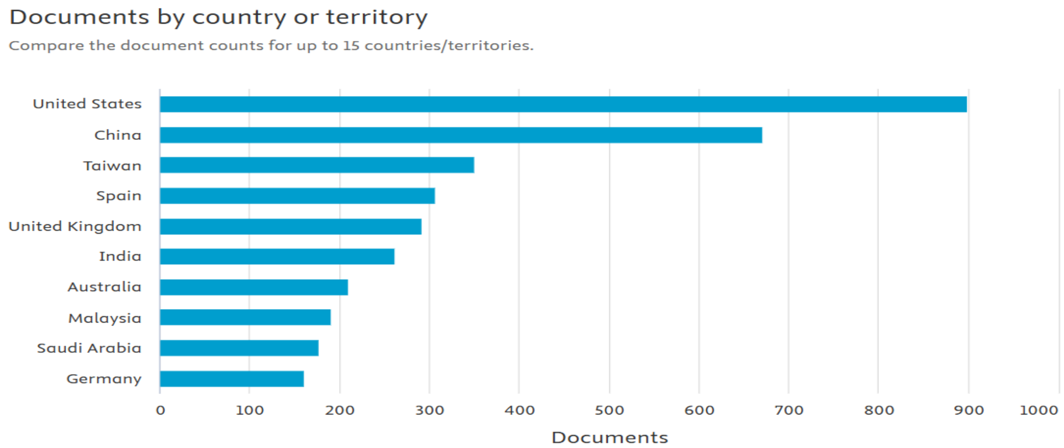
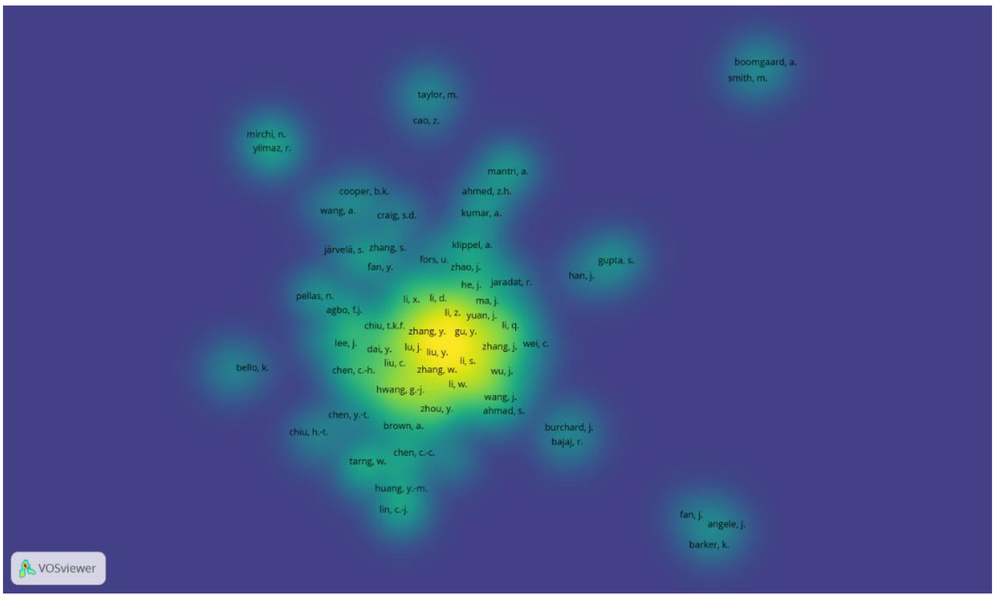


Figure 6: Dominant countries in research fields

This information proves invaluable for researchers' seeking collaborations, institutions developing research programs, and funding bodies identifying centers of excellence (Figure 5 and Figure 6). By mapping these intellectual communities, we gain insight into not only current research priorities but also potential future directions as these influential scholars continue to shape the evolution of immersive learning technologies.



