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THE EVOLVING LANDSCAPE OF IMMERSIVE TECHNOLOGIES IN EARLY CHILDHOOD EDUCATION: A BIBLIOMETRIC AND THEMATIC ANALYSIS

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ABSTRACT

Immersive technologies are becoming more visible in early childhood education, but the evidence base remains fragmented across different tools, learning settings, and reported outcomes, making it difficult to build a coherent understanding of the field. This study addresses that gap through a bibliometric analysis of peer reviewed journal articles indexed in the Scopus database. A total of 52 publications were examined using citation analysis and co word analysis with VOS viewer to map publication patterns, influential works, and major research themes. The findings show a steady increase in both publications and citations, suggesting growing academic interest in this area. Three major thematic clusters emerged, namely technology driven pedagogical innovation, contextual digital integration in early childhood environments, and child development-oriented outcomes. Although the field is expanding, the review highlights the need for stronger links to pedagogical theory, greater attention to equity and context, and more longitudinal perspectives on children's development. These findings offer a clearer evidence base for future research and practice.

keywords: immersive technologies, early childhood education , contextual digital integration.

1. INTRODUCTION

In recent years, there has been a lot of interest in incorporating immersive technologies like mixed reality (MR), augmented reality (AR), and virtual reality (VR) into early childhood education. Immersion technology provides interactive, multimodal experiences that can potentially engage young learners in new ways by bringing abstract ideas to life and increasing engagement. During the crucial time for cognitive development in early childhood, children learn the fundamentals of language, attention, memory, and problem-solving. Educators and academics are increasingly investigating how immersive tools can enhance these cognitive processes because of the significance of this developmental stage. Despite the increased interest, the topic is still fragmented, with few systematic assessments of the effects of immersive technology on early childhood cognitive development domains. This review aims to address this gap by synthesizing existing research, identifying patterns, and highlighting areas for further investigation. By focusing on the interplay between immersive technology and cognitive development, this paper contributes to understanding how such tools can effectively

2. IMMERSIVE TECHNOLOGY IN EARLY CHILDHOOD EDUCATION

In the landscape of modern education, immersive technology refers to tools that blend physical and digital environments to create interactive learning spaces, primarily through Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). Unlike traditional passive media, these technologies offer multimodal experiences that are increasingly relevant to Early Childhood Education (ECE) for their ability to visualize abstract concepts and foster active engagement (Nirmala et al., 2024).

Recent studies indicate a shift from novelty to pedagogical integration. For instance, Mixed Reality (MR) environments are now being utilized to support complex problem-solving and computational thinking skills in young children, allowing them to interact with digital elements in physical spaces (Hwang et al., 2023). Similarly, VR provides synthetic environments that can isolate specific learning tasks, which Septyani et al. (2025) found to significantly increase cognitive achievement scores in preschool settings by transforming static lessons into dynamic and navigable experiences.

2.1. The scope of cognitive development in early childhood

Early childhood is a critical developmental window characterized by the rapid maturation of executive functions, including attention, working memory, and inhibitory control (Berk, 2015). This review focuses on these foundational cognitive domains, as they determine a child's readiness for formal schooling and complex reasoning.

Current research suggests a strong intersection between immersive tools and these developmental milestones. Hashemi et al. (2025) demonstrate that VR training can directly target and improve executive functions, specifically enhancing attention span and cognitive dominance in young learners. By leveraging the interactive nature of these technologies, educators can create cognitive gyms where children practice memory and logic skills in a highly motivating context, effectively supporting the transition from sensorimotor exploration to preoperational thought (Yang et al., 2024).

2.2. Purpose of the Review

Despite the growing body of research reporting positive learning and cognitive outcomes associated with immersive technologies in early childhood education, the existing literature remains conceptually and methodologically fragmented. Many studies tend to examine specific technologies or short-term learning effects in isolation, with limited attention to broader developmental trajectories or integrated cognitive outcomes (Mitra,2024). As a result, evidence on how immersive technologies collectively influence key domains of early childhood cognitive development remains uneven and difficult to consolidate (Hou,20250.

