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Bibliometric Analysis: Trends and Development of Interactive Multimedia Research Based on Augmented Reality in Education

Damai Lintang Abdisa[1], Heca Apriliya Bekti Pratiwi[*2], Muhammad Fathan Mubiinaa[3], Muhammad Okhe[4], Rasyida Fauziah Murdiana[5]

[1] Universitas Negeri Malang, Jawa Timur, Indonesia; damai.lintang.2401216@students.um.ac.id
[2] Universitas Negeri Malang, Jawa Timur, Indonesia; heca.aprilya.2401216@students.um.ac.id
[3] Universitas Negeri Malang, Jawa Timur, Indonesia; muhammad.fathan.2401216@students.um.ac.id
[4] Universitas Negeri Malang, Jawa Timur, Indonesia; muhammad.okhe.2401216@students.um.ac.id
[5] Universitas Negeri Malang, Jawa Timur, Indonesia; rasyida.fauzia.2401216@students.um.ac.id

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Abstract

The development of interactive multimedia based on Augmented Reality (AR) in education has increased significantly in recent years; however, the research landscape remains fragmented and has not been comprehensively mapped. This study aims to analyze trends, intellectual structure, and the direction of research development on AR-based interactive multimedia in education through a bibliometric approach. A descriptive quantitative design was employed using 500 articles published between 2020 and 2026, retrieved through Publish or Perish based on Google Scholar data. The metadata were analyzed using VOSviewer to generate network, overlay, and density visualizations of keyword co-occurrence. The findings reveal four major research clusters: AR implementation in educational contexts, technology integration and student experience, mobile-based application development, and effectiveness and learning performance evaluation. Recent trends indicate a shift from media development toward empirical validation through systematic reviews and meta-analyses. The study concludes that AR research in education has entered a phase of scientific consolidation with a stronger emphasis on evidence-based evaluation, although further studies are needed to integrate instructional design principles, longitudinal perspectives, and affective as well as metacognitive dimensions.

Kata Kunci:

Analisis Bibliometrik; Augmented Reality (AR); Multimedia

Abstrak

Perkembangan multimedia interaktif berbasis Augmented Reality (AR) dalam pendidikan menunjukkan peningkatan signifikan, namun lanskap risetnya masih tersebar dan belum terpetakan secara komprehensif. Penelitian ini bertujuan

Interaktif; Teknologi Pendidikan; VOSviewer.

menganalisis tren, struktur intelektual, dan arah perkembangan riset multimedia interaktif berbasis AR dalam pendidikan melalui pendekatan bibliometrik. Metode yang digunakan adalah analisis kuantitatif deskriptif dengan memanfaatkan data 500 artikel periode 2020–2026 yang dihimpun melalui Publish or Perish berbasis Google Scholar. Data dianalisis menggunakan VOSviewer untuk memetakan co-occurrence kata kunci dalam bentuk network, overlay, dan density visualization. Hasil penelitian menunjukkan terbentuknya empat klaster utama, yaitu implementasi AR dalam pendidikan, integrasi teknologi dan pengalaman peserta didik, pengembangan aplikasi berbasis mobile, serta evaluasi efektivitas dan performa belajar. Tren terbaru memperlihatkan pergeseran fokus dari pengembangan media menuju pengujian efektivitas melalui systematic review dan meta-analisis. Simpulan penelitian ini menegaskan bahwa riset AR telah memasuki fase konsolidasi ilmiah dengan orientasi pada pembuktian empiris, meskipun masih terdapat peluang pengembangan pada aspek desain instruksional berbasis teori, studi longitudinal, serta dimensi afektif dan metakognitif.

Corresponding Author:
Heca Apriliya Bekti Pratiwi
Universitas Negeri Malang, Jawa Timur, Indonesia; heca.aprilya.2401216@students.um.ac.id

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INTRODUCTION

The development of digital technology in the era of Industry 4.0 and Society 5.0 has structurally and epistemologically transformed education systems. The integration of intelligent technologies, mobile computing, and data-driven systems has shifted education from traditional knowledge transmission models toward interactive, technology-based learning centered on students. From an Educational Technology perspective, this transformation goes beyond mere digitization of media; it entails a reconstruction of instructional design that places the learning experience at the core. Interactive multimedia has emerged as a strategic component, as it integrates multiple representations of information while facilitating active participation in knowledge construction.

