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iJIM International Journal of Interactive Mobile Technologies

iJIM | eISSN: 1865-7923 | Vol. 19 No. 10 (2025) | OPEN ACCESS

https://doi.org/10.3991/ijim.v19i10.53587

PAPER

Personalized and Interactive Mobile Learning in Early Childhood Education: A Bibliometric Study (2015–2024)

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ABSTRACT

Over the past decade, early childhood education (ECE) has undergone unprecedented transformations driven by rapid advancements in artificial intelligence (AI) and big data, as well as mobile and interactive technologies. Emerging technologies have profoundly reshaped the ECE landscape, fostering innovations in educational models, teaching methodologies, and learning experiences. This study conducts a bibliometric analysis to explore the evolution and innovation of emerging mobile and interactive models (EMIM) in ECE, with a specific focus on the application of personalized learning, adaptive learning, blended learning, intelligent tutoring, and AI-assisted learning on the foundation of EMIM. Through a bibliometric review of relevant literature over the last decade, this paper examines trends in annual publications, leading research sources, national and regional contributions, author collaborations, and the thematic evolution of research topics. The findings reveal a general upward trend in publication output in the emerging mobile and interactive models in early childhood education (ECE-EMIM) domain, with personalized learning and the application of mobile-enabled AI technologies emerging as central research themes. The United States, China, and European countries lead the field, with increasing cross-national collaboration. Moreover, research topics have progressively shifted from foundational technological exploration to more sophisticated personalized and intelligent learning models based on EMIM. As technological advancements continue, ECE-EMIM is poised to further drive global innovation in preschool education.

KEYWORDS

early childhood education (ECE), bibliometric analysis, artificial intelligence (AI), emerging mobile and interactive models (EMIM), personalized learning, blended learning, adaptive learning, AI-assisted learning

1 INTRODUCTION

With the rapid development of emerging mobile and interactive models (EMIM), the educational sector is continuously devising more effective teaching and learning

Xu, L., Rahman, M.N.A., Wong, S.Y., Zhongyao, C. (2025). Personalized and Interactive Mobile Learning in Early Childhood Education: A Bibliometric Study (2015–2024). *International Journal of Interactive Mobile Technologies (iJIM)*, 19(10), pp. 86–111. https://doi.org/10.3991/ijim.v19i10.53587

Article submitted 2024-12-01. Revision uploaded 2025-02-06. Final acceptance 2025-02-18.

models to cater to the diverse needs of both society and individuals. Technologies such as artificial intelligence (AI), big data, and the Internet of Things (IoT) are gradually being integrated into education, driving the shift from traditional learning to smart and mobile learning environments [1]. Early childhood education (ECE), encompassing educational activities for children from infancy to pre-primary age (typically 0 to 8 years old), aims to foster holistic development across cognitive, social, emotional, and physical domains [2]. Consequently, leveraging EMIM to enhance the quality of preschool education has become a central focus for both academics and practitioners.

Smart learning refers to the use of advanced information technologies, data analytics, and AI algorithms on EMIM to optimize the learning process and experience. It emphasizes improving learning outcomes through personalized environments, resources, and support [3]. Qureshi et al. [4] systematically analyzed the significance of the mobile-enabled learning paradigm in enhancing students' learning capabilities. Hoel and Mason [5] explored the differences between smart learning and traditional learning, conducting standardized assessments of the cognitive smart learning model and smartness level model. Taken together, smart learning aims to promote effective personalized learning through the application of emerging technologies on emerging mobile and interactive models.

In the context of ECE, smart learning involves the use of information technologies and AI to create interactive and mobile (ubiquitous) learning environments that foster exploration and play. These environments provide personalized, interactive, mobile, and sustainable learning experiences for preschool children. Akyol et al. [6] examined the trends in the use of digital technology in Turkish preschool education, finding that its applications are concentrated in areas such as STEM subjects, software, applications and games, distance learning, computer-aided education, and digital storytelling. Boude et al. [7] identified the essential elements that mobile applications should possess in ECE through qualitative research and found that mobile applications for preschool children must enhance cognitive processes while balancing entertainment and educational content.

Mobile technology has significantly enhanced interactive learning in ECE by offering personalized learning, gamified experiences, and real-time feedback. It not only increases the personalization, flexibility, and interactivity of learning but also provides students with tailored learning pathways through real-time feedback, data-driven insights, and intelligent algorithms. Personalized learning is an educational approach that seeks to tailor the learning experience according to each student's needs, abilities, and interests [8–9]. In ECE, the application of EMIM, particularly tablets and smartphones, provides flexible learning platforms that enable personalized learning. This form of personalized learning directly enhances interactivity, as children are able to engage in learning within an environment of self-selection and control, rather than merely passively receiving content. For example, the Khan Academy Kids app offers interactive learning content tailored to children's interests, allowing them to select and control their learning pace at any time on their mobile devices while receiving immediate feedback [10].

Adaptive learning builds on personalized learning by optimizing the educational process through real-time data analysis and feedback [11]. EMIM can provide additional practice when students perform poorly and swiftly advance to the next learning stage once a concept is mastered, thereby enhancing the personalization and targeting of learning. Applications such as DreamBox, for instance, automatically adjust the difficulty of questions or offer more suitable learning tasks based on

students' responses, learning speed, and mastery levels. This allows students to learn at a pace that best suits their individual needs [12].

Blended learning combines traditional classroom instruction with digital learning resources, preserving the benefits of face-to-face teaching while leveraging the flexibility and interactivity of technology [13]. The role of mobile technology in blended learning is primarily evident in its ability to enhance classroom interactivity through technology. For instance, teachers can use interactive platforms such as Seesaw to extend classroom assignments and discussions via mobile devices, fostering greater engagement outside the traditional classroom setting [14].

The introduction of intelligent tutoring systems (ITS) and AI-assisted learning has further advanced smart ECE. ITSs can offer tailored feedback and guidance based on a child's learning needs and abilities, helping them master specific skills and concepts [15]. In ECE, ITSs, utilizing mobile devices and interactive platforms, provide 24/7 learning support for children. This not only enhances the continuity of learning but also compensates for the lack of assistance from teachers and parents at certain times [16]. AI-assisted learning, through the implementation of interactive platforms, not only analyzes children's learning behaviors in real-time but also engages in intelligent dialogue, image interaction, and other forms of communication, thereby enhancing the sense of immersion in the learning process [17].

In this context, the motivation of this study is to systematically review and analyze research on emerging mobile and interactive models in early childhood education (ECE-EMIM) over the past decade using bibliometric methods. By employing key terms such as "personalized learning," "adaptive learning," "blended learning," "intelligent tutoring," and "AI-assisted learning," this study aims to investigate the application of innovative models and emerging technologies in ECE research from the last ten years. These selected keywords reflect core applications of intelligent ECE and represent the main trajectories of development within this field.

To our knowledge, there is currently no extensive bibliometric study on emerging technologies and innovative models in ECE. This study represents the first bibliometric analysis of the field, with specific objectives to examine trends over time in the adoption of smart learning technologies and models in ECE; identify key themes in published research; highlight the contributions of prolific scholars in the field; and explore publication networks and collaborations across institutions, countries, and regions. Additionally, the study aims to extract insights on the evolutionary directions of smart learning technologies and models for ECE. Based on this background, the study raises the following core research questions:

RQ1: From an empirical research perspective, what role does EMIM play in the current ECE research, especially for underrepresented regions and developing countries?
RQ2: What are the annual publication trends in global ECE-EMIM research over the past decade?
RQ3: Which countries/regions and publication sources are most prominent in ECE-EMIM research?
RQ4: What valuable insights can be derived regarding author and regional collaboration within the ECE-EMIM field?
RQ5: What are the main research themes in ECE-EMIM over the past decade?
RQ6: How have these research themes evolved over time, and what future developments can be anticipated in order to provide feasible recommendations for educators, policymakers, or technology developers?

