Immersive Technology: A Bibliometric Analysis of Extended Reality Research Trends in STEM Education

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ABSTRACT

Purpose of the study: This study aims to conduct a comprehensive review of the development of research on the use of XR technology in STEM education and its current status.

Methodology: A bibliometric review method was used in this study. Data related to research on the use of XR technology in STEM education during the period 2011-2025 was collected through the Scopus database. A total of 138 articles were selected for analysis. The dataset search was conducted from September 30, 2025, to October 1, 2025. Data analysis was performed using Biblioshiny software from Bibliometric RStudio and VOSviewer.

Main Findings: The results show that there is long-term scientific interest in research on the use of XR technology in STEM education, with an average annual growth rate of 26.2 and an average number of citations per document of 32.55. In addition, keywords such as metaverse, gamification, and virtual environment have significant potential in terms of future research, assuming that these keywords will be developed and integrated into STEM curricula and pedagogy.

Novelty/Originality of this study: This study offers an innovative contribution by integrating bibliometric analysis with an evaluation of XR implementation trends in STEM education, going beyond descriptive reviews. It identifies key research gaps, underexplored areas, and the potential impact of XR on learning effectiveness. The findings provide a practical foundation for educators, researchers, and policymakers to design measurable, effective, and sustainable XR-based learning strategies, while strengthening both methodological and practical contributions to immersive STEM education research.

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1. INTRODUCTION

The shift between the Industrial Revolution 4.0 and the Society 5.0 denotes the shift in the human role as the main actors in the industrial systems. Whereas the 4.0 era has witnessed the widespread use of technology, the Society 5.0 aids in the focus on human-centred development and integration of technology. Incorporating a human-computer interaction (HCI) approach will allow building a fair relationship between computing and human understanding and thus support the collaborative human-technology paradigm advocated by Society 5.0 [1].

The development of HCI has led to the emergence of various interactive technologies that play an important role in supporting 21st century learning processes, such as user experience-based systems, visual interfaces, and immersive technologies [2]. HCI has a strategic role in the context of STEM (Science, Technology, Engineering, and Mathematics) education, because STEM learning requires active interaction with the concepts of modelling, simulation, and problem solving [3]. The integration of HCI principles in the development of educational technology enables the creation of interactive, student-centred STEM learning environments.

STEM education is considered an important foundation in preparing human resources who are adaptable to developments in digital technology. Along with the rapid growth of digital technology, extended reality has emerged as one of the learning innovations with the potential to support STEM learning [4]. Augmented reality (AR), where the users experience the real world as it is augmented with computer-generated objects; virtual reality (VR), where the user only sees the computer-generated objects but does not interact with them; and mixed reality (MR), where the user can see the computer-generated objects as well as the real ones [5]. All these technologies are so called extended reality (XR).

XR is growing at a very high rate in many fields such as education, healthcare, tourism, commerce and entertainment. XR can be applied in the education sector as a bridge between lecture and learning [6]. Its use has brought significant contributions in a variety of fields. AR provides the convenience of visualization of an atomic and molecular structure, heat-transfer processes, and fluid flows in chemistry and physics [7]. Medicine and biology XR is used in surgery, clinical training, patient education, or interprofessional collaboration [8]. Academic institutions have been advantaged in the engineering field through VR-based virtual labs, which help cut down operation expenses, reduce the physical infrastructure, provide safer learning environments, and improve the competitiveness of institutional services provided to students with special needs [9].

However, despite the enormous potential of XR in STEM education, various studies show that the implementation of XR in the classroom is not yet fully optimal. Its application is still limited to visual presentations such as 3D images, animations or virtual objects, without deep integration into learning strategies and the development of higher-level skills. In the last decade, studies on the use of XR technology in education have developed rapidly. Various studies have discussed the definition, characteristics and conceptual framework of XR in learning. A number of studies also highlight the effectiveness of XR technology on learning interest, learning outcomes, motivation and student engagement [10], [11], [12]. In addition, several studies also examine the integration of XR with specific learning approaches in the context of STEM, such as project-based learning [13], problem-based learning [14] and inquiry-based learning [15]. Other studies have also highlighted factors that influence the effectiveness of XR, such as cognitive load [16], usability [17], self-efficacy [18], and student attitudes towards technology[19].

However, although the number of studies on the use of XR technology in STEM education continues to increase, there are still limitations in studies that comprehensively map the latest research trends, working patterns, and general development trends of XR in STEM education globally. Existing studies are generally partial, focusing on specific subjects or levels of education, and do not provide a comprehensive picture of the direction and evolution of XR research in the context of STEM education. For example, a study from Simge Uğurluer only focuses on the communication studies [20]

Bibliometric analysis is considered very important for identifying research maps, research gaps, and future research opportunities. Without systematic mapping, the development of XR research in STEM education will not be directed. Therefore, a study that comprehensively analyses the trends and impacts of XR use in STEM education is needed. Thus, the research results are expected to be a reference for researchers, educators, and policy makers in developing and implementing XR more effectively to improve the quality of STEM education in the future.