Conceptually, interactive multimedia combines text, images, audio, animation, and video within a digital environment that allows user control. Its interactivity and non-linearity align with the Cognitive Theory of Multimedia Learning, which emphasizes the integration of visual and auditory channels, and with constructivist perspectives that encourage exploration and reflection. With multimodal and adaptive design, interactive multimedia enhances cognitive engagement, motivation, and learning outcomes through more meaningful experiences (Arduini & Chiusaroli, 2021).

The evolution of interactive multimedia has further advanced through the integration of Augmented Reality (AR), which overlays virtual objects onto real-world environments in real time. The pedagogical advantage of AR lies in its ability to visualize abstract concepts in three dimensions and within contextual settings. Various studies have shown that AR enhances conceptual understanding and critical thinking skills by providing more concrete biological visualizations and dynamic visual interactions (Ramadhan et al., 2024; Muhammad Amin et al., 2023).

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Pedagogically, transforming abstract concepts into concrete representations remains a major challenge in learning. Two-dimensional representations often increase cognitive load and risk of misconceptions. AR bridges abstraction and reality by presenting contextualized three-dimensional visualizations, thereby supporting deeper and more exploratory cognitive elaboration (Ratih et al., 2025; Setyaningrum & Jaelani, 2025; Ahmad et al., 2021).

Although AR research in education has increased significantly and spans domains such as inclusive education and immersive exploration, existing literature remains scattered and structurally unmapped at a global level (Emma, 2024; Vanjari et al., 2021; Wang & Xie, 2025; Onyejelem & Aondover, 2024). Most studies focus on media development and effectiveness testing, while mapping the intellectual structure of the field remains limited. Therefore, bibliometric analysis is essential to identify publication trends, collaboration networks, keyword evolution, and research frontiers, providing an analytical foundation for developing evidence-based research agendas and instructional design in Educational Technology.

METHOD

This study employs a quantitative descriptive method with a bibliometric analysis approach (Donthu et al., 2021). This approach was chosen for its validity and reliability in comprehensively mapping trends and the developmental direction of existing scientific literature. The initial stage focused on collecting bibliographic data automatically using the software Publish or Perish (PoP). Literature retrieval utilized the Google Scholar database to access a broad range of relevant scholarly articles. The search was conducted using a combination of specific English-language keywords: "Augmented Reality", "Interactive Multimedia", and "Education", to ensure precise findings with a global scope. To maintain relevance and currency, the inclusion criteria were limited to publications from 2020 to 2026. Through this process, a total of 500 scholarly articles meeting the criteria were collected. Metadata from these articles—including title, author names, publication year, journal name, abstract, and citation count—was extracted and saved in Research Information Systems (.ris) format for further visualization analysis.

The subsequent stage involved data analysis and visualization using the software VOSviewer (van Eck & Waltman, 2010). The collected .ris metadata was imported into the application for bibliometric mapping, focusing on keyword co-occurrence to understand relationships among terms and clusters. Network visualization was employed to map topic clusters and examine the relationships between frequently co-occurring terms, where node size represents keyword frequency and connecting lines indicate the strength of their relationships in AR multimedia research. Overlay visualization was used to track the novelty of research topics over time, highlighting trends and shifts in focus from 2020 to 2026. Density visualization identified concentrations of research focus, with darker, denser areas representing high topic saturation, while lighter areas reveal research gaps or opportunities for further exploration in interactive media development.

RESULT AND DISCUSSION

Result

Based on data obtained from Google Trends using the keyword "augmented reality education" for the 2022–2026 period, the search interest pattern appears fluctuating but shows an upward trend toward the end of the observation period. The search index ranges from 0 to 100, where a value of 100 represents the highest level of popularity within the selected timeframe.