In response to these limitations, the present review synthesizes recent empirical findings to provide a more cohesive understanding of the field. By drawing on systematically assessed studies, this paper identified emerging patterns in how augmented reality, virtual reality, and mixed reality influence foundational cognitive domains in early childhood, particularly memory and problem-solving. By analyzing findings from systematic assessments, this paper;

i. identified emerging patterns in how Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) specifically influence cognitive domains like memory and problem-solving.

3. METHODOLOGY

3.1 Bibliometric approach

Bibliometric analysis is the application of statistical and mathematical methods to books and

other media to demonstrate historical movements and collaboration patterns in research (Pritchard, 1969). This methodology is particularly valuable for its ability to handle large volumes of unstructured data, allowing for a comprehensive overview of a scientific landscape that traditional reviews cannot easily manage (Ellegaard & Wallin, 2015). Bibliometrics offers a more objective, macroscopic view of the literature without the need to narrow the sample size significantly (Linnenluecke et al., 2020). Generally, the field is divided into a primary procedure, science mapping, which visualizes the cognitive structure and evolution of the field (Cobo et al., 2011). To achieve the study's objectives, the study utilized a specific co-word analysis science mapping technique. Co-word Analysis was utilised to decipher the conceptual structure of the field, this method examines the co-occurrence of keywords within document titles, abstracts, or index terms (Callon et al., 1983). It operates on the assumption that words appearing together frequently represent a thematic link, allowing researchers to visualize the semantic network of a discipline (Whittaker, 1989). By analyzing these clusters, researchers can identify both established core themes and emerging topics that are likely to shape future inquiry (He, 1999).

3.2. Search string

The following search string was applied as displayed in Table 1, to identify relevant literatures related to immersive technologies like mixed reality (MR), augmented reality (AR), and virtual reality (VR) into early childhood education;

Table 1: Search string in Scopus database

No	Keywords	Justification
1	immersive technologies	an umbrella keyword to capture studies examining interactive and experiential digital learning environments across disciplines.
2	mixed reality (MR)	to identify research integrating real and virtual learning spaces that may not be explicitly classified under AR or VR
3	augmented reality (AR)	due to its widespread application in enhancing engagement, visualization, and contextual learning in early childhood education.
4	virtual reality (VR)	to capture studies focusing on fully immersive digital environments and their cognitive, social, and affective learning outcomes.

4. RESULTS AND ANALYSIS

The results of the bibliometric analysis based on the final dataset of publications on immersive technologies in early childhood education is discussed in this section. Figure 1 presents the annual distribution of publications and citations on immersive technologies in early childhood education providing an overview of the growth and scholarly impact of research in this field over time.

The initial search of the Scopus database yielded 2,024 documents. Following the application of inclusion and exclusion criteria, including document type and relevance screening, the dataset was refined to 52 journal articles, which formed the basis for subsequent citation and co-word analyses. This filtering process ensured that only peer-reviewed journal publications with direct relevance to immersive technologies in early childhood education were retained, thereby enhancing the reliability and analytical focus of the bibliometric results presented in the following subsections