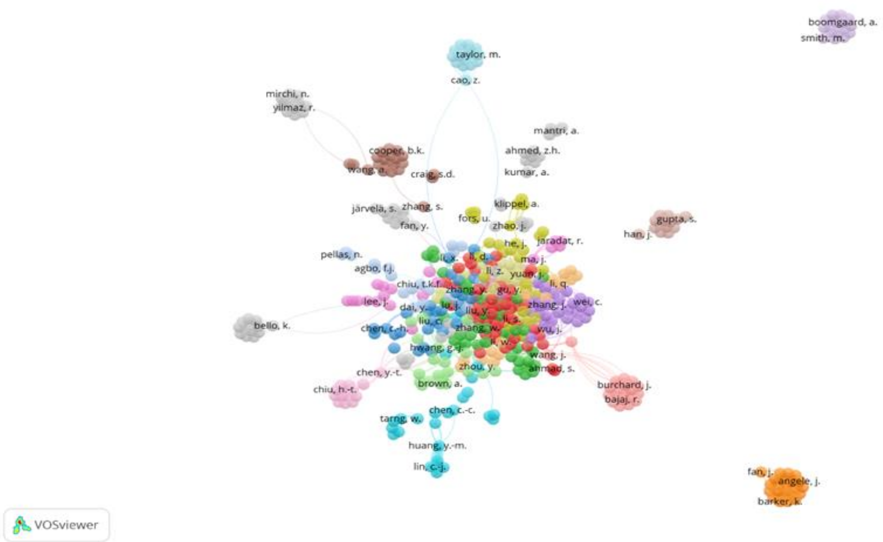


Figure 7: Authors with linked research articles cluster

This visualization reveals key insights into collaborative networks in AI, AR/VR, and immersive learning research. Central authors like "zhang j." and "liu y." serve as intellectual hubs connecting research clusters through extensive co-authorship networks (Figure 7). These influential researchers bridge methodological approaches and application domains, facilitating interdisciplinary innovation. The network displays collaborative clusters formed around shared interests or institutional affiliations. These connected groups represent established research teams with specialized expertise in specific aspects of immersive learning, from adaptive AI systems to medical training applications. Cluster size and density reflect the maturity of different research communities. The visualization also highlights isolated authors who bring fresh perspectives or specialized knowledge. Edge thickness indicates collaborative intensity, with thicker connections showing frequent co-authorship. This metric identifies productive partnerships that have significantly contributed to the field's knowledge base.

This research analysis of keyword frequency in the literature reveals critical insights into the research landscape of AI, AR, and VR in educational contexts. In Figure 8, the most prominent keywords—"Students," "Virtual reality," "Artificial intelligence," and "Augmented reality"—appear with remarkable frequency, establishing themselves as the foundational pillars of this research domain. Their dominance in the literature underscores not merely their prevalence but their conceptual centrality to ongoing scholarly conversations. These terms serve as both the subject matter and methodological framework through which researchers approach questions of immersive learning, indicating how thoroughly these technologies have permeated educational research paradigms.