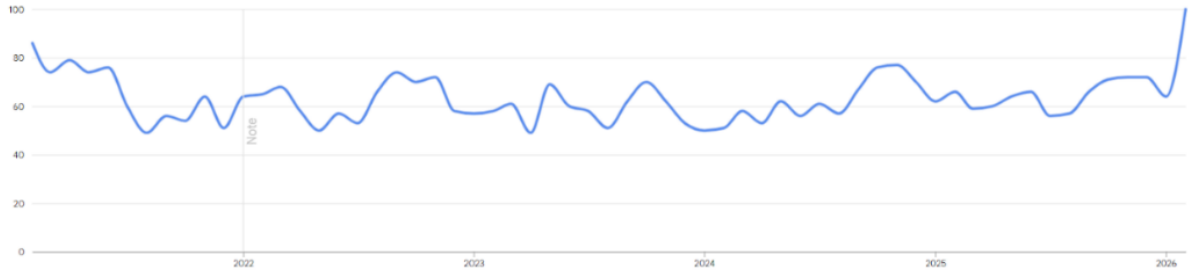


Figure 1. Augmented Reality (AR) Graph Using Google Trends.

The graph indicates that search interest in augmented reality in education experienced several declines in the middle of the observed period, but increased significantly again toward 2025–2026. This suggests that AR in education remains relevant and continues to attract strong interest in both academic and practical domains.

These findings are consistent with a systematic review by Sinaga and Wachid (2025), which reported a significant increase in AR research in education in recent years. Furthermore, a meta-analysis by Weng and Chen (2023) revealed a growing number of empirical studies examining the effectiveness of AR in science learning. The recent rise in search interest may also be associated with the expanding discourse on the effectiveness and impact of technology-based learning, as discussed by Buchner and Kerres (2023), who highlighted the dominance of media comparison studies in AR research within higher education.

Thus, data from Google Trends reinforces the results of bibliometric analyses indicating that augmented reality in education is a continuously developing field with strong potential for further research. Based on the analyzed literature, six main articles were identified as highly relevant to the keyword "Augmented Reality in Education". These articles make significant contributions to the advancement of AR research, including empirical studies, meta-analyses, and theoretical reviews. The highest citation counts are presented in Table 1.

Table 1. Key Literature on Augmented Reality in Education (2022–2025).

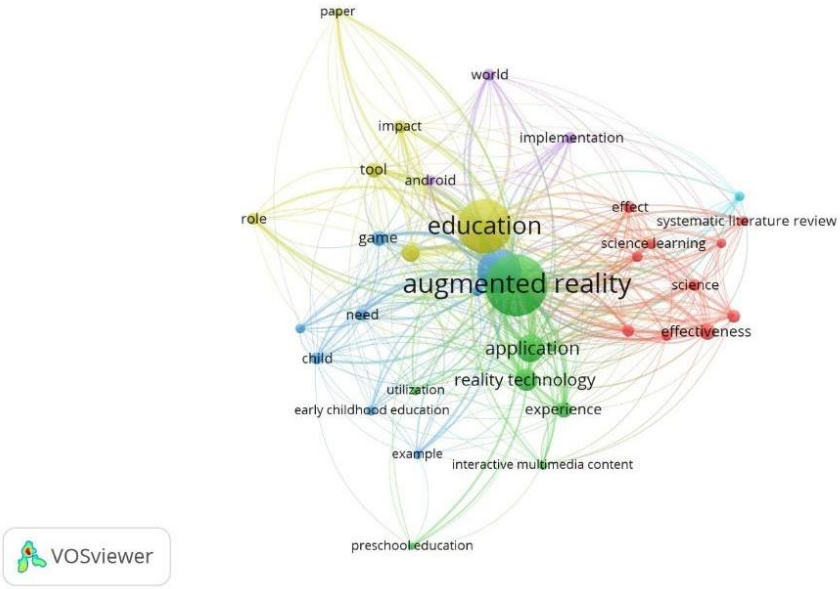
No.	Title	Name	Year
1.	The effectiveness of Articulate Storyline 3-based media on student learning outcomes in elementary schools	Budiarto & Jazuli	2022
2.	The Cambridge Handbook of Multimedia Learning (3rd ed.)	Mayer	2022
3.	Media comparison studies dominate augmented reality research in higher education	Buchner & Kerres	2023
4.	The impact of augmented reality on students' learning performance in science education: A meta-analysis	Weng & Chen	2023
5.	The past, present, and future of the cognitive theory of multimedia learning	Mayer	2024
6.	A systematic review of augmented reality's impacts on education	Sinaga & Wachid	2025