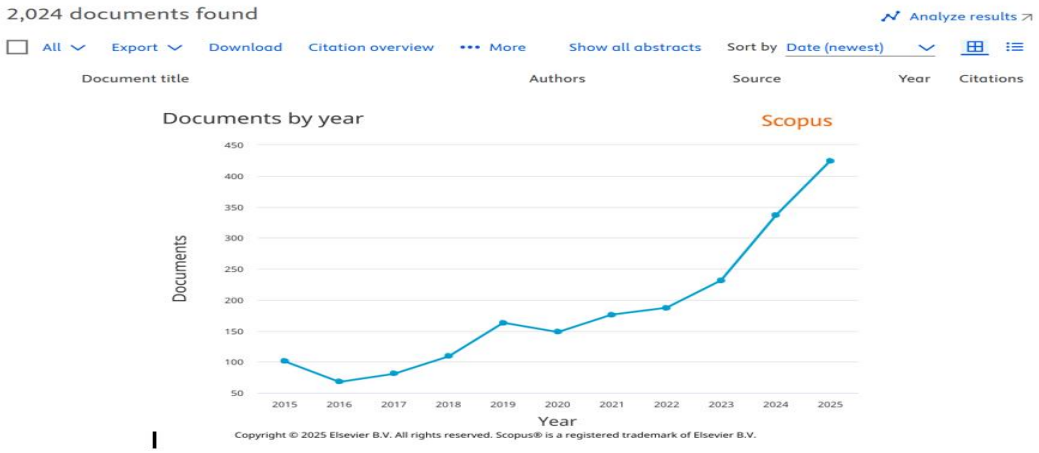

Figure 1: Annual distribution of publications and citations on immersive technologies in early childhood education.

4.1 Citation Analysis

Building on the publication and citation trends

illustrated in Figure 1, this subsection examines the intellectual influence of individual publications within the refined dataset. While Figure 1 provides a longitudinal overview of research growth and citation accumulation in the field, citation analysis (Table 2) enables a more granular assessment of which publications have exerted the greatest scholarly impact. Using VOS viewer, a citation network was constructed to identify highly cited works that form the core knowledge base of research on immersive technologies in early childhood education. To ensure analytical robustness, a minimum citation threshold of five citations was applied, resulting in the inclusion of ten highly influential publications. These sources represent foundational and frequently referenced contributions that have shaped theoretical perspectives, methodological approaches, and empirical directions within the field.

Table 2: Citation highly cited publications in immersive technologies and early childhood education.

Author	Cited by
Bailey, J. O., & Bailenson, J. N. (2017). Immersive virtual reality and the developing child. In *Cognitive development in digital contexts* (pp. 181-200). Academic Press.	102
Plumert, J. M., Kearney, J. K., & Cremer, J. F. (2007). Children's road crossing: A window into perceptual–motor development. *Current Directions in Psychological Science*, *16*(5), 255-258.	58
Wargo, J. M., & Alvarado, J. (2020). Making as worlding: young children composing change through speculative design. *Literacy*, *54*(2), 13-21.	30
Wohlwend, Karen & Scott, Jill & Yi, Joanne & Deliman, Amanda & Kargin, Tolga. (2018). Hacking Toys and Remixing Media: Integrating Maker Literacies into Early Childhood Teacher Education. 10.1007/978-981-10-6484-5_10.	24
Hutchison, A. (2018). Using virtual reality to explore science and literacy concepts. *The Reading Teacher*, *72*(3), 343-353.	23
Aslan, S., Durham, L. M., Alyüz, N., Okur, E., Sharma, S., Savur, C., & Nachman, L. (2024). Immersive multi-modal pedagogical conversational artificial intelligence for early childhood education: An exploratory case study in the wild. *Computers and Education: Artificial Intelligence, 6*.	20
Tariq, M. U. (2025). Gamification and Virtual Reality: Transforming Early Childhood Language Learning. In *Digital Pedagogy in Early Childhood Language Development* (pp. 25-52). IGI Global Scientific Publishing.	13
Shaw, P. A., Traunter, J. E., Nguyen, N., Huong, T. T., & Thao-Do, T. P. (2021). Immersive-learning experiences in real-life contexts: Deconstructing and reconstructing Vietnamese kindergarten teachers' understanding of STEAM education. *International Journal of Early Years Education, 29*(3).	12
Wang, X., Abdul Rahman, M. N. B., & Nizam Shaharom, M. S. (2024). The impacts of augmented reality technology integrated STEM preschooler module for teaching and learning activity on children in China. *Cogent Education, 11*(1).	10
Hossain, E., Cahoon, M. L., Liu, Y., Kurumada, C., & Bai, Z. (2022, October). Context-responsive asl recommendation for parent-child interaction. In *Proceedings of the 24th International ACM SIGACCESS Conference on Computers and Accessibility* (pp. 1-5).	9

4.2. Co-word analysis

The co-word analysis was conducted to examine the conceptual structure of research on immersive technologies in early childhood education. From an initial set of 2,416 keywords extracted from the final dataset, a minimum occurrence threshold of 17 was applied to ensure analytical robustness and network stability. Following this filtering process, 12 keywords met the inclusion criteria and were retained for co-occurrence analysis.