To address this gap, this paper presents a comprehensive bibliometric review of extended reality (XR) research in STEM education during the period from 2011 to 2025. The analysis focuses on research productivity, citation patterns, and the evolution of thematic trends within the field. More specifically, this study aims to answer three main research questions: (1) how XR research in STEM education has evolved over time; (2) which journals, authors, institutions, countries, and articles have exerted the greatest influence on XR research in STEM education; and (3) what key themes and future research directions characterize XR research in STEM education.

2. RESEARCH METHOD

The paper has conducted a thorough review of the development of research on the use of XR technologies in STEM education and its present state. In order to achieve this goal, a bibliometric review methodology was used. A quantitative, descriptive, and exploratory method, bibliometrics utilises an array of different techniques to trace, compile, and analyse metadata, and, as such, provides an evaluation of the development and progression of a knowledge field over a certain period [21]. In the context of educational technology research, this is highly relevant because educational technology research requires not only the evaluation of instructional effectiveness, but also the mapping of research trends, the adoption of new technologies, and collaboration between researchers and institutions. A bibliometric review is compiled by determining the research objectives, outlining the article selection criteria, searching for literature, extracting data, and analysing the data.

2.1. Database Selection

Scopus was the data source of this study since it covers a wide academic area, a large literature index, and it has a wide scope of scholarly products [22], [23]. It has over 29,000 indexed journals and over 94 million records such as scientific articles, book chapters, conference papers, and patents [24]. Also, Scopus has a user-friendly interface where authors are well-informed, citation rates, and research impact can be observed.

2.2. Search Strategy, Article Selection, and Data Analysis

The dataset search was conducted on September 30, 2025, and focused on titles, abstracts, and keywords. Since Scopus is constantly updated, the records obtained will be an indication of the state of affairs as of 1 October 2025. The database query was the following string: TITLE-ABS-KEY ("immersive technology" OR "extended reality" OR "XR" OR "virtual reality" OR "augmented reality" OR "mixed reality" AND "STEM education" OR "science technology engineering mathematics education"). The first search provided 432 documents, including conference papers (n = 222), journal articles (n = 144), book chapters (n = 24), conference reviews (n = 22), reviews (n = 13), errata (n = 2), editorials (n = 2), retractions (n = 1), notes (n Upon the application of the inclusion and exclusion criteria (see Table 1), 138 articles were picked to continue with the analysis.

Research Information Systems (.RIS) and Comma Separated Values (.CSV) format were used to store the extracted data. The bibliometric analysis instruments were realised using Biblioshiny software of Bibliometric RStudio and VOSviewer, where percentages, rankings and evolution of the thematic analysis were provided by Biblioshiny RStudio and the co-occurrence, co-citation and mapping of science was done by VOSviewer [25], [26].

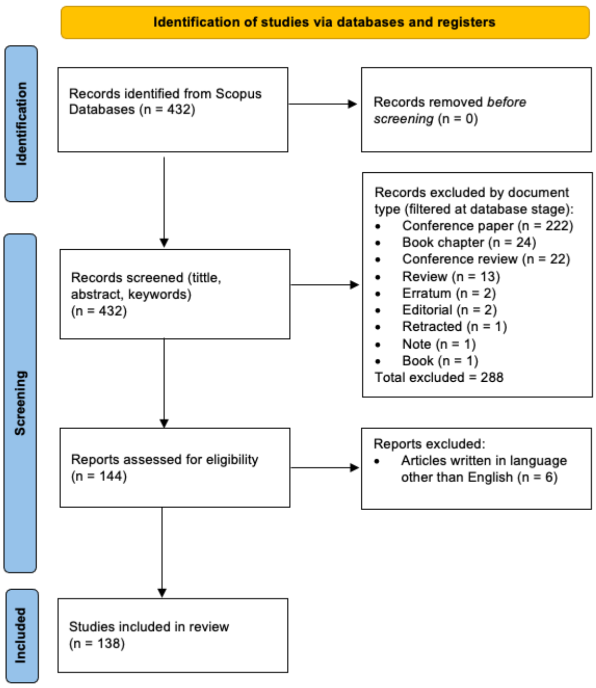

Figure 1. Flow diagram of study selection

Table 1. Inclusion and Exclusion Criteria for Article Selection

Criteria	Inclusion	Exclusion
Publication Type	Peer-reviewed journal articles	Conference papers, book chapters, dissertations, technical reports
Language	Articles written in English	Articles in languages other than English