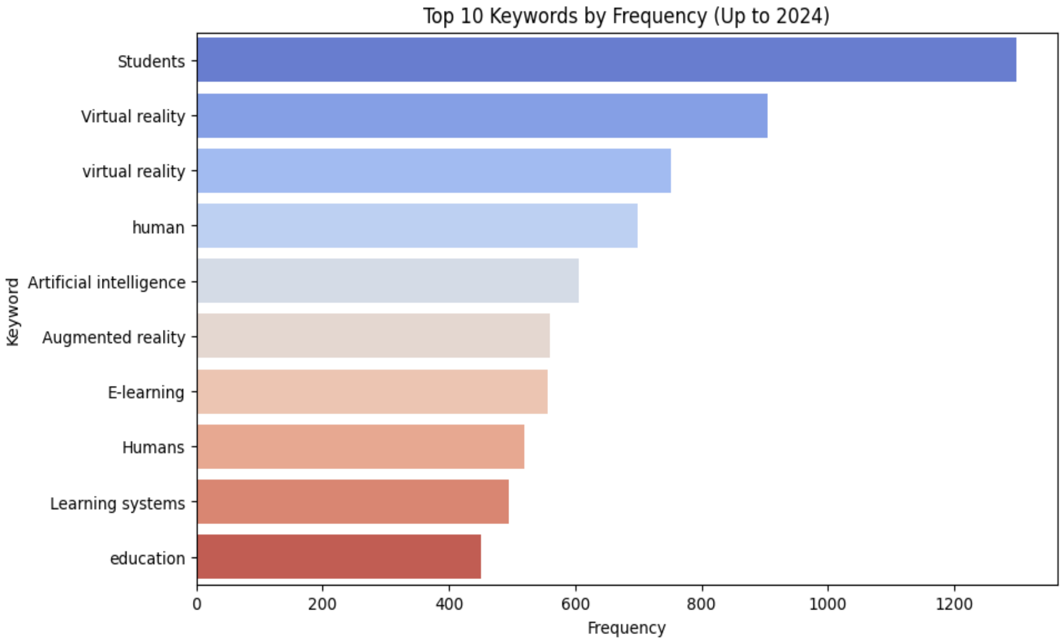


Figure 8: Top 10 Keywords by Frequencies in Bibliographic data

Beyond these core terms, the frequent appearance of keywords like "human," "learning systems," and "education" highlights the deeply interdisciplinary nature of this research field as shown in Figure 8. This frequency pattern demonstrates how researchers are actively working at the intersection of computer science, cognitive psychology, educational theory, and human-computer interaction. The prevalence of these terms suggests that studies in this domain are not merely concerned with technological implementation but are equally focused on human factors, pedagogical implications, and learning outcomes. This balanced keyword distribution indicates a maturing research field where technical innovation is increasingly guided by educational principles and human-centered design approaches.

The keyword frequency analysis also reveals emerging trends and potential research gaps (Sahabudin et al., 2024). While the dominant keywords establish the field's central focus, the presence of terms related to specific applications (such as medical training, language learning, and skill development) suggests growing specialization within the broader domain. This pattern of keyword distribution provides valuable guidance for researchers seeking to position new work within existing literature clusters or identify underdeveloped areas where novel contributions might have impact.

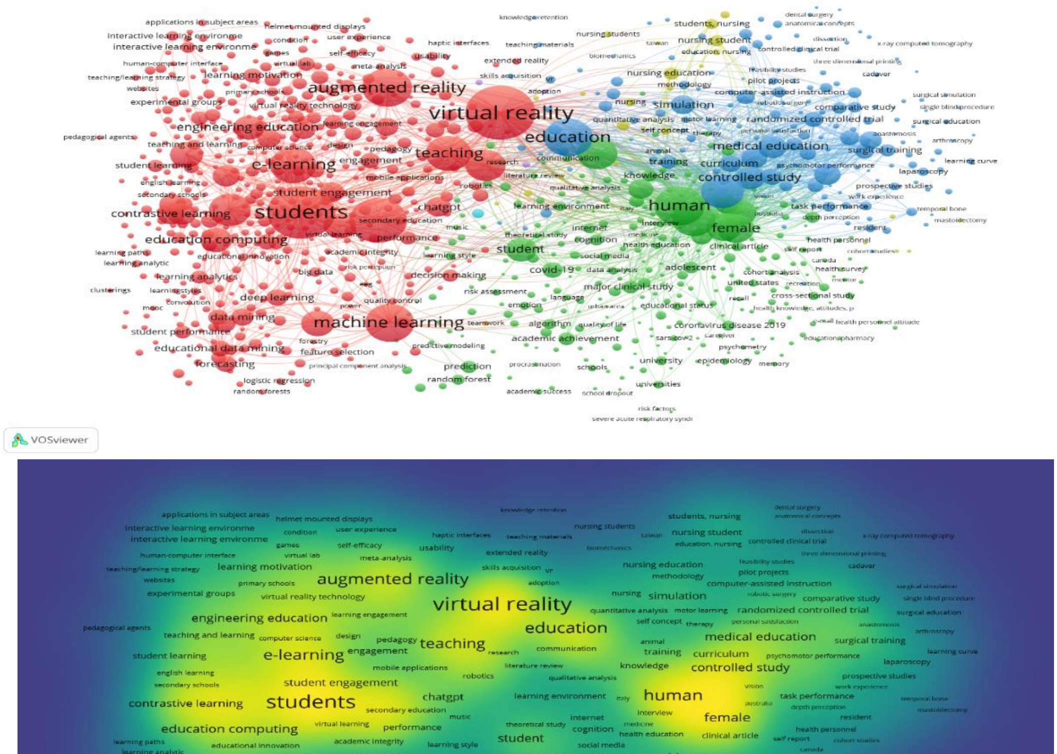


Figure 9(a): Keywords network analysis. (b) Keywords network density analysis

Figure 9(a) and 9(b)'s network visualization created with VOSviewer maps keyword relationships in AI, AR, and VR education literature. This bibliometric analysis uses nodes to represent keywords (sized by frequency) and connecting edges to show co-occurrence patterns. These connections reveal which concepts commonly appear together in publications, forming the foundation for understanding this interdisciplinary field. Analysis of central keywords reveals "students," "virtual reality," "augmented reality," "machine learning," and "education" as dominant nodes in the research landscape. These terms not only appear with high frequency but also serve as connective hubs linking various research domains. Their centrality in the visualization demonstrates how these concepts form the core vocabulary around which discussions of immersive learning technologies revolve. These keywords naturally organize into clusters that represent distinct but interconnected research themes, particularly highlighting the integration of AI-driven educational technologies with immersive learning environments.