As presented in Table 3, the retained keywords reveal a research field strongly centred on technology-mediated learning systems within early childhood contexts. The keyword learning systems recorded the highest total link strength, indicating its central positioning within the network and its role in connecting technological, pedagogical, and learner-related constructs. Closely related keywords such as virtual reality, augmented reality, and immersive demonstrate that immersive modalities form the core technological foundation of the field.

The prominence of virtual reality and e-learning reflects a growing emphasis on digitally mediated learning environments that extend beyond traditional classroom practices. Their strong co-occurrence with educational technology and teaching suggests that immersive tools are increasingly framed within structured instructional designs rather than being treated as standalone innovations. This trend points to a shift toward pedagogically purposeful integration of immersive technologies in early childhood education.

Keywords associated with educational context and learners, including early childhood education,

early childhood, students, and education, are closely interlinked with the technological core. This clustering pattern indicates that existing research prioritises classroom implementation, learner engagement, and instructional relevance, aligning immersive technologies with developmental and pedagogical considerations specific to early childhood settings.

Interestingly, the presence of engineering education within the co-word network highlights an emerging interdisciplinary orientation. Its association with immersive technologies suggests that early childhood research is increasingly engaging with STEM-related learning approaches, including problem-solving, spatial reasoning, and foundational computational thinking, supported through immersive learning environments.

Overall, the co-word analysis identifies three interconnected thematic emphases: immersive learning technologies, pedagogical and instructional practices, and early childhood educational contexts. While the network structure demonstrates increasing conceptual coherence, the relatively limited number of high-frequency keywords indicates that the field remains in an early consolidation phase. This highlights the need for more theoretically integrated and longitudinal research examining how immersive technologies influence cognitive development outcomes in early childhood education.

Table 3: Top 12 keywords in the co-occurrence of keywords analysis.

Rank	Keyword	Occurrences	Total Link Strength
1	Learning systems	8	35
2	Virtual reality	14	34
3	E-learning	10	33
4	Engineering education	8	32
5	Early childhood education	7	30
6	Early childhood	9	29
7	Augmented reality	10	28
8	Students	6	26
9	Immersive	8	23
10	Teaching	5	22
11	Education	5	18
12	Educational technology	5	17

Overall, the co-word network reveals a research field structured around a limited number of high-frequency and strongly interconnected keywords, indicating an emerging but still consolidating conceptual landscape. While immersive learning technologies and digitally mediated instructional practices form the core of the network, keywords related to child development and psychological outcomes occupy more peripheral positions. This distribution suggests an imbalance in thematic emphasis and provides the basis for a cluster-level analysis to further examine how these conceptual patterns are organised within the literature.

4.3. Thematic Clustering of Research on Immersive Technologies in Early Childhood Education

To further examine the conceptual organisation of the field, a cluster-based analysis of the co-word network was conducted using VOS viewer. The analysis identified three distinct yet interconnected thematic clusters, representing technology-driven pedagogical innovation, contextual integration of digital technologies in early childhood settings, and child development-centred research outcomes. The interpretation of these clusters is presented below.

Figure 3 and Table 4 jointly illustrate the thematic structure of research on immersive technologies in early childhood education as revealed through co-word network analysis. Three interconnected clusters were identified, each representing a distinct but complementary conceptual emphasis within the literature. Rather than functioning as isolated themes, the clusters reflect a layered organization of the field, spanning technological innovation, contextual implementation, and child-centred developmental outcomes.