3. RESULTS AND DISCUSSION

3.1. RQ1. How has XR research in STEM education evolved over time?

3.1.1. Bibliometric Indicators of XR Research Growth in STEM Education

The bibliometric measures outlined in Table 2 provide a numerical evaluation of the evolution of the XR-related studies in the STEM education in the period between 2011 and 2025. The number of publications in the volume is characterized by the steady increase, 138 articles were published in the period, and the average growth is 26.2 per year. This trend supports the claim that the XR technologies, including augmented, virtual, and mixed reality, have risen to the level of a growing scholarly significance in STEM education. The average age of the documents is 2.93 years, which means that the majority of the literature is recent, which is also consistent with the active development of immersive technologies in the various fields of application, such as in education, industry, health, and entertainment. The described wave is also a reflection of an active technological growth of XR devices and greater scholarly interest in their potential uses [27], [28].

Measures related to publication indicate that the references cited are 1,219 in 138 documents with an average of 8.83 references per publication and providing evidence of a significant amount of interaction with the previous scholarship. At the same time, the mean citation count per document is 32.55, which indicates a growing scientific impact in the field of the research of digitally mediated learning.

Patterns of authorship show that 523 authors who belong to 42 nationalities took part in this corpus of work. In single-author articles, the proportion is only 0.94 0.94I percent, which shows the spirit of collaboration that the field has. The co-authorship of each article is on average 4.09, which is a sign of strong interdisciplinary integration such as collaboration across psychology, computer science, and engineering [29]. The rate of international collaboration was 19.57% which implied the increased rates of global collaborative efforts and the corresponding possibility of expansion of cross-border research networks. Besides, collaborations in research may trigger innovation, improve the quality, skills, knowledge, and relevance of research results [30], [31].

Table 2. Bibliometric Indicators of XR Research Growth in STEM Education

Category	Metric	Value
Temporal Indicators		
	Timespan	2011:2025
	Annual Growth Rate %	26.2
	Document Average Age	2.93
Publication Metrics		
	Total Documents	138
	Average Citations Per Document	32.55
	Total Sources	98
	Total References	1,219
Authorship Patterns		
	Total Authors	523
	Single-Authored Documents	13
	Co-Authors Per Document	4.09
	International Co-Authorships %	19.57
Document Types		
	Article	138
Document Contents		
	Keywords Plus (Id)	500
	Author Keywords (De)	822

3.1.2. Annual Distribution

The Scopus database was searched to retrieve 138 articles including those that were published in 2011 to October 1, 2025. The first work, which was published in the International Journal of Emerging Technologies in Learning in 2011, was the beginning of the scholarly pathways. The level of publication was quite low and uneven in the period between 2011 and 2019. A notable growth in the XR related STEM education studies came between the years of 2021 and 2024 pushed by the growing international interest in the application of immersive technology to the educational setting. During this time, 42 countries provided research into the literature. The highest output of publication occurred in 2024 and had an approximate 650 percent growth compared to the first developmental year (2011-2015). It is interesting to note that the 2025 data of what is published is still not complete because the data was collected in the middle of the year.

The patterns of citation show that the early XR research in STEM education, especially the ones published in the period between 2011 and 2015, achieved the highest citation levels with 15 citations in 2011, 13 in 2013, and 11 in 2015. Remarkably, despite the increased number of publications in 2024, the frequency of citation then started to decrease. Such phenomenon implies that an early work has a powerful conceptual implication, which forms the primary points of reference and theoretical basis of later works. Reduced rate of citation of more recent publications does not always imply a difference in the level of scholarship but it could be a result of a change in the research interests as well as a change in the direction of the disciplines in the field. Also, the exponential increase in the academic publications on the topics of the XR made the authors diffuse the attention to a wider range of sources, which reduces the mean citations per article. There are other contributory causes including shifting research interests, the emergence of new technologies, high journal submission fees, and changed academic priorities, which have also led to the decrease in the citation rates with time [32]..

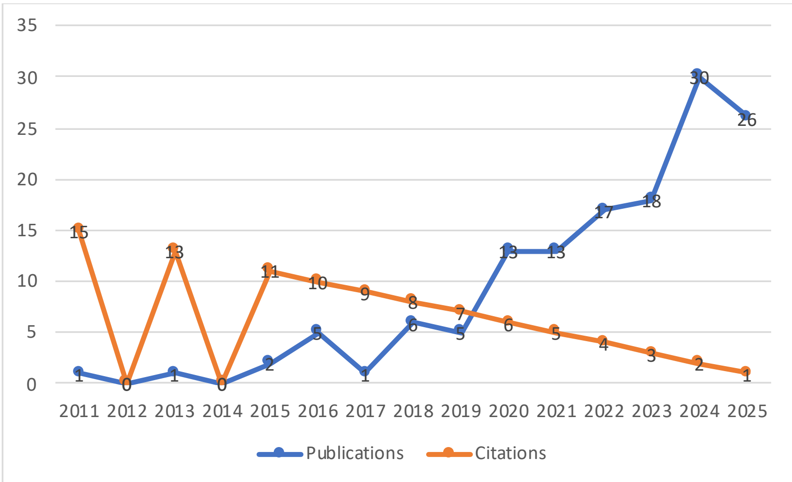

Figure 2. Annual distribution of research on the application of XR technology in STEM education

3.2. RQ2. Which journals, authors, institutions, countries, and articles have had the greatest influence on XR research in STEM education?