Based on Table 1, the article with the highest number of citations is *The Past, Present, and Future of the Cognitive Theory of Multimedia Learning* by Mayer (2024), with 745 citations, followed by *The Impact of Augmented Reality on Students' Learning Performance in Science Education: A Meta-Analysis* by Weng and Chen (2023), with 711 citations. This indicates that studies grounded in multimedia learning theory and meta-analyses examining the effectiveness of AR have exerted a particularly strong influence on the development of technology-enhanced education research.

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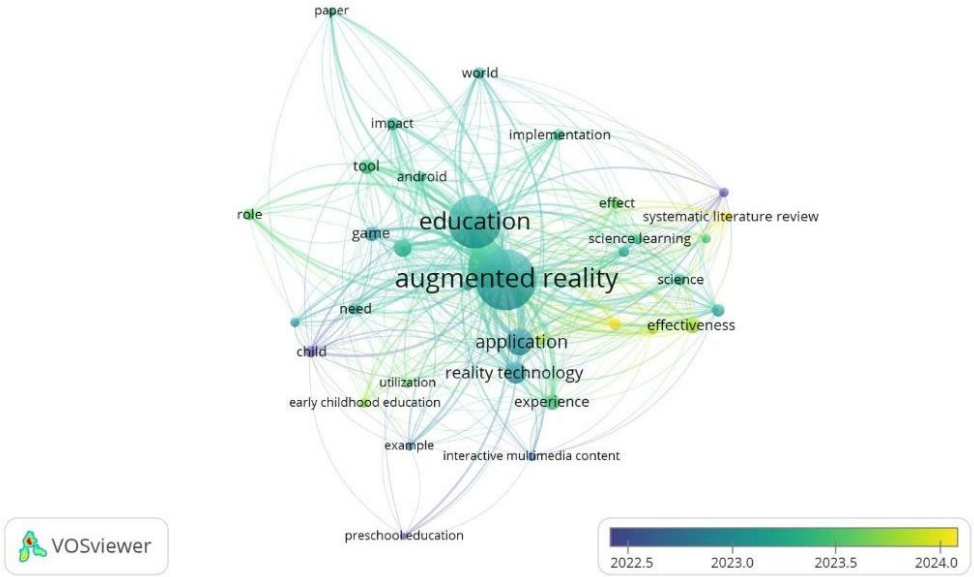
Meanwhile, the article *A Systematic Review of Augmented Reality's Impacts on Education* by Sinaga and Wachid (2025) has not yet received citations, which is likely due to its relatively recent publication year, limiting the time available for other researchers to reference it.

The identification of significant themes in each study was conducted through overlay visualization and density visualization analyses. These findings were generated by calculating keyword pairs (co-occurrence analysis) using the software VOSviewer. Each cluster is associated with related terms, indicating interconnections and the evolving development of research in the field of augmented reality in education.