As summarized in Table 4, Cluster 1 (Red) represents the technological and pedagogical core of the research landscape. This cluster is anchored by keywords such as learning systems, educational technology, artificial intelligence, robotics, and computational thinking, indicating a strong focus on the design and pedagogical application of advanced digital and immersive systems in early childhood education. The central positioning of early childhood education and teaching within this cluster suggests that immersive and AI-enabled technologies are

increasingly conceptualized as instructional tools rather than peripheral innovations. This reflects a growing body of research examining how immersive technologies support structured learning environments, particularly within STEM-oriented and technology-enhanced pedagogical frameworks.

Cluster 2 (Blue) occupies an intermediary position within the network and captures the contextual integration of digital technologies in preschool and kindergarten settings. Keywords such as technology, ICT, digital competence, preschool, and kindergarten indicate an implementation-oriented thematic focus. As shown in Table 4, this cluster functions as a connective layer linking the technology-intensive emphasis of Cluster 1 with the developmental orientation of Cluster 3. Its positioning suggests that much of the literature is concerned with how immersive and digital tools are operationalized within real educational environments, including issues related to infrastructure, teacher readiness, and institutional capacity in early childhood contexts.

In contrast, Cluster 3 (Green) is distinctly child-centred and developmentally oriented. This cluster is characterized by keywords such as child development, psychology, early childhood intervention, and demographic descriptors including male and female. As outlined in Table 4, the thematic emphasis here shifts away from technology design toward developmental and psychosocial outcomes. The relative separation of this cluster from the technological core highlights a notable pattern within the literature: while immersive technologies are widely studied, fewer studies explicitly foreground long-term developmental trajectories or psychological outcomes in early childhood populations.

Taken together, the integrated interpretation of Figure 3 and Table 4 indicates that research on immersive technologies in early childhood education is structured around three complementary domains: technology-driven pedagogical innovation, contextual digital integration in early learning environments, and child development-focused outcomes. However, the clustering pattern also reveals an imbalance in emphasis, with stronger conceptual density around technological and instructional themes than around developmental and longitudinal perspectives. This suggests that, although the field is gaining coherence, further integration between technological innovation and child development theory remains an important direction for future research.

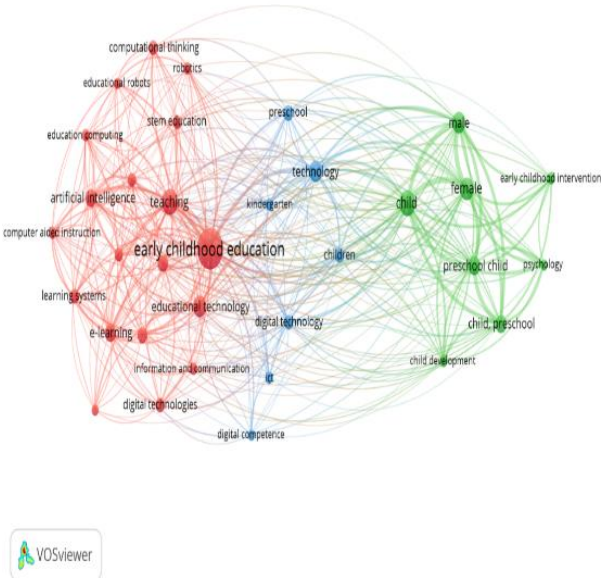

Figure 3: Network visualization of co-word analysis.

Table 4: Overview of Thematic Clusters Derived from Co-Word Network Analysis.

Cluster No. and colour	Cluster label	Essential representative keywords
1 (Red)	Immersive and AI-enabled educational technologies for early childhood learning	learning systems, educational technology, artificial intelligence, virtual reality, augmented reality, computational thinking
2 (Blue)	Digital technology integration in preschool and kindergarten contexts	digital technology, ICT, preschool, kindergarten, digital competence
3 (Green)	Child development and psychological outcomes in early childhood populations	child development, psychology, early childhood intervention, preschool child