2 METHODS

This study adopts a comprehensive approach, leveraging the Web of Science Core Collection (WoSCC) and Scopus databases to evaluate research on ECE-EMIM over the past decade. By tracing and analyzing the development and evolution of ECE-EMIM through WoSCC and Scopus, we aim to understand how academic research has shifted over time and explore the relationships and distinctions between emerging technologies and innovative models within the ECE context. The bibliometric analysis involved identifying and filtering relevant literature, as outlined in the preferred reporting items for systematic reviews and meta-analyses (PRISMA) flowchart (see Figure 1). This process includes conducting bibliometric searches using the target databases (WoSCC and Scopus) and performing bibliometric analysis with Bibliometrix and Biblioshiny as scientific mapping tools.

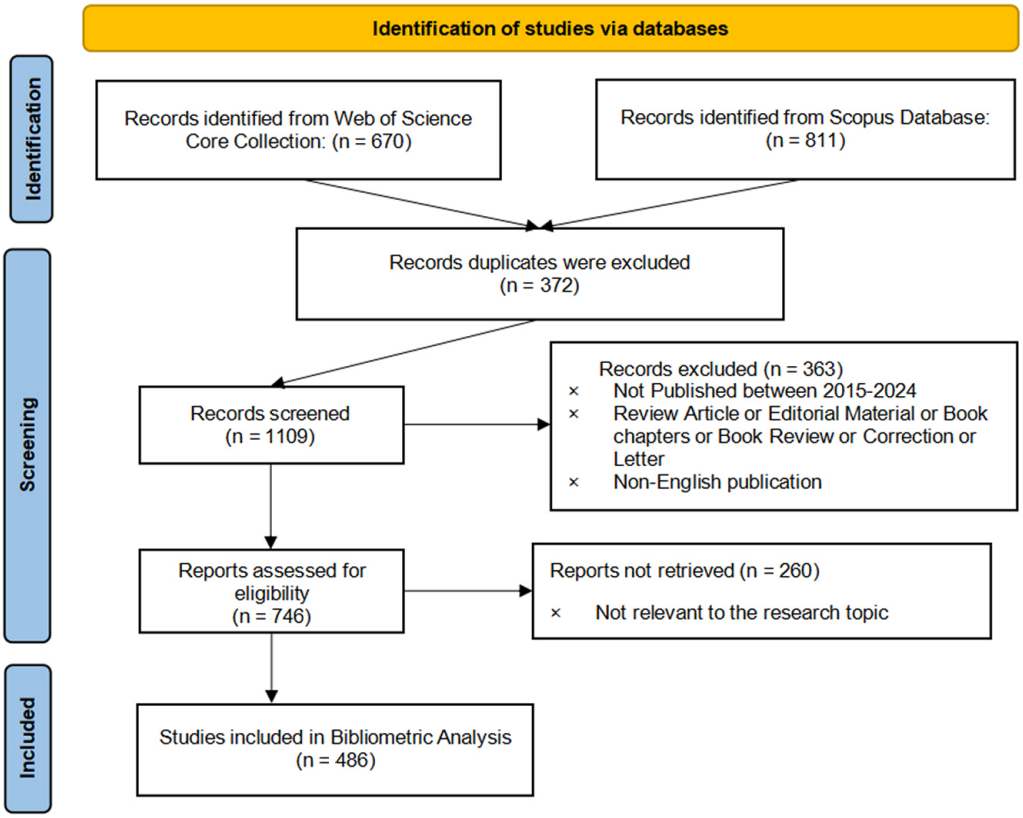

Fig. 1. Flowchart of the research methodology

2.1 Data collection and screening

In this study, we have utilized both the WoSCC and Scopus databases as the primary sources of information. By integrating these two databases, we ensure comprehensive coverage of the literature and the reliability of our findings. The WoSCC database provides high-quality, peer-reviewed academic resources, while Scopus expands our scope, particularly in terms of regional and interdisciplinary research, thus mitigating the limitations inherent in relying on a single database. The combination of these two data sources allows for greater diversity in literature and enhances the representativeness of the study, ultimately improving its comprehensiveness and accuracy.

The search query was formulated as follows in WOSCC: TS = ("personalize learn" OR "personalize* teach*" OR "Adaptive Learn*" OR "Blended learn*" OR "Hybrid learn*" OR "Intelligent Tutor*" OR "Custom learn*" OR "AI-assist* learn*" OR "AI learn*") AND ("early childhood" OR "young child*" OR "preschool*" OR "kindergarten*" OR "childcare*" OR "children*"). For the Scopus database, the query was formulated as: TITLE-ABS-KEY ("personalize learn" OR "personalize teach" OR "Adaptive Learn*" OR "Blended learn*" OR "Hybrid learn*" OR "Intelligent Tutor*" OR "Custom learn*" OR "AI-assist* learn*" OR "AI learn*") AND TITLE-ABS-KEY ("early childhood" OR "young child*" OR "preschool*" OR "kindergarten*" OR "childcare*" OR "children*"). Data was collected in December 2024 using keywords that encompass a broad range of emerging technologies and innovative models within the ECE domain. These keywords were selected to capture the latest trends in personalized learning, adaptive teaching, and AI-driven educational approaches for young children.

It is worth noting that we deliberately avoided using broad terms such as "smart learning" or "intelligent learning" in the bibliometric search to ensure precision and avoid overly general concepts. "Smart learning" or "intelligent learning" are highly broad terms that encompass diverse learning models, technologies, and educational settings. Such generalization could lead to search results that include a large volume of irrelevant or non-specific literature, undermining the focus of the study. Instead, we opted for more specific keywords such as "personalize* learn*," "adaptive learn*," and "blended learn*," which precisely define the application contexts and technological means associated with ECE. This strategy allowed for a more accurate screening of relevant literature, ensuring that the search results closely aligned with the ECE-EMIM field.

Using these keywords, a total of 670 records were initially retrieved from the WoSCC database and 811 from the Scopus database. Research published outside the 2015–2024 timeframe was excluded to ensure that the data reflects current trends. To focus exclusively on original research articles, we also eliminated review papers, editorial materials, book chapters, corrections, and letters. To maintain consistency and avoid language-based biases, non-English publications were excluded. It is important to note that the exclusion of non-English literature may introduce certain regional and cultural biases, particularly by overlooking significant studies published in other languages. Significant differences exist across countries in terms of education systems, social structures, technological development, and perceptions of ECE. Research in non-English-speaking countries is often based on distinct social, cultural, and educational contexts, making the methods and conclusions drawn on certain issues unique. These cultural differences mean that relying solely on English-language literature might overlook educational methods or technologies that have proven effective in other cultures. For example, education research in some developing countries may place greater emphasis on equity and access to resources, while developed countries may prioritize technological innovation or the application of psychological theories. Such regional disparities create complementary research, offering diverse insights into global education reforms. Therefore, the exclusion of non-English literature, while driven by language constraints, limits our understanding of region-specific issues and solutions. Although this exclusion is based on practical limitations, it inadvertently reinforces academic centralization, diminishing the importance of diverse, cross-cultural research. This limitation could impact the comprehensiveness of the final research, especially in areas where non-English studies may offer important, alternative viewpoints. To address this limitation, we plan to expand the scope of our literature search in the future to include studies in additional languages, thereby further enhancing the comprehensiveness of the research. After these preliminary exclusions, 746 articles were assessed for eligibility. Subsequently, using a manual screening process, we excluded 260 articles

unrelated to the ECE-EMIM research focus. Following this rigorous screening and eligibility assessment, 486 studies were included in the final bibliometric analysis.

2.2 Bibliometric analysis methods

Upon completion of the data selection process, bibliometric analysis was conducted using Bibliometrix and Biblioshiny. Bibliometrix offers a comprehensive suite of bibliometric tools capable of analyzing publication performance across various dimensions, including authors, journals, institutions, and countries [18]. It supports analyses of citations, co-citations, and collaboration networks, thereby revealing the structural dynamics and developmental trends within research domains. Moreover, it facilitates time-series analyses to identify the evolution and emerging trends in the ECE-EMIM field.