Four major thematic clusters emerge from the visualization. The Education and Learning cluster encompass terms related to pedagogical approaches and outcomes, including "students," "learning engagement," "e-learning," and "teaching." This cluster emphasizes researchers' focus on improving instructional methodologies and enhancing student performance through technological innovation. The Immersive Technologies cluster features terms like "augmented reality," "virtual reality," "extended reality," and "simulation," demonstrating the significant research investment in technologies that create experiential learning environments. The density of this cluster suggests robust exploration of how these technologies can transform traditional educational approaches into more engaging, interactive experiences.

The AI and Data Science cluster, containing terms such as "machine learning," "data mining," "deep learning," and "predictive modeling," reflects the growing application of artificial intelligence in educational contexts. This cluster illustrates how researchers are increasingly leveraging computational approaches to develop personalized learning systems, perform educational analytics, and support evidence-based decision-making in educational settings. The Health and Medical Education cluster, featuring "medical education," "surgical simulation," "nursing students," and "dissection," demonstrates the particular relevance of immersive technologies in healthcare training, where hands-on experience is crucial but often limited by practical and ethical constraints.

The visualization reveals key keyword connections. Links between "students" and terms like "motivation," "engagement," and "performance" highlight the focus on student outcomes when implementing new technologies. These connections show how innovations address educational challenges like maintaining interest and improving results. Similarly, connections between "virtual reality" and terms like "simulation" and "training" demonstrate VR's role in creating practical skill development environments that safely replicate real-world scenarios. Links between "machine learning" and terms like "data mining" and "learning analytics" show how AI methodologies analyze educational data at scale. This represents a shift toward evidence-based practices that use data to improve teaching and learning strategies. This research highlights AI's potential to transform both educational delivery and evaluation.

The interdisciplinary nature of this research field becomes evident through this visualization. Researchers are actively exploring the synergistic potential of combining AI, AR, and VR to create more effective, engaging, and accessible learning environments across multiple domains. The clustering patterns reveal emerging specialized research areas, including AI-powered adaptive learning systems that respond to individual student needs and immersive medical training simulations that allow for risk-free practice of complex procedures. These subfields represent promising directions for future research and application, suggesting that the convergence of these technologies will continue to evolve and reshape educational practices across disciplines.

The bibliometric analysis reveals several key aspects of the AI-AR-VR convergence in education research landscape. The field exhibits remarkable interdisciplinary characteristics, with researchers from diverse backgrounds including computer science (Abdrakhmanov, Tuimebayev, et al., 2024), education, healthcare (Ali et al., 2024; Awais et al., 2021; Bailey et al., 2023), psychology (Abbiati et al., 2024; Awais et al., 2021), and engineering (Abellán-Nebot, 2020; Abotaleb et al., 2023; Aboushal & Gharib, 2020) contributing to a rich knowledge ecosystem that crosses traditional academic boundaries. This integration of multiple disciplines has facilitated comprehensive approaches to solving complex educational challenges through technological innovation. The data shows particularly strong connections between technology development and educational implementation, with research clusters forming around applications in medical training, language acquisition, architectural visualization, and other specialized domains.

Analysis of keyword frequencies and citation patterns highlights emerging research trends, with immersive learning environments (Abdrakhmanov, Tuimebayev, et al., 2024), AI-driven analytics (Alkhalil et al., 2021; Anand & Mitchell, 2022), and personalized education pathways dominating recent publications. These trends reflect a paradigm shift from traditional educational models toward adaptive systems that respond to individual learner needs and provide contextually relevant experiences. Publications increasingly focus on how AI algorithms can process learner data to dynamically adjust content delivery within immersive environments, creating educational experiences that adapt in real-time to student performance, preferences, and learning styles. This emphasis on personalization represents a significant departure from one-size-fits-all approaches to education.

The collaboration network visualization demonstrates how researchers are actively forming intellectual communities around specific applications and methodological approaches. These collaborative clusters typically develop around shared research interests, institutional affiliations, or geographical proximity, creating centers of expertise that drive innovation in particular niches. The visualization reveals both densely connected research teams with sustained collaborations and emerging networks that represent newer research directions. These collaborative structures facilitate knowledge transfer between technology developers and educational practitioners, helping to bridge the gap between theoretical innovation and practical implementation.