4.4. Discussion

4.4.1. Key issues and recommendations

- ***Fragmented Pedagogical Integration of Immersive Technologies***

The bibliometric findings indicate that while immersive technologies such as virtual reality, augmented reality, artificial intelligence, and robotics are increasingly studied in early childhood education, their pedagogical integration remains fragmented. The co-word analysis shows strong emphasis on technological terms and instructional tools, but comparatively weaker linkage to coherent pedagogical frameworks and learning theories specific to early childhood development. This suggests that many studies focus on technological

affordances or short-term learning outcomes without sufficiently grounding their interventions in developmentally appropriate pedagogies. (Chee, 2002). To address this issue, it is crucial to establish comprehensive frameworks that align technological integration with established pedagogical theories, ensuring that immersive technologies enhance rather than overshadow foundational learning principles.

4.4.2. Recommendation

Future research should explicitly anchor immersive technology interventions within established early childhood pedagogical frameworks, such as play-based learning, constructivist approaches, and sociocultural learning theory. Researchers and practitioners are encouraged to design studies that examine how immersive tools support age-appropriate learning processes, including exploration, social interaction, and scaffolding, rather than treating technology as an add-on to existing instructional practices. (Dengel et al., 2021). Moreover, collaboration among educators, researchers, and technology developers is essential to create resources that effectively integrate immersive technologies into early childhood education curricula.

- ***Limited focus on developmental and longitudinal outcomes***

Although child-related keywords such as child development and psychology appear in the co-word network, they are less central than technology-focused terms. This imbalance suggests that current research prioritises technological implementation and immediate engagement outcomes over deeper developmental effects. (Johnston, 2021). There is a lack of longitudinal evidence examining how immersive technologies influence cognitive, socio-emotional, and self-regulatory development over time in early childhood populations. Future studies should adopt longitudinal and mixed-method research designs to evaluate the sustained developmental impacts of immersive technologies. (Araiza-Alba et al., 2020) Researchers should move beyond short-term performance metrics and include indicators such as executive function, language development, social competence, and emotional regulation. Such approaches would provide a more comprehensive understanding of how immersive technologies contribute to holistic child development.

- ***Uneven research emphasis across educational contexts and learner characteristics***

The cluster analysis reveals uneven attention to contextual and learner-level factors, including demographic variables and educational settings. While keywords such as preschool and kindergarten are present, there is limited differentiation across socio-cultural contexts, institutional conditions, and learner diversity. The presence of male and female keywords suggests emerging interest in child-level differences, but these aspects remain underdeveloped within the broader research landscape.

Research on immersive technologies in early childhood education should place stronger emphasis on contextual and equity-related considerations, including socio-economic background, cultural context, institutional readiness, and teacher capacity. Existing studies often overlook how these contextual factors shape access to, implementation of, and outcomes from immersive learning interventions. Greater attention to differential impacts across diverse learner groups is therefore essential to ensure that immersive technologies contribute to inclusive and equitable early childhood education practices. Policymakers and educators should prioritize context-sensitive implementation strategies that align technological adoption with local educational needs, institutional capacities, and developmental priorities.

- ***AI-integrated immersive technologies in early childhood education***

Addressing these gaps also requires deeper exploration of the intersection between immersive technologies and generative artificial intelligence (AI). The integration of AI-driven adaptive learning systems with immersive platforms offers significant potential to enhance personalization in early childhood education. Such systems can tailor learning experiences to individual developmental needs, thereby promoting engagement and deeper learning outcomes. Evidence suggests that well-designed virtual reality applications can support cognitive development and social skills in young children, particularly when they accommodate diverse learning styles and abilities (Hou, 2025). When combined with AI-enabled personalization, immersive environments may also foster collaborative learning experiences that enhance peer interaction and social development.

However, the growing integration of generative AI within immersive technologies raises important concerns regarding equity and accessibility. While AI applications can enhance learning through

customization, their effectiveness depends on adequate infrastructure, digital resources, and teacher training, which may be unevenly distributed across educational contexts (Naida et al., 2024). Without deliberate policy intervention, these disparities risk reinforcing existing educational inequalities. Consequently, policymakers must prioritize equitable access to technological resources and sustained professional development to ensure that the benefits of immersive and AI-enhanced learning are accessible to all children.