3.2.1. Most Productive Journals

Table 3 lists the top journals that have been used to generate XR studies in STEM education. Such outlets are differentiated by the volume of publications and academic contributions in terms of total citations and h -index values. The Journal of Computer Assisted Learning, Educational Technology Research and Development, Education Sciences, and Interactive Learning Environments each published four articles, positioning them as key outlets for disseminating research on XR-enhanced STEM learning.

In terms of academic influence, the Journal of Computer Assisted Learning records the most outstanding performance with the highest total citations (TC=339) and an h-index of 4, followed by Educational Technology Research and Development, which has 248 citations and the same h-index. Both journals reflect a high level of visibility and scientific influence, indicating that the articles published in them are attractive and highly readable among authors and academic practitioners. In terms of publishers, John Wiley & Sons and MDPI each host three of the listed journals, while Springer Nature publishes two. These publishers hus serve as major channels for advancing research on educational technology and immersive learning environments.

Based on the year of initial publication, most journals began featuring XR-related STEM education articles between 2020 and 2025. Computers In Human Behavior, published by Elsevier, was the first journal to introduce work in this domain in 2015. This suggests that studies on XR in the context of STEM education have gained attention in the last five years, consistent with the rapid development of digital learning adoption in educational environments.

Table 3. Most Productive Journals

Source	Publisher	TP	TC	h-index	Publication Start Year
Journal of Computer Assisted Learning	John Wiley & Sons	4	339	4	2020
Educational Technology Research and Development	Springer Nature	4	248	4	2021
Education Sciences	Multidisciplinary Digital Publishing Institute (MDPI)	4	104	4	2020
Interactive Learning Environments	Taylor & Francis	4	67	3	2022
Computers in Human Behavior	Elsevier	3	170	3	2015
Electronics (Switzerland)	Multidisciplinary Digital Publishing Institute (MDPI)	3	23	2	2024
Technology, Knowledge, and Learning	Springer Nature	3	3	1	2016
Applied Sciences (Switzerland)	Multidisciplinary Digital Publishing Institute (MDPI)	2	32	2	2023
Computer Applications in Engineering Education	John Wiley & Sons	2	18	1	2022
British Journal of Educational Technology	John Wiley & Sons	2	7	2	2025

3.2.2. Most Productive Authors

Table 4 presents the leading authors contributing to XR research in STEM education. These authors have made significant contributions to scientific studies on the subject, as indicated by total publications (TP), total citations (TC), and h-index. Johnson, Mina C. from Arizona State University emerges as the most prolific scholar, producing five publications and receiving 505 citations with an h-index of 4, indicating both strong productivity and notable scholarly impact. In contrast, several authors, such as Iacono, Saverio (Università degli Studi di Genova) and Cai, Yiyu (Nanyang Technological University) have only started publishing in recent years (2023-2024) with two to three publications and an h-index of 2.

Interestingly, there is a notable patterns among authors affiliated with the Massachusetts Institute of Technology (MIT), including Wang, Annie; Anteneh, Melat R.; Roy, Dan; and Thompson, Meredith M. Their publication and citation counts are closely aligned, ranging from two to three publications and 35–47 citations, with h-index values between 2 and 3. This suggests sustained collaboration and consistent research influence within the group. Meanwhile, contributors from Europe, such as Beil Fabian from Rheinland-Pfälzische Technische Universität Kaiserslautern-Landau, have two publications with 44 citations, while Bartolomea, Hannah from Arizona State University only authored two publications, but has received the second highest number of citations (84), which indicates the high quality and relevance of her scientific work.

Overall, this data show that authors with a longer publication history (starting in 2018) tend to have higher citations and h-index values compared to those who entered the field after 2020. This suggests that the average citations per article are strongly tied to publication age, as older works have a greater likelihood of being cited [33].