Biblioshiny, a visualization interface based on Shiny, provides an interactive platform that allows for the rapid generation of analytical results and visual representations [19]. By graphically displaying citation relationships, collaboration networks, and other relevant metrics, it aids in the swift identification of key literature and researchers within the ECE-EMIM domain.

This study conducts a comprehensive bibliometric analysis of ECE-EMIM research over the past decade, focusing on several key dimensions: source analysis, author analysis, paper analysis, and thematic analysis. Source analysis identifies the journals and publications that are most frequently cited or produce the most relevant research within the ECE-EMIM field. This aspect aids researchers and educational practitioners in pinpointing influential journals and publishers, thereby emphasizing high-quality research outputs and enhancing understanding of major research trends in the domain. Author analysis delves into the contributions of key authors in the field, illuminating who the leading figures are and their primary research directions. By recognizing prolific or highly cited authors, researchers can gain insights into the key contributors in the domain, as well as their research networks and collaborative relationships. Paper analysis involves evaluating individual research outputs to assess their influence and citation frequency within the discipline, identifying which specific studies have made significant contributions to ECE-EMIM. Thematic analysis helps to discern the focal themes and concepts that have been prioritized during specific time periods in research. This analysis facilitates the identification of emerging trends, research gaps, or topics currently attracting attention in the field.

3 SPECIFIC RESULTS

This section provides a detailed analysis of the extracted and filtered collection of articles related to ECE-EMIM, examining multiple facets, including sources, authors, citations, keywords, and collaboration networks.

3.1 Publication statistics

Table 1 presents statistical data on the volume of publications in ECE-EMIM research from 2015 to 2024. The overall trend indicates a steady increase in publication numbers, reflecting a growing interest among researchers in the ECE-EMIM field, particularly in recent years. From 2015 to 2019, the number of publications

gradually rose from 40 in 2015 to 57 in 2019. However, a slight decline was observed between 2019 and 2021, with the count dropping from 57 to 50. This downturn may be attributed to the impacts of events such as the COVID-19 pandemic, which shifted research efforts towards immediate educational challenges [20]. The pandemic significantly affected the education sector, leading researchers to redirect their focus toward addressing the urgent educational demands arising during this crisis, thereby reducing their engagement with technological innovations. From 2021 to 2024, a recovery in publication numbers was noted, increasing from 50 in 2021 to 65 by 2024, marking a decade-high record. This resurgence is likely fueled by a post-pandemic demand for remote education, online learning platforms, and technological support, prompting researchers to reexamine the potential contributions of EMIM to early childhood education.

Table 1. Annual scientific publication from 2015–2024

Year	Publication
2015	40
2016	36
2017	48
2018	41
2019	57
2020	46
2021	50
2022	49
2023	55
2024	65

3.2 Source analysis

The distribution of journals serves to illustrate the spatial representation of literature within a specific academic discipline and the scholarly orientation of the journals involved. A statistical analysis of the distribution of key journals in the ECE-EMIM domain reveals the primary publications focusing on this field. As indicated in Table 2, *Education and Information Technologies* stands out as the leading source, contributing 15 articles, thereby affirming its significant role in disseminating research pertinent to ECE-EMIM. The *ACM International Conference Proceeding Series* ranks second with 11 articles, followed closely by the *British Journal of Educational Technology*, with 9 articles, highlighting its established focus on technology-enhanced education. Other notable sources, including *Education Sciences* and *Frontiers in Education*, each contributed 7 articles, underscoring their importance as platforms for research dissemination in this emerging area. Furthermore, conferences play a crucial role in the ECE-EMIM field, with proceedings such as *CEUR Workshop Proceedings, Lecture Notes in Networks and Systems*, *Advances in Intelligent Systems* and *Computing, and Communications in Computer and Information Science* appearing among the top ten sources. Collectively, these conference proceedings contributed 36 articles to the top ten list, demonstrating the dynamic nature of ECE-EMIM research and the rapid exchange of ideas facilitated through conference proceedings.

Table 2. Top 10 sources

No.	Sources	Articles
1	Education and Information Technologies	15
2	ACM International Conference Proceeding Series	11
3	British Journal of Educational Technology	9
4	Education Sciences	7
5	Frontiers in Education	7
6	Ceur Workshop Proceedings	7
7	Lecture Notes in Networks and Systems	7
8	Advances in Intelligent Systems and Computing	6
9	Communications in Computer and Information Science	5
10	Computers & Education	5

3.3 Author analysis

Journals serve as key platforms for disseminating academic achievements, while authors, as the primary contributors of research content, play a pivotal role in shaping the impact and competitiveness of these publications. Identifying core authors is a crucial aspect of bibliometric research. Table 3 presents the top ten authors contributing to ECE-EMIM research, ranked by publication volume. Notably, *Macaruso P* and *Lathama A* lead the list, with 10 and 8 articles, respectively, underscoring their significant influence in the field. Following closely are *Macaruso P*, *Agarwal M*, and *Nkambou R*, each contributing 6 articles, further emphasizing their substantial role in advancing ECE-EMIM research. *Restrepo MA* ranks next with 5 articles, while *Aljameel SS*, *Boote B*, *Crockett KA*, and *Glenberg AM* each contributed 4 articles, demonstrating their consistent engagement with this growing domain. These authors represent the driving force behind the evolving landscape of ECE-EMIM research, reflecting the collaborative and dynamic nature of this field.

Table 3. Top 10 authors

No.	Authors	Articles
1	MOSTOW J	10
2	LATHAM A	8
3	MACARUSO P	6
4	AGARWAL M	6
5	NKAMBOU R	6
6	RESTREPO MA	5
7	ALJAMEEL SS	4
8	BOOTE B	4
9	CROCKETT KA	4
10	GLENBERG AM	4

Figure 2 presents a visualization of the authors' collaboration network, illustrating the relationships and cooperative dynamics among researchers in the ECE-EMIM domain. In this network, nodes represent authors, while edges indicate co-authorship relationships, with color and clustering offering insights into different collaborative groups within the ECE-EMIM field. The visualization reveals several tightly knit clusters of authors, underscoring a robust collaborative effort prevalent in ECE-EMIM research.

Authors such as Ying Rui, He Jiayu, Landay James A., and Brunskill Emma appear to be more central in the network, indicating that they may have broad collaborations or are well-connected with multiple co-authors across different clusters. The density of connections varies across the network, with some authors having strong collaborative ties (evident by many edges) while others maintain more independent relationships with fewer co-authors. Authors such as He Jiayu, Ying Rui, and Brunskill Emma act as potential connectors or bridges between different clusters, facilitating the sharing of ideas and cross-collaboration within the field.