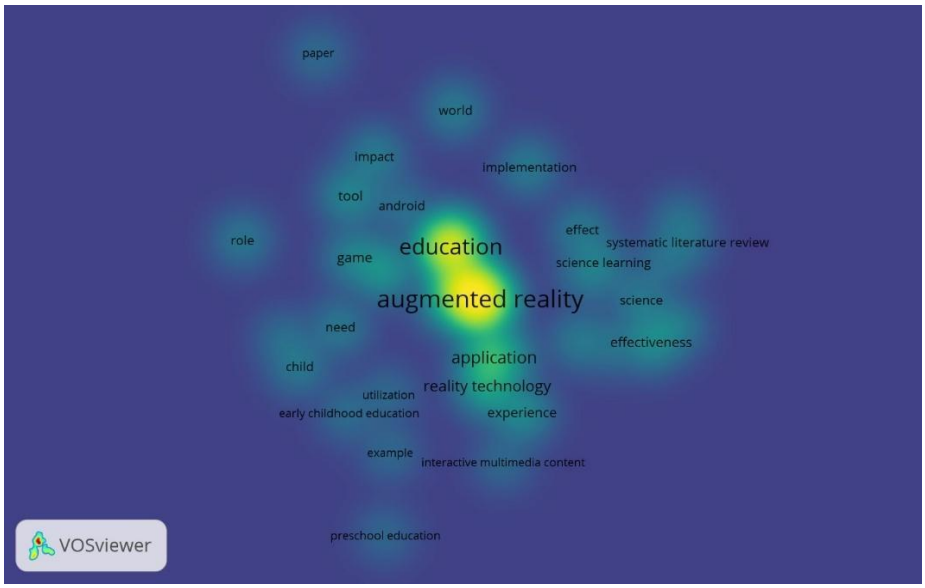
Picture 2. *Network Visualization.*

The relationships among terms are illustrated in Figure 2 through network visualization, where connections are represented as a network of lines linking one term to another. The thicker the connecting lines and the larger the node size, the stronger the relationship between the corresponding keywords. This visualization demonstrates that the terms *augmented reality* and *education* serve as the central nodes of the network, exhibiting the highest level of interconnectedness compared to other terms.



Picture 3. *Overlay Visualization.*

The research trends of augmented reality in the field of education are illustrated in Figure 3 through overlay visualization. Brighter colors (yellow) represent more recent and emerging keywords in the latest research period, while darker colors (blue–green) indicate topics that were explored earlier. Based on this visualization, themes such as *effectiveness*, *systematic review*, and *learning performance* appear as the most recent research focuses. This shift suggests a transition from application development–oriented studies toward research emphasizing impact evaluation and research synthesis in augmented reality–based learning.



Picture 4. *Density Visualization.*

Furthermore, the density visualization is presented in Figure 4. The darker the yellow color and the larger the appearing circles, the higher the density and frequency of occurrence of those keywords in the literature. This indicates that research on these topics is more prevalent and widely studied. Conversely, when the color fades and blends into the green background, it suggests that the research frequency on those topics is relatively lower.

Table 2. Summary of Clusters and Research Trends on Augmented Reality in Education.

Cluster	Dominant Keywords	Thematic Focus	Trend & Density
Cluster 1	*Augmented reality*, *education*, *media*	Implementation of AR in Educational Contexts and Learning Media	High Density, Serving as the Research Network Hub
Cluster 2	*Technology*, *student*, *application*	Integration of AR Technology and Student Engagement	Stable and Continuously Growing in Recent Years
Cluster 3	*Learning performance*, *effectiveness*, *meta-analysis*	Evaluation of AR's Impact and Effectiveness on Learning Outcomes	Emerging as a Recent Trend (Yellow Overlay)
Cluster 4	*Android-based AR*, *development*, *learning media*	Development of AR-Based Applications and Learning Media	Trend Increasing During the 2022–2025 Period

Based on the mapping results, several clusters were identified, each representing different yet interconnected research focuses. Each group or cluster contains relationships among terms that reflect prevailing research trends. The most dominant terms in Cluster 1 center on *augmented reality*, *education*, and *application*, indicating that research is still largely dominated by studies examining the implementation and effectiveness of AR in learning contexts.

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This clustering is important for understanding the interconnections among subtopics and for providing insights into the future direction of research development. Through bibliometric analysis, the mapping of augmented reality research in education can serve as a foundation for further studies, particularly in integrating instructional design grounded in multimedia learning theory and evaluating learning effectiveness (Buchner & Kerres, 2023; Mayer, 2022; Mayer, 2024; Sinaga & Wachid, 2025; Weng & Chen, 2023). Moreover, this mapping highlights opportunities for the development of AR as an innovative learning medium that supports educational transformation in the digital era.