Table 4. Productive and Influential Authors

Author	Scopus ID	Affiliation	Number of Publications	Total Citations	h-index	Publication Start Year
Johnson, Mina C.	6507238066	Arizona State University	5	505	4	2018
Iacono, Saverio	56890949700	University of Genoa	3	7	2	2023
Roy, Dan	57203986113	Massachusetts Institute of Technology	3	47	3	2018
Thompson, Meredith M.	57205744232	Massachusetts Institute of Technology	3	47	3	2018
Wang, Annie	57205741673	Massachusetts Institute of Technology	3	47	3	2018
Anteneh, Melat R.	57219010961	Massachusetts Institute of Technology	2	35	2	2020
Azam, Abu Bakr	57999247200	Nanyang Technological University	2	47	2	2024
Bartolomea, Hannah	57215301618	Arizona State University	2	84	2	2021
Beil, Fabian	24079838200	Rheinland-Palatinate University of Technology Kaiserslautern-Landau	2	44	2	2019
Cai, Yiyu	7401750566	Nanyang Technological University	2	47	2	2024

3.2.3. Most Productive Institutions

Table 5 presents the most productive institutions in XR research within STEM education, highlighting their publication output, citation impact, and the year of their first contribution to the field.

Table 5. Most Productive Institutions

Affiliation	TP	TC	Publication Start Year
Arizona State University	7	509	2016
Nanyang Technological University	5	204	2021
National Institute of Education	4	185	2021
National Taiwan Normal University	4	301	2015
The Education University of Hong Kong	3	102	2023
Graz University of Technology	3	841	2016
Massachusetts Institute of Technology	3	47	2018
University of Genoa	3	7	2023
National Taiwan University of Science and Technology	3	164	2017
Pennsylvania State University	2	2	2024

Table 5 shows the ten most productive and influential institutions based on the number of publications on the application of XR in STEM education. Arizona State University ranks first with seven publications, the first of which was published in 2016, followed by Nanyang Technological University and the National Institute of Education, which published their first articles in 2021, with five and four publications, respectively. In terms of total citations, Technische Universitat Graz ranks first with a total of 841 citations. Although The Education University of Hong Kong only began contributing in 2023, it has already accumulated 102 citations, demonstrating notable early influence.

Several other institutions such as Technische Universitat Graz, Massachusetts Institute of Technology, Università degli Studi di Genova, and National Taiwan University of Science and Technology also exhibit fairly high productivity, each producing three publications. Institutional research productivity is typically shaped by the availability of funding, strong organizational support, and access to qualified human resources [34].

3.2.4. Most Productive Countries

Table 6 presents the top ten most prolific and impactful countries that carry out the research in the area of extended-reality (XR) in STEM education, as the analysis conducted of 42 national settings. The United States holds the first place as it has already published 46 works, which have received 1,149 citations, the first of which was published in 2016. It is important to note that the East Asian countries (China, Taiwan, and Hong Kong) provide a significant contribution to the literature: in China alone, 12 papers have been published with 239 citations, in Taiwan, 11 papers with 450 citations, and in Hong Kong, where the scholarly output is not yet very active, but has already reached five articles with 143 citations each.

In South East Asian, Malaysia (total publications = 9; total citations = 136) and Singapore (total publications = 7; total citations = 219) are represented. The number of their publication volumes is small, compared to larger economies but both are active scholars and show an increasing interest in XR applications in STEM learning. According to temporal analysis, most countries started publishing first in 2015, and the United Kingdom was the first country to get involved in the field, having published first in 2011.

Altogether, the pieces of evidence gathered in Table 6 indicate that XR research in the realm of STEM education has undergone significant international growth throughout the past decade. Even though the United States remains the dominant research productivity location, acute gains in research activity can be traced in the Asian nations, in particular, East and southeast Asia. These trends support geographic diffusion of inquiry, which highlights the collaborative networks and diffusion of immersive technologies in varied institutional settings.

Table 6. The 10 Most Productive and Influential Countries

Country	TP	TC	Publication Start Year
USA	46	1149	2015
China	12	239	2015
Taiwan	11	450	2015
Malaysia	9	136	2018
Spain	9	783	2018
Germany	8	91	2019
Singapore	7	219	2020
Hong Kong	5	143	2021
UK	5	788	2011
Chile	5	81	2022

3.2.5. Articles with the Highest Number of Citations

Table 7 outlines the ten most highly cited articles on XR integration in STEM education. The article with the highest impact is Virtual laboratories for education in science, technology, and engineering: A review (2016), published in Computers and Education, which has accummulated 737 citations. This paper serves as the main reference in studies on the use of virtual laboratories for STEM-based learning. The second most cited article, Augmented reality for STEM learning: A systematic review (2018), also published in Computers and Education, has received 700 citations. This data show that the topic of XR usage in STEM learning is one of the main focuses in technology-integrated education research.

Several other articles have also demonstrated substantial scholarly impact. For instance, Metaverse in Education: Contributors, Cooperations, and Research Themes (2023), published in IEEE Transactions on Learning Technologies, has garnered 94 citations in just two years, indicating that research on the metaverse is becoming a trend in education. Overall, the data presented in Table 7 indicate that publications with a literature review approach have a wider range of influence, as reflected in the number of citations obtained. In general, literature review studies have more co-authors. Prior studies reveal that papers with more co-authors often achieve greater citation impact [35]. Additionally, journals with strong impact metrics naturally attract more citations [36].