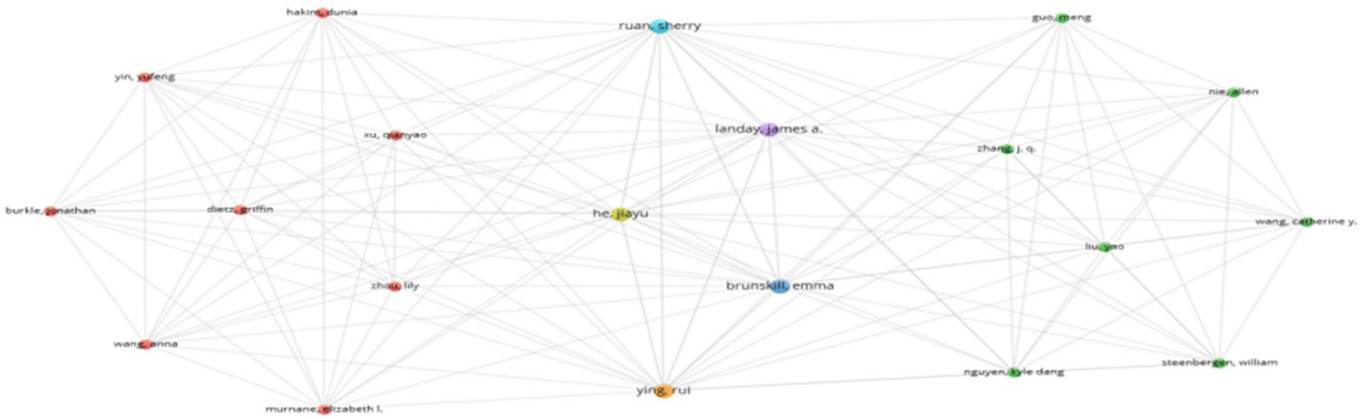

Fig. 2. Collaboration network: Co-authorship between authors

Figure 3 showcases the co-citation network of references. Here, nodes symbolize the cited references, and edges depict co-citation relationships, indicating the frequency with which two references are cited together within the same research paper. The size of the nodes corresponds to their citation frequency, while color clusters categorize references by thematic similarity or prevalent co-citation patterns. In the figure, the green cluster emphasizes the psychological aspects of learning and the development of adaptive learning technologies, with the work of Vygotsky [21] positioned at the core of the network. His foundational theories on social learning and educational psychology serve as a cornerstone of contemporary ECE-EMIM research. The yellow cluster primarily focuses on technology and learning design, featuring key works such as Klinkenberg et al. [22] and VanLehn [23]. The purple cluster, revolving around Muller and Cohen [24], highlights the importance of robust experimental design and quantitative assessment in educational research. The red cluster, centered on research such as Schechter et al. [25], indicates a focus on how educational technology and computer-based interventions support learning design and outcomes. The connections among references in educational technology, adaptive learning models, and psychological frameworks underscore the interdisciplinary nature of the ECE-EMIM field, covering themes ranging from cognitive theories of learning to the design and implementation of ITSs. Additionally, the clustering of recent references, particularly around the work of Schechter et al. [25], reflects the latest developments in ECE-EMIM, signaling a shift in ECE toward the integration of advanced algorithms and data-driven approaches.

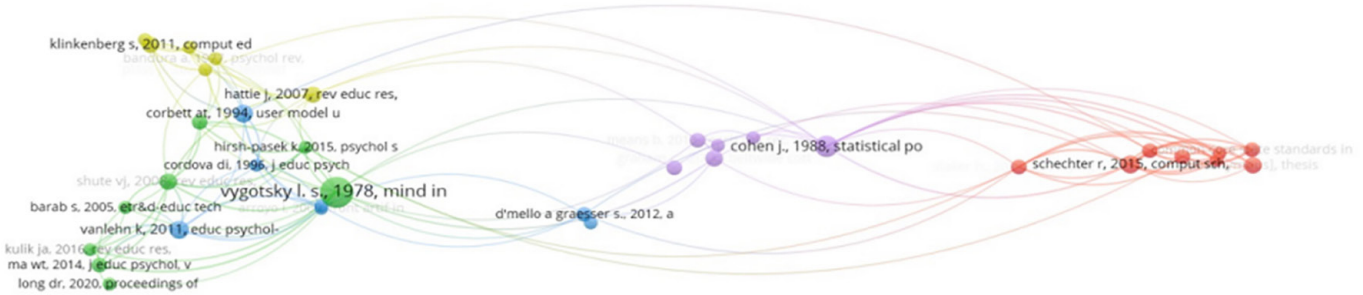

Fig. 3. Co-citation network of references

Table 4 presents the top ten countries by publication volume in the ECE-EMIM research domain. The USA emerges as the dominant contributor, with 185 articles, significantly surpassing other nations. This positions the USA as a leading center for research and development in ECE-EMIM, highlighting its strong emphasis on the application of EMIM within ECE. This leadership may be attributed to resource availability, robust academic-industry collaborations, and policy support for educational innovation. China follows in second place with 62 articles, reflecting the country's strategic investment in educational technology. The United Kingdom (60 articles) and Germany (57 articles) closely trail, underscoring Europe's considerable influence in this research domain. Other nations, including India, Italy, Spain, Romania, Canada, and Indonesia, contribute substantial research outputs, with paper counts ranging from 52 to 19.

The data illustrates a broad geographic distribution of research activities in ECE-EMIM, encompassing both developed nations (such as the USA, United Kingdom, Germany, and Canada) and emerging economies (such as China, India, and Indonesia). The participation of countries such as Romania (24 articles) and Indonesia (19 articles) indicates that ECE-EMIM research is not confined to traditionally dominant research regions but is increasingly gaining traction in underrepresented areas.

Table 4. Top 10 countries

No.	Country	Articles
1	USA	185
2	CHINA	62
3	UK	60
4	GERMANY	57
5	INDIA	52
6	ITALY	33
7	SPAIN	27
8	ROMANIA	24
9	CANADA	23
10	INDONESIA	19

Figure 4 provides a visualization of the co-citation collaboration network among countries. In this network, nodes represent countries, while edges indicate collaborative links between them. The size of the nodes and labels signifies the centrality and influence of each country within collaborative research. Notably, the USA emerges

as the most prominent player in the network, serving as a key hub for global collaboration. Its significant position and extensive connections underscore its central role in advancing ECE-EMIM research, as it acts as a primary collaborator for numerous nations, facilitating the exchange of knowledge and research expertise.

China occupies an important position in the network as well, demonstrating clear collaborative ties with the USA and other countries, such as Japan and Slovenia. This suggests that China's influence and breadth of collaboration in ECE-EMIM research are gradually increasing.

European countries, including Germany, France, the United Kingdom, and the Netherlands, form a dense cluster, indicating strong regional cooperation within Europe. Other clusters, such as those in the Middle East and North Africa (MENA) region, including nations such as Qatar, Egypt, and Saudi Arabia, highlight collaborative efforts within specific areas. The robust regional clusters in Europe, the Asia-Pacific, and the Middle East reflect concentrated research activities in these regions. Furthermore, countries with fewer connections—such as Indonesia, Malaysia, Kenya, and Iran—may benefit from establishing partnerships with more connected nations to develop a more diversified research network and resource base, potentially accelerating the advancement of emerging mobile and interactive models in early childhood education.

Different countries and regions have distinct understandings and approaches to education. For example, Western nations generally place greater emphasis on personalized education, student-led learning, and the development of critical thinking, while some Asian and Middle Eastern countries may prioritize collectivism and traditional, teacher-centered educational models. The acceptance and frequency of EMIM usage are also influenced by cultural contexts. In more conservative cultures, there may be a lower acceptance of educational technology, with resistance to replacing traditional teaching methods. Moreover, developing countries often face challenges such as insufficient educational resources and a lack of technological infrastructure, making the widespread adoption of educational technology particularly difficult.

As illustrated in Figure 4, countries in the so-called 'Third World' (typically referring to developing nations) occupy a more peripheral position in the global network. Nations such as Kenya, Pakistan, India, Egypt, and Argentina, for example, are situated at the outer edges of the network and have relatively indirect connections to other countries. This reflects their ongoing reliance on and receipt of technological support within broader collaborative efforts. For instance, weak mobile technology infrastructure, issues with internet coverage, limited mobile device penetration, and resistance to technology adoption and training remain significant barriers to the successful implementation of EMIM in these regions.

However, collaboration between developing and developed countries can facilitate the transfer and localization of technological knowledge. Take China's partnership with African nations such as Kenya, for instance, where EMIM is being used to provide low-cost, efficient educational resources to students in these regions. In conclusion, despite challenges related to technological infrastructure, cultural adaptation, and policy support, cross-national collaboration—particularly between developing and developed nations—can drive technological innovation, reduce educational disparities, and improve educational equity.

Overall, the network illustrates a broad spectrum of international collaboration, particularly characterized by the extensive connections of the USA with multiple countries. This indicates a trend toward globalization in ECE-EMIM research, with increasing inter-country cooperation and the enhancement of mechanisms for knowledge sharing and technological exchange. However, many African countries

and certain nations in South America do not display significant collaborative activity within this network. Although countries such as Kenya are present, the overall contribution or collaboration from these regions in ECE-EMIM research remains limited.