Discussion

This study aims to map the intellectual structure and dynamic development of interactive multimedia research based on Augmented Reality (AR) in education during the 2020–2026 period. Based on bibliometric analysis of 500 scientific articles visualized using VOSviewer, the findings indicate that AR research in education has evolved within a multidisciplinary structure integrating pedagogical aspects, interactive multimedia design, and digital technology system integration. These findings explicitly address the research problem by demonstrating that AR is no longer positioned merely as a visual support tool, but rather as a complex and integrated digital learning ecosystem.

Compared to previous studies published in reputable international journals such as Computers & Education, which initially focused on testing learning effectiveness through experimental designs, the results of this study reveal a paradigm shift. Contemporary research no longer emphasizes solely the comparison of learning outcomes between control and experimental groups but has moved toward optimizing immersive instructional design, enhancing learning experiences, and integrating adaptive technologies. Thus, it can be concluded that AR research has entered a phase of systemic integration within the broader digital transformation of education.

The findings were obtained through keyword co-occurrence analysis and network visualization, which revealed strong interconnections among the terms "augmented reality", "interactive learning", "student engagement", and "instructional design". The density of these relationships indicates that AR is now understood as a medium for active and participatory learning. Overlay visualization also demonstrates temporal development: publications from 2020–2022 focused primarily on media development and learning outcome measurement, whereas publications from 2023–2026 show increasing attention to immersive learning, artificial intelligence integration, adaptive learning systems, and the educational metaverse ecosystem. This pattern aligns with international publications in the British Journal of Educational Technology, which emphasize the positioning of AR as part of immersive pedagogical strategies grounded in experiential learning.

From a theoretical perspective, these findings confirm the continued relevance of constructivist theory in AR-based learning environments. The dominance of active learning and student-centered learning concepts indicates that AR supports independent knowledge construction through contextual exploration and three-dimensional simulation. Research published in Computers in Human Behavior further demonstrates that AR environments can enhance cognitive engagement and intrinsic motivation when designed with appropriate pedagogical approaches. Therefore, constructivist theory is not only maintained but reinforced within immersive digital learning contexts.

However, the results also indicate increasing scholarly attention to instructional design and cognitive load. This suggests that AR implementation without structured instructional planning may generate excessive cognitive load. Consequently, Cognitive Load Theory retains a crucial role in AR-based instructional design. These findings do not contradict the theory but rather extend its application to multimodal and immersive environments. The integration of AR must carefully balance visual stimulation with learners' cognitive processing capacity.

When compared with national studies published in Sinta-indexed journals, differences in research orientation become evident. Most national studies still concentrate on Android-based AR media development and effectiveness testing through pretest–posttest designs. Although these studies contribute empirically to improving learning outcomes, they tend to adopt a product-oriented approach and have not extensively developed theoretical models or systemic frameworks. In contrast, international research has advanced toward integrating AR with learning analytics, artificial intelligence, and ecosystem-based adaptive learning design. This comparison reveals a gap between national and international research trends that needs to be addressed through theoretical strengthening and systemic innovation.

From an educational management perspective, these findings indicate that AR implementation is not merely a learning media innovation but part of institutional digital transformation. AR integration requires strategic planning, digital leadership, organizational readiness, and data-driven policy. The adoption process can be analyzed using innovation diffusion theory and strategic technology adoption models. Therefore, AR management within educational institutions should be understood as a systematic organizational change process rather than a short-term technological intervention.

Based on the integration of bibliometric findings and comparisons with previous research, this study proposes a modification of the Technological Pedagogical Content Knowledge framework. The advancement of immersive technologies, artificial intelligence integration, and adaptive learning systems indicates that the technological knowledge dimension within TPACK has expanded in meaning. Accordingly, a conceptual reinforcement termed Immersive-TPACK is proposed, emphasizing the integration of adaptive immersive technologies within the relationship between pedagogy and content knowledge. This proposal does not replace the TPACK framework but refines it to better align with contemporary immersive digital learning realities.