Table 7. Articles with the Highest Number of Citations

Paper, Year, DOI	Journal	TC
Virtual laboratories for education in science, technology, and engineering: A review, 2016, 10.1016/j.compedu.2016.02.002	Computers and Education	737
Augmented reality for STEM learning: A systematic review, 2018, 10.1016/j.compedu.2018.05.002	Computers and Education	700

Immersive VR and education: Embodied design principles that include gesture and hand controls, 2018, 10.3389/frobt.2018.00081	Frontiers Robotics AI	276
Motivation, engagement, and performance across multiple virtual reality sessions and levels of immersion, 2021, 10.1111/jcal.12520	Journal of Computer-Assisted Learning	138
Using virtual reality in the classroom: preservice teachers' perceptions of its use as a teaching and learning tool, 2019, 10.1080/09523987.2019.1583461	Educational Media International	121
Augmented reality enhanced cognitive engagement: designing classroom-based collaborative learning activities for young language learners, 2021, 10.1007/s11423-020-09893-z	Educational Technology Research and Development	114
Designing VR Experiences – Expectations for Teaching and Learning in VR, 2021, N/A	Educational Technology and Society	100
Impact of augmented reality lessons on students' STEM interest, 2017, 10.1186/s41039-016-0039-z	Research and Practice in Technology Enhanced Learning	100
Metaverse in Education: Contributors, Cooperations, and Research Themes, 2023, 10.1109/TLT.2023.3277952	IEEE Transactions on Learning Technologies	94
Developing a hands-on activity using virtual reality to help students learn by doing, 2020, 10.1111/jcal.12389	Journal of Computer Assisted Learning	93

3.3. RQ3. What key themes and future research trends characterize XR research in STEM education?

The dominant topics and research trajectories in XR-based STEM education were identified through keyword occurrence analysis. Each keyword was represented by a circle, the size of which indicates the frequency of occurrence or popularity of the keyword in question. The network visualization process was carried out using VOSviewer software. In order for VOSviewer to produce a keyword co-occurrence network to be visually examined, a minimum number of keyword occurrences of five times was implemented.

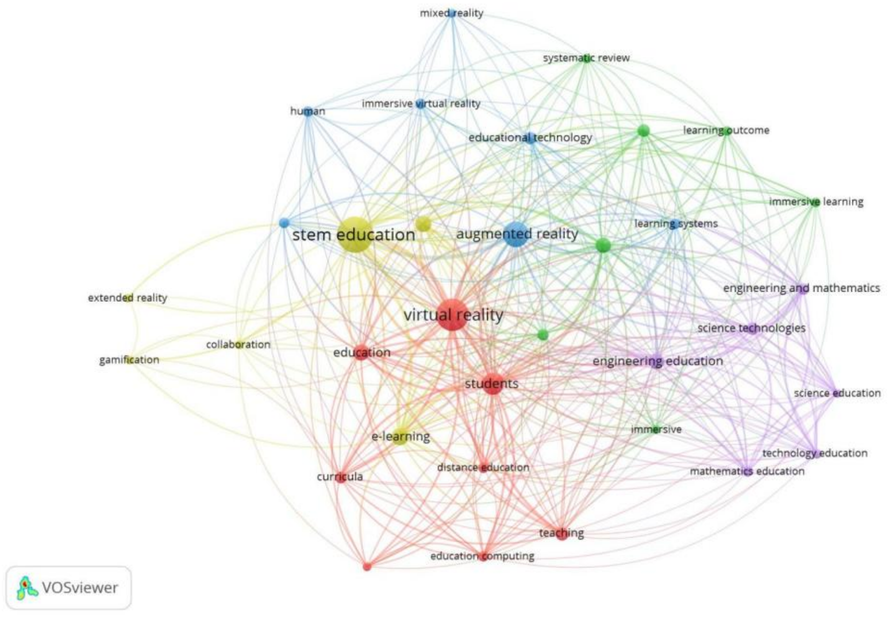

Figure 3. Network visualization of keyword co-occurrence

Figure 3 highlights the most frequently used terms, including e-learning with a total of 18 occurrences, indicating that Extended Reality is widely positioned as an integral part of the digital learning ecosystem in STEM education. The rapid development of e-learning, especially after the increased need for online and hybrid learning [37], [38], has encouraged researchers to explore XR as a solution to overcome the limitations of online learning interaction and visualisation. Other terms such as "curricula" reflect researchers' awareness that the successful implementation of XR in STEM education is highly dependent on alignment with the curriculum. XR cannot be effectively integrated without adjusting the learning objectives, competency outcomes, and material structure that have been established in the curriculum. In addition, the demands of the 21st-century curriculum, which emphasises critical thinking, problem-solving, creative thinking and interdisciplinary learning skills, have encouraged researchers to explore how XR can be adopted as part of STEM curriculum design [39], [40].