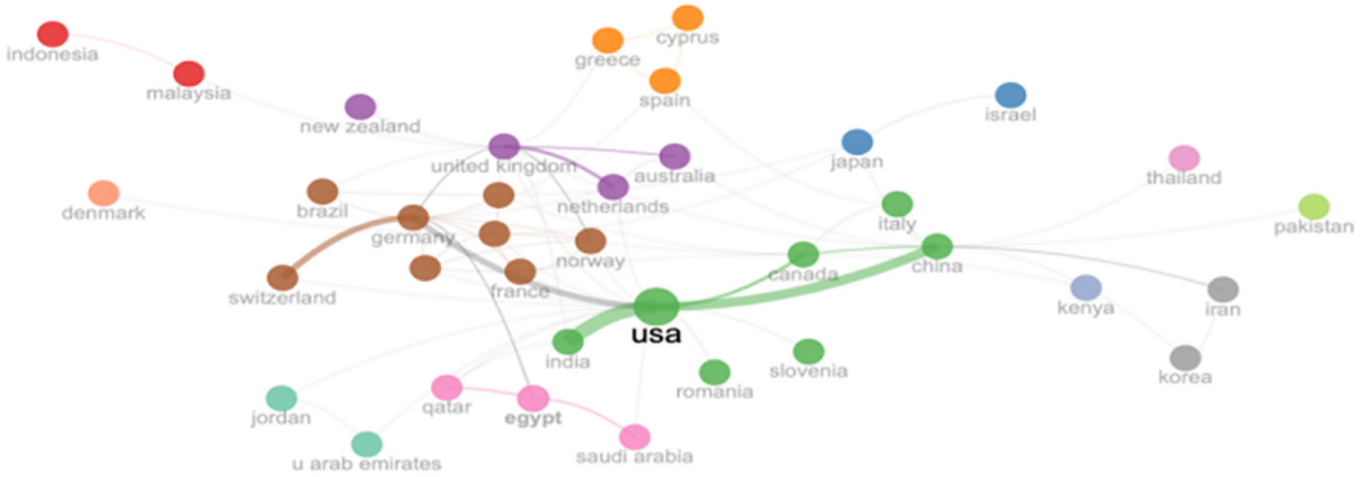

Fig. 4. Collaboration network – Co-authorship between countries

3.4 Literature analysis

This section aims to reveal details related to the most frequently cited papers included in the dataset utilized for this bibliometric analysis. Table 5 lists the top ten most cited publications from 2015 to 2024. Overall, the high-impact literature encompasses a wide range of topics, including the application of EMIM in ECE, educational equity, and teacher training. Research trends indicate a growing focus on the impact of emerging technologies on EMIM—such as social robots, virtual classrooms, and gamified learning—on children's learning outcomes, teacher efficacy, and educational equity as these innovations gain traction in the field.

Table 5. Top 10 highly cited paper

Rank	Title	Reference	Total Citations
1	Teaching and learning with children: Impact of reciprocal peer learning with a social robot on children's learning and emotive engagement	CHEN HL, 2020	101
2	Exploring the Impact of TeachME™ Lab Virtual Classroom Teaching Simulation on Early Childhood Education Majors' Self-Efficacy Beliefs	BAUTISTA NU, 2015	68
3	An Adaptive Learning with Gamification & Conversational UIs: The Rise of CiboPoliBot	FADHIL A, 2017	65
4	Closing the gender gap in STEM with friendly male instructors? On the effects of rapport behavior and gender of a virtual agent in an instructional interaction	KRÄMER NC, 2016	51
5	Why Is Toma Late to School Again? Preschoolers Identify the Most Informative Questions	RUGGERI A, 2017	48
6	Supporting children's math learning with feedback-augmented narrative technology	Ruan S, 2022	38

(Continued)

Table 5. Top 10 highly cited paper *(Continued)*

Rank	Title	Reference	Total Citations
7	The effectiveness of adaptive versus non-adaptive learning with digital educational games	VANBECELAERE S, 2020	39
8	Shaping productive help-seeking behavior during robot-child tutoring interactions	Ramachandran A, 2016	36
9	Validity for the Assessing Classroom Sociocultural Equity Scale (ACSES) in Early Childhood Classrooms	CURENTON SM, 2020	32
10	Young Children Detect and Avoid Logically Inconsistent Sources: The Importance of Communicative Context and Executive Function	DOEBEL S, 2016	31

The following section provides a concise overview of the 10 most frequently cited publications in the field of ECE-EMIM globally.

Chen et al. [26] investigated the application of social robots in ECE, specifically analyzing how these robots facilitate cognitive development and emotional engagement through interactive learning with children. This publication stands as the most cited work in the ECE-EMIM domain, underscoring its significance in examining the interactions between children and AI, particularly regarding the effective integration of technology into classroom teaching. Social robots, as interactive learning tools, can simulate the behavior of human teachers or peers, fostering emotional engagement and motivation through interactive feedback. With the support of mobile technologies, these robots can interact remotely in various contexts, enhancing the flexibility and accessibility of learning.

Bautista and Boone [27] analyzed the effects of the TeachME™ virtual classroom simulation system on the self-efficacy beliefs of students majoring in ECE. TeachME™ serves as a virtual learning environment designed to enhance teaching skills through simulated classroom interactions. Virtual classrooms, as an application of EMIM, provide an immersive learning environment that supports preschool education majors in engaging in interactive learning and reflection without the constraints of a traditional classroom setting. Accessing these virtual environments through mobile devices allows for more flexible, personalized learning experiences.

Fadhil and Villafiorita [28] introduced an adaptive learning system, CiboPoliBot, which integrates gamification and conversational user interfaces. CiboPoliBot, as an interactive platform, utilizes voice assistants and AI technologies to provide children with personalized learning experiences. The gamified elements motivate children to engage, while adaptive algorithms make personalized recommendations based on the child's learning data, thereby enhancing the learning outcomes. This study emphasized the impact of user interaction design in educational technology on learning outcomes, offering new perspectives for future educational software and system design.

Krämer et al. [29] explored the relationship between gender disparities and educational outcomes in virtual environments, focusing on the influence of the virtual teacher's gender and behavior on gender differences in STEM fields. Virtual agents can engage in personalized interactions with students through voice, video, and interactive interfaces. By utilizing interactive platforms, students are able to build relationships with virtual agents in diverse contexts, which plays a crucial role in reducing gender biases and enhancing student engagement.

Ruggeri et al. [30] concentrated on how children acquire information through questioning, particularly in preschool educational settings, examining children's cognitive development and question-generation abilities. By analyzing children's questioning behavior, the study provided recommendations for fostering critical thinking and logical reasoning skills in education. The exploration of question-oriented learning methods in ECE offers theoretical support for educational innovation and may influence how teachers guide students in exploration and inquiry during lessons. Such activities can be conducted through educational applications on mobile devices, utilizing technologies such as speech recognition and touch interfaces to help children engage in cognitive training through interactive questioning and answering, while also fostering their critical thinking skills.

Ruan et al. [31] examined the impact of various feedback mechanisms on children's math learning outcomes through the application of feedback-augmented technology. Their findings suggest that EMIM—such as interactive storytelling apps and AI-powered tutoring chatbots—can significantly enhance both the experience and effectiveness of math learning for children. This aligns closely with the prevailing emphasis in ECE on personalized, adaptive, and interactive learning models, offering compelling evidence to inform the future design of mobile-based learning systems.

Vanbecelaere et al. [32] compared the effectiveness of adaptive and non-adaptive learning within digital educational games. Adaptive learning games adjust game content by collecting real-time data from children, such as their quiz responses and learning progress, to provide personalized learning paths. EMIM enables children to learn anytime and anywhere, while interactive interfaces enhance learning motivation and effectiveness through instant feedback.

Ramachandran et al. [33] conducted a between-subjects study to explore the role of social robots—an integral component of ITSs—in children's learning environments. These robots can be deployed across various settings, such as homes and classrooms, offering flexible, on-demand learning support. Together with tablets, smartphones, and other mobile devices, they form a personalized learning ecosystem. The study provides compelling evidence that social robots can serve as a vital element within the mobile learning landscape, enhancing children's learning outcomes through adaptive feedback, fostering productive learning behaviors, and enriching multimodal interactions. In the future, mobile educational technology can draw on the findings of this study to incorporate similar adaptive assistance features into mobile learning applications, enhancing children's self-regulation and engagement in remote learning environments.