Perhaps most striking is the rapid growth trajectory observed in publication output. The exponential increase in research articles, particularly since 2020, signals extraordinary interest in leveraging these technologies for educational purposes. This acceleration correlates with several factors, including technological advancements that have made AR/VR hardware more accessible, breakthroughs in machine learning algorithms that enable more sophisticated adaptive systems, and real-world catalysts such as the COVID-19 pandemic that heightened demand for innovative remote learning solutions (Abalkheel, 2021). The sustained nature of this growth suggests not merely a temporary trend but a fundamental transformation in how educational experiences is conceptualized, designed, and delivered across multiple domains.

CONCLUSION

This scientometric analysis offers a comprehensive overview of the integration of Artificial Intelligence (AI), Augmented Reality (AR), and Virtual Reality (VR) within immersive learning environments. The findings reveal a significant increase in research interest since 2020, largely driven by rapid technological advancements and global shifts in educational practices. The combination of these technologies is shown to be transformative, enabling new forms of personalized, interactive, and contextually rich learning experiences that go beyond the capabilities of traditional methods.

The study identifies a wide range of interdisciplinary applications, including medical training, architectural visualization, language learning, and adaptive education systems. These diverse implementations highlight the growing momentum of this convergence across academic and professional domains. AI, AR, and VR are collectively enhancing learner engagement, improving knowledge retention, and expanding access to experiential education, especially in situations where hands-on practice may be constrained by safety, cost, or logistical barriers.

Despite the promise, several challenges remain. Technical limitations, ethical concerns, and issues related to accessibility and inclusivity continue to hinder broader adoption. Addressing these barriers is essential to ensure that the benefits of immersive learning are equitably distributed across different learning populations and regions. As the technology poised many positive benefits especially in levelling inclusivity issues and bridging geographical barriers especially in educational domain where not only student can comprehensively be involved in immersive learning environment, yet the helps teachers to deliver quality teaching materials to students in rural areas.

Future research should focus on long-term impact assessments, cross-disciplinary collaboration, and the creation of evidence-based frameworks to guide implementation. By doing so, educators, researchers, and policymakers can ensure that the integration of immersive technologies into education contributes to meaningful and inclusive learning transformations. The convergence of AI, AR, and VR represents not only a technological advancement but also a fundamental shift in how knowledge is delivered and experienced.

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Competing Interest Declaration

The authors declare that there are no conflicts of interest regarding the publication of this article. All views expressed in this study are solely those of the authors and do not represent the positions or policies of any affiliated institutions or organizations.

Consent to Participate Declarations: All authors give their full consent to participate in this study and to the publication of this manuscript.

Consent to Publish Declarations: All authors give their full consent for the publication of this manuscript and affirm that the content has not been previously published or submitted elsewhere.

Availability of Data and Material

Material and data for this study are available from attached link:
https://www.scopus.com/results/results.uri?s=TITLE-ABS-KEY%28%28%22students%22+OR+%22learners%22+OR+%22K-12+education%22+OR+%22higher+education%22+OR+%22STEM+education%22%29+AND+%28%22artificial+intelligence%22+OR+%22machine+learning%22+OR+%22augmented+reality%22+OR+%22virtual+reality%22+OR+%22immersive+technologies%22%29+AND+%28%22learning+outcomes%22+OR+%22engagement%22+OR+%22motivation%22+OR+%22academic+performance%22+OR+%22skill+acquisition

%22%29%29&limit=10&origin=searchhistory&sort=plf-f&src=s&sot=a&sdt=a&sessionSearchId=199faa45ecc33e84dde63b4bdca81374

Ethics Approval

This research is a part and partial that was conducted under the MRECID 202133-9908 and UPTM/IT/2025-175025(112) approved by UPTM Ethics Board and Research Management Institute (RMIC).

Author Contributions Statement

Conceptualized the study; M.N.A.R., N.D.A., M.S.M., S.R., & Z.Y.
Design the methodology; N.R., M.A., M.N.A.R., M.I.M.N., N.Y., & M.Z.G.
Data acquiring, analysis, and reporting; M.I.M.N., M.N.A.R., N.D.A., & M.Z.G.
Write, review and editing the manuscript; M.N.A.R., N.D.A., M.D., S.R., & M.A.,
Provide critical feedback; N.R. & Z.Y.

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