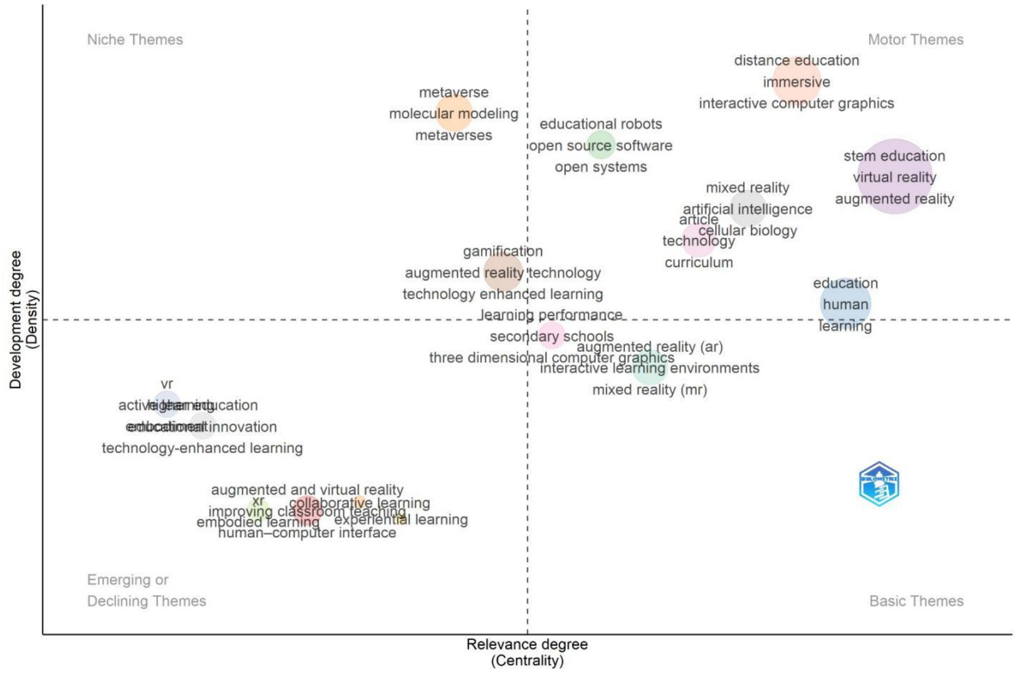

Figure 4. Thematic map of conceptual structure by keyword

Figure 4 displays the thematic map categorizing XR-related keywords into four grups: Niche Themes, Motor Themes, Emerging or Declining Themes, and Basic Themes. These clusters are determined by two dimensions: the X-axis (Centrality), representing the importance of a theme is within the broader research field, and the Y-axis (Density), indicating the level of thematic development.

Motor Themes consist of keywords such as virtual reality, augmented reality, mixed reality, and STEM education. These themes have the highest level of development and have been extensively researched, making them the main focus of research studies. Research in this category is generally applied and emphasizes the effectiveness of XR in improving students' understanding, skills, and motivation to learn. Reinforcing this observation, a systematic review examined research related to VR’s potential in fostering student motivation, self-efficacy, and engagement in learning. The findings highlight that VR features, such as immersive visualization, 3D manipulation, and dynamic interactivity enhance students' learning skills and motivation, ultimately leading to improved understanding [41]. Additionally, [42] a further study study also offer a systematic review related to the benefits and challenges of XR in learning. The research revealed that the benefits of using XR include improved learning and increased motivation, while the challenges include technical issues and high cost constraints.

Basic Themes exhibit high centrality and low density, which means that keywords in this category often appear in XR research in STEM education, but have not been explored in depth. Keywords in this category, such as education and learning indicate that the pedagogical aspects of XR have not been explored in depth, and therefore research related to instructional design, learning theory, and cognitive processes in learning experiences using XR technology can be applied as further investigation. Crogman et al confirmed that the integration of XR technology in education related to pedagogical issues and the impact of XR use on health needs to be further explored in depth [43].

Emerging or Declining Themes contain keywords with low centrality and density, meaning these keywords have just emerged and have not yet developed or are experiencing a decline in interest in research. Keywords such as embodied learning, experiential learning, and collaborative learning fall into this category. While these themes are highly relevant to the use of XR technology, scientific literature shows that their application and discussion in STEM is scarce. This provides new research opportunities to explore how XR can be employed to optimize experience-based learning and virtual collaboration that enrich STEM learning process. As emphasized by Kwon [44] the sustainability of technological innovation opens up opportunities for experiential learning in virtual environments identical to real-world experiences.