Curenton et al. [34] presented the Sociocultural Equity Assessment Scale (ACSES) for early childhood classrooms and validated its effectiveness. This scale measures the sociocultural equity of interactions between teachers and students in the classroom. By developing and validating an assessment tool, this study promoted attention to sociocultural equity within classrooms. This tool allows for real-time data collection and analysis through EMIM, providing teachers with instant feedback to help them assess and improve the sociocultural equity of the classroom. Through the interactive platform, teachers can access more dynamic data, enabling them to implement personalized interventions.

Doebel et al. [35] examined how young children identify and avoid logically inconsistent information sources, emphasizing the roles of communicative context and executive function in children's information evaluation. This study contributes

new insights to the study of early cognitive development and information processing, particularly regarding how education can support children in developing critical thinking and information judgment skills. Its implications extend broadly across educational psychology and instructional design. Interactive platforms can help children practice evaluating the logical consistency of information through virtual environments and voice interactions. The convenience of mobile devices enables children to engage in this training across different contexts, enhancing their information assessment skills and executive functions.

The significance of these ten highly cited publications in the ECE-EMIM domain extends beyond their specific inquiries; they reflect multiple global educational research trends encompassing technology, educational equity, personalized learning, teacher training, and early cognitive development. These studies reflect the diverse applications of EMIM in ECE. Whether through social robots, virtual classrooms, adaptive learning, gamified learning, or conversational user interfaces, these technologies provide children with personalized and highly interactive learning experiences. As technology advances, these platforms not only enhance student engagement but also offer real-time feedback during the learning process, fostering both cognitive and emotional development.

3.5 Thematic analysis

Figure 5 presents a visual representation of a word cloud based on the experimental dataset, highlighting the most frequently encountered terms related to ECE-EMIM. The size and thickness of each term indicate its prominence within the academic literature. “Blended learning” emerges as the most prominent term. EMIM supports this approach, allowing students to use devices such as tablets and smartphones to engage in learning during extracurricular time through interactive learning apps, video tutorials, and more. At the same time, face-to-face interactions with teachers and peers in the classroom deepen their understanding.

Equally notable are the terms “intelligent tutoring systems” and “artificial intelligence,” which reflect a growing focus on AI technologies and smart systems designed to deliver personalized support to learners. EMIM enables this intelligent tutoring system to be accessed anytime and anywhere through smartphones or tablets. The presence of terms such as “flipped classroom,” “gamification,” and “special education” indicates an exploration of various instructional strategies. The “flipped classroom” model disrupts traditional teaching paradigms by delivering instructional content online, and its potential effectiveness in personalized early education is likely to be scrutinized. For ECE, the flipped classroom not only provides more personalized learning paths but also enhances students’ active learning capabilities through interactive learning platforms. Gamified learning is characterized by the use of rewards, tasks, and feedback mechanisms to motivate student engagement. This highly interactive form of learning stimulates children’s curiosity and interest, making it particularly well-suited to the ECE stage, where it supports learning in a joyful environment. Gamified EMIM, such as Classcraft, enhance student participation through interactive tasks and challenges, making the learning process both more enjoyable and motivating [36]. The word cloud also includes terms such as “autism spectrum disorder” and “dyslexia,” highlighting a heightened awareness of early education and the diverse needs of learners, including considerations for special education.

Fig. 5. Word cloud

Keyword co-occurrence analysis, based on the bibliometric concepts of citation coupling and co-citation, reveals research themes or directions within the field by examining the intrinsic relationships among keywords that appear within the same publication [37]. Keywords that frequently co-occur indicate a closer relationship. Figure 6 visualizes the keyword co-occurrence network, where nodes represent keywords, and edges indicate their co-occurrence in publications. The size of the nodes reflects the frequency of the keywords, while color-coded clusters denote thematic groupings of keywords that often appear together in research discussions.

The prominence of "blended learning" and its connections with related terms such as "adaptive learning" and "machine learning" reflect an emphasis on combining traditional and digital methodologies to create personalized and flexible learning environments. EMIM extends learning beyond the classroom, breaking through spatial limitations and enabling learning anytime and anywhere. The strong ties between keywords such as "artificial intelligence," "intelligent tutoring systems," and "educational technology" indicate an ongoing effort to balance technological advancements with effective teaching practices. The goal is to improve educational outcomes through AI while addressing the needs of teachers and learners. EMIM has the capability to collect and analyze students' learning data, providing real-time feedback and recommendations, thereby enabling dynamic adjustments to learning paths and enhancing learning outcomes. Particularly in ECE, AI can assist children in understanding complex concepts through interactive interfaces while ensuring a high level of engagement and interactivity in the learning process. The clusters around "game-based learning" and "personalized learning" highlight the importance of designing inclusive and engaging learning environments. Gamified learning, through the integration of mobile platforms and interactive technologies, leverages game elements such as points, rewards, and challenges to enhance students' engagement and motivation in the learning process. The interconnected nature of keywords such as "early childhood education," "teacher professional development," and "adaptive learning" points to a focus on improving early education quality, developing effective tools to support diverse learners, and training educators to effectively integrate technology into teaching.

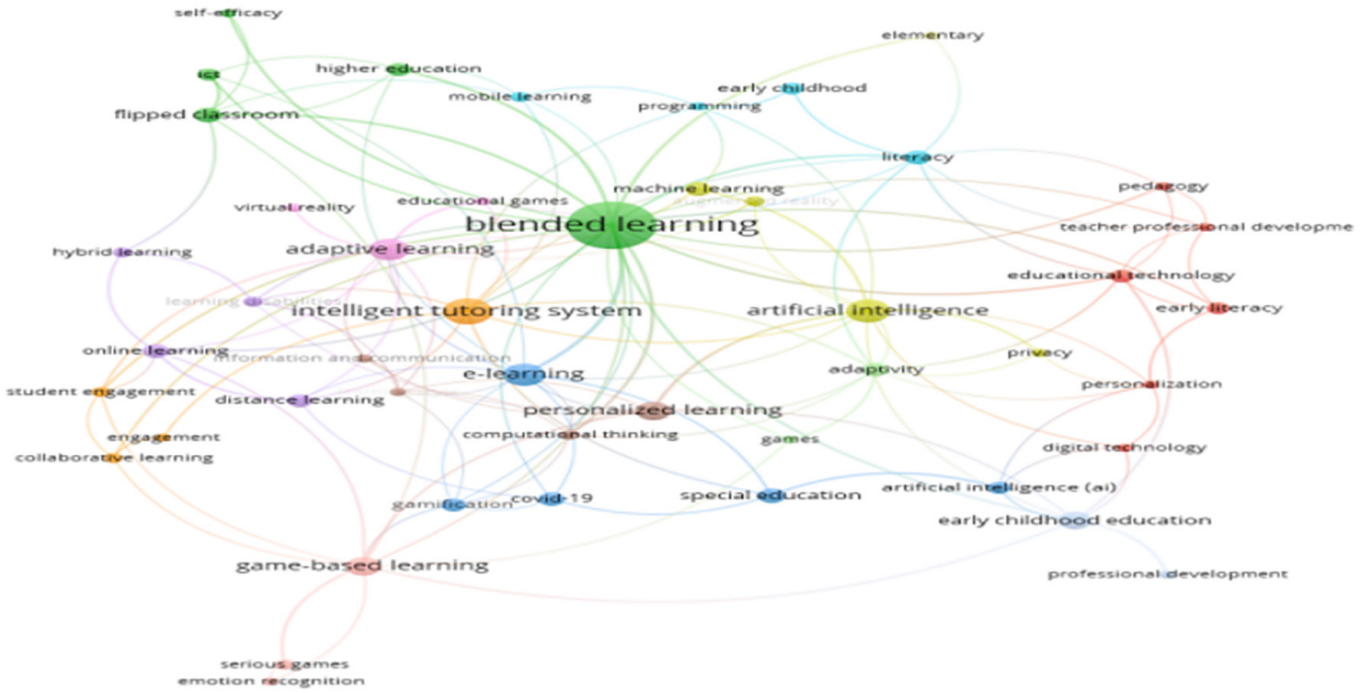

Fig. 6. Co-occurrence: Keyword network

Figure 7 provides a visual representation of trend themes, elucidating key thematic trends in ECE-EMIM and their temporal evolution. The size of the circles represents the frequency of terms, indicating their prominence within the academic discourse. Notably, the emergence of terms such as “online learning” and “remote learning” may correlate with global events such as the COVID-19 pandemic, which has shifted educational practices into more remote and technology-mediated environments. This adaptation has influenced research directions, propelling greater AI-driven support in early education. EMIM, such as educational apps and online learning platforms, plays a pivotal role in remote education.