Ethical considerations further complicate the adoption of AI-integrated immersive technologies in early childhood education. The collection and analysis of children's learning data raise concerns related to privacy, consent, and data security, particularly given the vulnerability of young learners. Clear regulatory guidelines and ethical frameworks are therefore essential to protect children's rights while maintaining transparency and trust among educators and families. Importantly, such frameworks should be informed by diverse stakeholder perspectives, including educators, parents, and child development specialists, to ensure that technological deployment aligns with children's best interests and supports holistic development (Chen, 2025).

Teacher preparation and professional development represent another critical dimension of successful implementation. Educators must be equipped not only with technical competencies but also with pedagogical understanding of how immersive and AI-enabled tools can be integrated in developmentally appropriate and equitable ways. Ongoing professional development has been shown to enhance teachers' confidence and effectiveness in using technology to support diverse learners (Aliyu, 2025). In addition, collaborative professional networks can facilitate the exchange of best practices and collective problem-solving as educators navigate the complexities of emerging technologies.

Finally, stakeholder engagement and systematic evaluation are essential for sustainable and responsible integration of immersive technologies and generative AI. Engagement with parents, communities, and local organizations can ensure culturally responsive and contextually appropriate implementation, strengthening inclusivity and shared ownership (Rodríguez et al., 2024). At the same time, robust evaluation mechanisms, including longitudinal research designs, are needed to assess both educational outcomes and ethical implications over time (Cozzens et al., 2002). Collaborative frameworks involving researchers, educators, policymakers, and technology developers can further support continuous improvement and knowledge sharing (Fong & Harris, 2015). Through reflective and adaptive implementation, immersive and AI-driven technologies can be leveraged to enhance early childhood learning while reducing, rather than exacerbating, existing educational disparities (Yilmaz et al., 2024).

5.CONCLUSION

This review employed a bibliometric approach to map and synthesise research on immersive technologies in early childhood education, with particular attention to cognitive development. Analysis of publication trends, citation patterns, and co-word thematic structures reveals a field organised around three interrelated domains: technology-driven pedagogical innovation, contextual integration in early childhood settings, and child development–oriented outcomes. While the expanding literature reflects growing scholarly interest, it remains fragmented, particularly in aligning technological interventions with developmentally grounded pedagogy and longitudinal outcomes. Methodologically, this study demonstrates the value of bibliometric and co-word analysis for clarifying conceptual structures and identifying research gaps. In practical and policy terms, the findings provide an evidence-informed basis for reflective decision-making on the design and implementation of immersive and AI-enhanced learning initiatives, emphasising pedagogical alignment, developmental appropriateness, and contextual equity.

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technology

Details of the AI usage are given below:

1.Vosviewer to create image
2.Grammarly to edit the language
3.ChatGPT to support language refinement and improve clarity of expression.

Author	Contribution
Assoc. Prof. Dr. Nirumala Rothinam	Led SLR design; conducted database searches, screening, and thematic synthesis; drafted the manuscript; approved final version; accountable for all aspects of the work.
Prof. Dr. Sivabala Naidu	Contributed to searches and thematic synthesis; provided methodological guidance and critical revisions; approved final manuscript; accountable for accuracy and integrity.
Dr Ruuhina Mohd Sani	Assisted in data interpretation and synthesis; critically revised analytical sections; approved final manuscript; accountable for scholarly content.
Prof. Dr. Ranjit Singh Gill	Supported searches and appraisal; contributed to interpretation and revisions; approved final manuscript; accountable for content reliability.
Assoc. Prof. Dr. Ramachandran Vengrasalam	Participated in searches and theme validation; revised manuscript for clarity; approved final version; accountable for content integrity.
Assoc. Prof. Dr. Samikannu Jabamoney	Contributed to searches, data verification, and synthesis; revised methods/results sections; approved final manuscript; accountable for accuracy.

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