Overall, this study successfully addresses the research problem by demonstrating that the structure of AR research in education has developed multidimensionally and become increasingly integrated with intelligent learning systems. The findings confirm constructivist theory, extend the application of Cognitive Load Theory in immersive contexts, identify gaps between national and international research trends, and propose a conceptual modification through Immersive-TPACK. Therefore, this discussion contributes both theoretically and practically to the advancement of educational management scholarship in the era of immersive digital transformation.

CONCLUSION

Based on a bibliometric analysis of 500 articles published between 2020 and 2026 and visualized using VOSviewer, it can be concluded that interactive multimedia research based on Augmented Reality (AR) in education has experienced significant development and has formed a systematically clustered intellectual structure. This structure reveals four major trends: (1) AR implementation in learning contexts, (2) integration of technology with learner experience, (3) development of mobile learning–based applications, and (4) evaluation of learning effectiveness and performance. These findings explicitly answer the research problem by demonstrating that the development of AR in education is not unidimensional but rather multidimensional and interconnected, with the concepts of "augmented reality" and "education" serving as the central nodes within the knowledge network.

The overlay visualization further indicates a shift in research trends from a primary focus on technological product development toward evidence-based approaches through systematic reviews and meta-analyses. This transition suggests that AR research in education has entered a phase of scientific consolidation, where empirical validation and research synthesis have become central priorities. Consequently, research development is no longer solely oriented toward technical

innovation but also toward demonstrating measurable impacts on instructional quality, learner engagement, and improved learning performance.

From a theoretical perspective, these findings confirm the relevance of the Cognitive Theory of Multimedia Learning and the Technological Pedagogical Content Knowledge framework in explaining AR integration in educational settings. However, the increasing complexity of immersive technologies indicates that the technological knowledge dimension requires further strengthening to accommodate the interactive, contextual, and adaptive characteristics of AR. Therefore, this study contributes conceptually by highlighting the need for a more integrative framework that is responsive to immersive technologies in educational management, ensuring that AR integration is not merely technical but also strategic and pedagogical in nature.

The implications of this research for educational management lie in the importance of strategic planning, organizational readiness, and data-driven decision-making in AR implementation within educational institutions. Digital transformation involving AR demands adaptive educational leadership, innovation-supportive policies, and continuous evaluation of instructional effectiveness. Thus, this study not only enriches the scientific mapping of AR in education but also provides a forward-looking direction for policy development and educational management practices grounded in immersive technology and oriented toward sustainable improvement in learning quality.

ACKNOWLEDGMENT

This study affirms that the entire scientific substance—including the formulation of research problems, construction of the theoretical framework, interpretation of bibliometric analysis results, and derivation of conceptual implications—was developed through a synthesis of literature from reputable international journals indexed in Scopus and nationally indexed journals in Sinta, as well as data processing conducted using VOSviewer. The knowledge generated in this article is grounded in empirical analysis of scientific publication metadata and the integration of established theories in educational management and learning technology.

The use of Artificial Intelligence (AI), including generative language models such as ChatGPT, was strictly limited to technical assistance functions, namely supporting editorial refinement, improving academic language accuracy, enhancing inter-paragraph coherence, and increasing efficiency in manuscript editing. AI was not employed to generate research data, conduct statistical analyses, determine findings, or draw scientific conclusions. All data analysis processes, interpretation of findings, theoretical validation, and reference selection remained entirely under the author's control as the researcher.

Therefore, the use of AI in this study functions solely as a writing assistance tool rather than as a primary source of knowledge or a substitute for scientific reasoning. Academic responsibility, originality of ideas, analytical integrity, and citation accuracy remain fully attributable to the author. This approach aligns with established principles of publication ethics, which position AI as a supportive instrument rather than an intellectual contributor in the production of scientific knowledge.

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