Since around 2020, the increasing frequency of terms such as “artificial intelligence” and “personalized learning” underscores a trend focused on exploring how AI can be directly applied to customize early education experiences. Adaptive learning applications track students’ learning progress in real time through mobile devices and dynamically adjust the course difficulty and content based on their individual needs. The ongoing presence of “game-based learning” indicates educators’ interest in making learning engaging and interactive. EMIM provides robust technological support for gamified learning, making the learning process more engaging and interactive. The inclusion of terms such as “adaptive learning” and references to specific conditions such as “autism” and “dyslexia” suggests that research is increasingly dedicated to creating inclusive and supportive AI-driven educational tools to meet the diverse needs of learners. This reflects a concerted effort to ensure that all children can access personalized learning more conveniently and effectively, regardless of the learning challenges they face. EMIM offers a user-friendly and accessible learning environment for children with special needs. For example, apps designed specifically for dyslexia can utilize speech recognition and synthesis features to help students overcome learning challenges, while interactive games for children with autism can support their holistic development by enhancing social interaction and emotional expression skills.

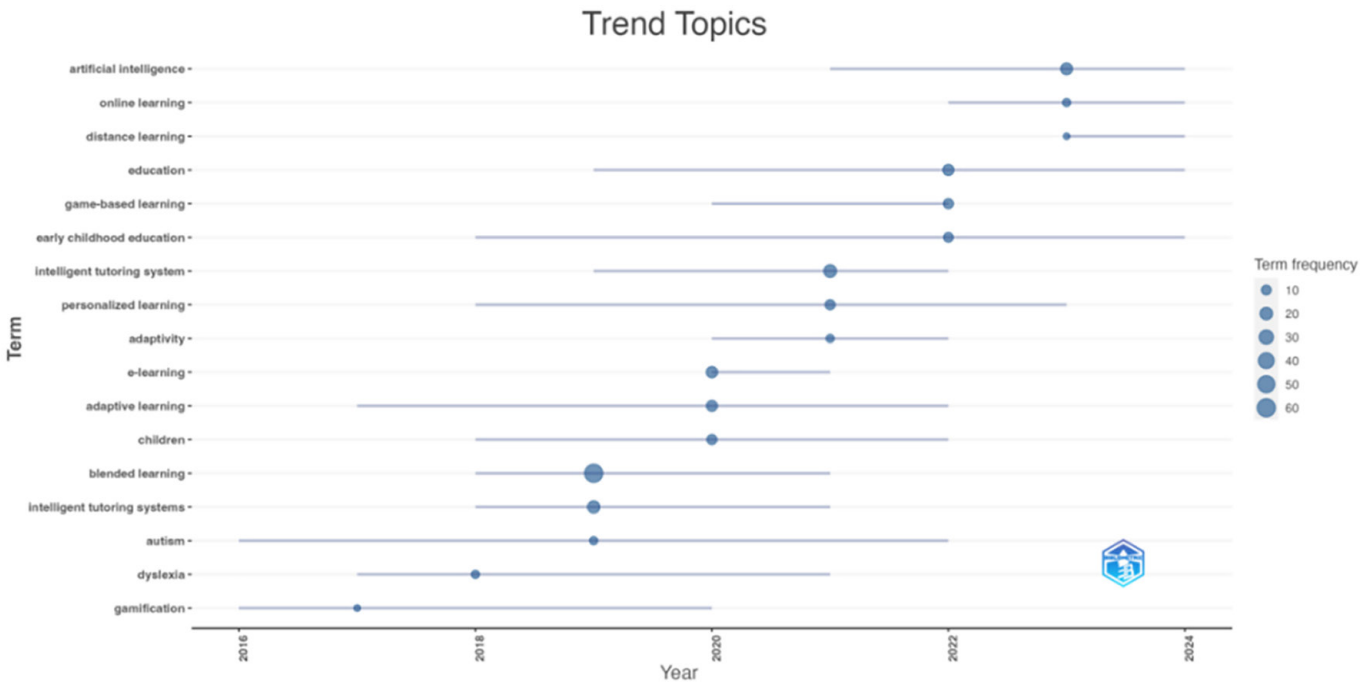

Fig. 7. Trend topics

4 DISCUSSIONS

This paper aims to provide a comprehensive bibliometric assessment of ECE-EMIM research. By conducting an in-depth investigation of multiple perspectives—such as sources, authors, keywords, and countries—and employing visual representations (including collaboration networks and thematic trend maps), this analysis encompasses 486 English-language articles published from 2015 to 2024. This meticulous evaluation reveals valuable insights and hidden trends.

RQ1: From an empirical research perspective, what role does EMIM play in the current ECE research, especially for underrepresented regions and developing countries?

From an empirical research perspective, EMIM plays a crucial foundational role in current ECE studies, driving the formation of personalized, adaptive, and highly interactive learning environments. A study in Greece [38] examined teachers' views on the use of mobile devices in ECE, concluding that the main benefit of EMIM is its ability to facilitate the educational process and provide an interactive learning environment. EMIM enhances engagement and motivation through gamification, touch-based interaction, and multimedia content such as audio, video, and animations. Booton et al. [39] analyzed the role of mobile applications in children's language learning, finding that personalized tools based on EMIM can improve children's story comprehension and word learning, and mobile AR applications can increase children's enthusiasm for language learning. EMIM, equipped with AI and data analytics capabilities, enables adaptive learning models, providing real-time feedback based on children's learning responses. Vaiopoulou et al. [40] investigated the benefits of implementing real-world math education using mobile devices such as tablets in kindergartens and recommended the integration of mobile devices in early childhood classrooms, with the development of suitable applications tailored

to the developmental level of target children. In summary, emerging learning models based on EMIM are an integral part of shaping the future of ECE, ensuring flexibility, accessibility, and alignment with the developmental needs of each child.

The application of EMIM in ECE, particularly in developing countries, has become a vital tool for narrowing the educational gap. Developing nations often face challenges such as limited educational resources, teacher shortages, and inadequate infrastructure, especially in remote areas, where traditional educational models struggle to provide sufficient support. EMIM, however, can overcome these physical barriers by offering affordable and easily accessible educational resources to a wide range of preschool children. For example, Kenya's M-Shule platform leverages mobile devices to deliver content in subjects such as mathematics, language, and basic education, enabling children to access learning materials through smartphones or tablets, even in the absence of formal school education [41]. Education systems in developing countries face challenges such as gender inequality and social class disparities, with many vulnerable groups—such as girls, ethnic minorities, and children with disabilities—experiencing significant gaps in educational opportunities. Platforms such as Khan Academy in India, delivered through mobile devices, play a crucial role in bridging these gaps. In particular, they offer a means to address gender inequality by overcoming traditional barriers that limit girls' access to education, thus providing more equitable educational opportunities [42]. While EMIM holds significant potential in ECE in developing countries, it still faces a number of challenges and limitations. In many developing nations, particularly in remote areas, inadequate internet coverage and unstable power supplies restrict the widespread adoption of mobile learning. Furthermore, mobile education platforms are often primarily designed in English, yet developing countries are characterized by diverse languages and cultural backgrounds. Without localized language support and cultural adaptation, these platforms may struggle to engage and effectively assist local children. However, with ongoing technological advancements and improvements in infrastructure, developing countries are poised to unlock the full potential of EMIM in education, contributing more to global educational equity in the future.