Niches Theme are characterized by high density and low centrality. These themes develop intensively in a limited scope but have strong connections with the main structure of XR research in STEM education. Keywords such as metaverse and gamification fall into this category. Pregowska [45] noted that the metaverse provides great opportunities to bring about substantive changes in the education sector. Meanwhile, studies conducted by Chen [46] and Gerini et al [47] revealed that the combination of gamification elements with extended reality technology in producing virtual laboratories contributes to the continuous exploration of immersive technology and gamification in educational and training environments. These niche themes have strong potential to significantly contribute to future research if developed extensively and integrated with STEM curriculum and pedagogical needs [48].

Overall, the analysis results indicate that the trend of research on the use of XR technology in STEM education has increased significantly over the past decade, demonstrating growing academic interest in integrating XR into the learning process. These findings are in line with the study Henry Matovu, which highlights the increased interest of researchers in immersive technology in science education [49]. Although quantitative trends show significant growth, the distribution pattern of research indicates a concentration in certain countries, such as the United States, the United Kingdom, and China. Meanwhile, other regions, including developing countries, are relatively underrepresented. This indicates an imbalance in access to technology and resources, which is in line with findings of Arfa Afzal regarding the adoption of educational technology in a global context [50].

Thematically, keyword analysis shows that XR research in STEM education often focuses on science and mathematics learning at the K-12 and university levels, with few studies emphasising engineering education specifically. This pattern is interesting because it contradicts the predictions of constructivist theory proposed by Piaget and Vygotsky [51], which emphasises that learning experiences based on interaction and object manipulation are very important in all STEM domains, including engineering. These findings indicate a research gap, where most XR studies tend to be conceptual and focus on basic science, while the domains of engineering and technology remain relatively unexplored. This is also in line with the observation that most XR studies focus on strengthening conceptual [52], [53] understanding rather than developing practical skills. In addition, the results of several studies report that the use of XR technology is diverse and varied, with some using mobile-based XR with limited interactivity, while others use advanced hardware-based XR with a highly immersive experience [54], [55]. These differences indicate that XR does not solely depend on technology, but also on instructional design and pedagogical integration, as supported by Mayer's cognitive theory of multimedia learning [56], which emphasises that effective learning experiences require the optimal integration of content and media.

Although this study is informative as far as its contribution to the development of XR research is concerned, it is limited in a number of ways. To start with, the review is limited to 138 pieces of literature published in 2011-2025, which might ignore any other studies that might be conducted during this time period and provide alternative views. Secondly, the use of the Scopus database only could have predisposed the elimination of relevant contributions indexed in other databases. Therefore, the next studies must also diversify data by using more bibliographic databases to come up with a more comprehensive analysis. Also, authors suggest the need to investigate less-researched areas to expand the academic ground and initiate a wave of innovation in using XR technology in STEM education.

4. CONCLUSION

The article is a present study that provides the descriptive and bibliographic evaluation of research paths and research agendas in terms of the implementation of extended -reality (XR) in STEM education during the years 2011-2025. The results show that there is a long-term scholarly interest of the article as the average annual growth rate is 26.2 and the mean number of citations per document is 32.55. With 523 authors representing 42 countries, the corpus is co-created by a group of authors, and the rate of international collaboration is 19.57 which was considered to be a high level of cooperation on the global scale and further opportunities of creating cross-border collaborative networks based on XR in STEM learning. This field of study predicts the most impactful journals, authors, institutions, countries and most often cited publications. Johnson, Mina C considers the most prolific one with five papers bearing 505 citations and having h-index of 4, which is a relatively high productivity and scientific impact compared to the colleagues in the same industry. The most commonly used periodical is specified as the Journal of Computer Assisted Learning and plays a central role in the development of the sphere. Arizona State University is mentioned as the university that made the greatest contribution. Also, the most cited work is the 2016 monograph, Virtual laboratories for education in science, technology, and engineering: A review. The United States has the highest status of the powerful and influential country with 46 articles and 1,149 citations, and the next country is China with 12 articles and 239 citations. The thematic clusters and research projection are sorted into four categories, namely Niche Themes, Motor Themes, Emerging or Declining Themes, and Basic Themes. All the clusters are supported by a series of high-frequency keywords. The facets of the virtual environment, including the notion of the metaverse, gamification, and virtual reality, have a significant potential in terms of future research, assuming that they will be advanced and incorporated into the STEM syllabus and teaching methods smoothly.

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Generative AI and AI-assisted technologies were used to improve language clarity and fluency in preparing this work. The author is still solely responsible for all intellectual and creative contributions, including the paper's structure, arguments, and interpretations. AI is used in conjunction with human inspection to guarantee the work's originality and academic integrity.

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