RQ2: What are the annual publication trends in global ECE-EMIM research over the past decade?

Over the past decade, there has been a notable upward trend in the number of publications in the ECE-EMIM field. This trend reflects the academic community's sustained interest in ECE-EMIM, particularly in the post-pandemic era, where the demand for remote education and technology-supported learning has surged significantly [43]. The number of publications increased from 40 in 2015 to 65 by 2024. Although fluctuations occurred during the interim (e.g., from 2019 to 2021 due to COVID-19), the overall trajectory indicates growth. This shift in publication volume can be attributed to the increasing prevalence of emerging technologies—such as AI, personalized learning, and blended learning—within ECE. Researchers and educators are progressively recognizing the importance of these technologies in enhancing educational quality and learning experiences. The pandemic further accelerated the demand for remote learning tools and technology support, prompting the academic community to refocus its efforts in this area. Therefore, it is anticipated that the number of ECE-EMIM-related studies will continue to rise in the future, driven by technological advancements and evolving educational needs.

RQ3: Which countries/regions and publication sources are most prominent in ECE-EMIM research?

An analysis of publication sources reveals that the journal *Education and Information Technologies* dominates the ECE-EMIM research landscape, followed by journals such as the *British Journal of Educational Technology*. Conference proceedings also play a significant role in this domain, indicating that ECE-EMIM research is vibrant, with scholars rapidly disseminating their latest findings through conferences. At the national and regional levels, the USA leads with 185 publications, underscoring its preeminence in ECE-EMIM research. China, the United Kingdom, and Germany follow closely, reflecting these countries' strong interest in the application of technology and innovation in ECE.

RQ4: What valuable insights can be derived regarding author and regional collaboration within the ECE-EMIM field?

The networks of author collaboration and regional partnerships illustrate the significant collaborative efforts within ECE-EMIM research. Notable authors, such as MACARUSO P and MOSTOW J, have published rich articles, constituting a critical research force in the field. Analysis of author collaboration networks reveals multiple clusters of closely cooperating authors, indicating frequent collaboration among different research teams, which facilitates knowledge dissemination and research advancement.

International collaboration among countries is equally important. The USA, not only leading in research quantity, occupies a central position in international collaboration networks, signifying its role as a pivotal hub for global ECE-EMIM research. China's increasing collaboration with the USA and other nations highlights its rising prominence in this field. This international cooperation indicates a global acceleration in ECE-EMIM research, where cross-regional collaboration aids in the sharing of knowledge and technologies. Additionally, countries in the so-called 'Third World', such as India, Pakistan, Kenya, and Egypt, have established partial connections through cooperation with developed nations such as the United States and the United Kingdom. This indicates that Third World countries are playing an increasingly important role in educational technology research and application, driving the adoption of EMIM in education through collaboration with technologically advanced countries. As educational technology continues to evolve, it is crucial for Third World countries to strengthen international cooperation, particularly with developed nations and other developing countries, to foster the development of more localized and culturally adaptive educational technology products. By creating international collaboration alliances, these countries can promote the sharing of technology and the exchange of educational resources, particularly in addressing global educational inequality and advancing inclusive education. Finally, international organizations such as the United Nations can provide funding and policy support to assist developing nations in building mobile education infrastructure and facilitating the digital transformation of education.

RQ5: What are the main research themes in ECE-EMIM over the past decade?

Keyword co-occurrence analysis and word cloud visualizations reveal the primary research themes in the ECE-EMIM domain. The most prominent theme is "blended learning," underscoring its crucial role in personalized learning and

technological application [44]. Other significant themes include "intelligent tutoring systems," "artificial intelligence," and "flipped classroom," which reflect researchers' focus on effectively integrating technology with traditional teaching methods to enhance the quality of ECE [45–46]. Special education topics, such as "autism spectrum disorders" and "reading disabilities," have also become important research directions, demonstrating researchers' commitment to creating inclusive educational environments [47–48]. The application of AI technologies continues to evolve, providing personalized educational support and learning tools for children with special educational needs [49].

RQ6: How have these research themes evolved over time, and what future developments can be anticipated in order to provide feasible recommendations for educators, policymakers, or technology developers?

1. *Thematic evolution analysis*: Analysis of thematic evolution indicates that ECE-EMIM research has transitioned from a foundational stage focused on basic technologies to a phase of expanded application. Early studies emphasized the application of foundational technologies such as mobile learning and adaptive learning, while recent years have seen the gradual integration of new technologies such as blended learning and augmented reality, with AI emerging as a core theme. Particularly following the COVID-19 pandemic, the rise of remote learning technologies (such as online learning and distance learning) has further propelled the development of this field.
2. *Analysis of future research trends:* The evolution of research trends not only reveals the technological shifts within the ECE-EMIM field but also provides significant insights for future research and practice. This evolution suggests that future ECE-EMIM research will increasingly concentrate on how technology can support personalized learning, provide educators with improved teaching tools, and meet diverse learning needs. Research in the ECE-EMIM domain is progressing towards a more intelligent, personalized, and globalized direction, driving the pursuit of educational equity and quality on a worldwide scale. Future studies are likely to continue exploring effective technology integration across various educational settings to offer optimal learning experiences for every child. Additionally, forthcoming research will delve deeper into how emerging technologies such as AI and virtual reality (VR) can provide innovative solutions for ECE. These technologies not only promise to enhance learning experiences but also offer educators more effective teaching tools. To fully harness the potential of these technologies, it is imperative to focus on their application in ECE-EMIM within the context of technological innovation.
3. *Recommendations for educators, policymakers, and technology developers:* Based on the aforementioned outlook on research trends, the following recommendations aim to assist various stakeholders in better addressing emerging challenges and formulating adaptive strategies.

Emerging mobile and interactive models not only offers students a flexible learning experience but also provides educators with more tools and methods to support personalized learning and development. From a critical perspective, the implementation of blended learning is not merely about combining online and offline modalities but must also consider educational equity, teacher training and support, and the assessment of learning outcomes. Recommendations: Educators should focus on optimizing the implementation of blended learning models, particularly

by enhancing teacher training in technology integration. Additionally, governments and policymakers should take steps to reduce technological inequalities, ensuring that all children can benefit from these emerging models. Furthermore, learning platforms should be consciously designed not to rely solely on technology but also to encourage student interaction and emotional development.

The application of AI in personalized learning, intelligent tutoring, and assessment holds significant promise, yet teachers remain responsible for providing emotional support and fostering social skills. Recommendations: Educators should regularly assess the fairness of AI algorithms to ensure they are free from bias. Gamified learning, through enhancing student engagement and motivation, can also help students master content more effectively. However, educators should design gamified content that aligns with learning objectives, avoiding the sacrifice of educational outcomes for the sake of entertainment.

To fully harness the potential of emerging technologies such as AI and gamification in ECE, attention must be paid to the fairness of technological applications, data privacy, teacher support roles, and the balance of educational objectives. Recommendations: Educators, policymakers, and technology developers should engage in critical reflection and interdisciplinary collaboration to ensure these technologies provide meaningful support for children's holistic development.

5 CONCLUSION

This paper analyzes the evolution and innovation of EMIM in ECE using bibliometric methods, highlighting their impact on personalized learning, adaptive learning, blended learning, intelligent tutoring, and AI-assisted learning. The study identifies key trends in ECE-EMIM technologies, showing how these enhance learning experiences and promote cognitive and social development in preschool children. It reveals that ECE-EMIM research has evolved from exploratory to more integrated approaches, with a focus on personalized, adaptive, and blended learning on EMIM. Cross-national and interdisciplinary collaboration has driven innovation, with the US, China, and Europe leading the field. Additionally, research themes continue to expand, reflecting ongoing innovation. Future research will focus on advancing the personalization and adaptability of ECE through emerging technologies such as mobile interactivity and VR, opening new avenues for preschool education development.

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