

REVIEW ARTICLE

Mapping the Future of Augmented Reality in 21st Century Education: A Comprehensive Bibliometric Review

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ABSTRACT

Augmented Reality (AR) technology has emerged as a transformative tool in education, integrating digital information into the user's real-world environment. This study aims to explore global research trends in AR for education through bibliometric analysis. The primary objective is to identify the evolution of publications, influential sources, leading authors, and productive countries in AR research. Using data from Scopus (2020–2024), 1,232 documents were analyzed. The study reveals that the United States leads in research productivity, followed by China, Indonesia, Malaysia, and Germany. The research highlights the rising trend in AR publications, with annual growth rates of 23.15%. Key journals like "Education and Information Technologies" and "Education Sciences" are at the forefront, showcasing the interdisciplinary nature of AR in education. Prominent authors such as Archana Mantri and Liru Chen contribute significantly to the field. This research also identifies emerging trends in mobile applications, STEM education, and the integration of AR with virtual reality. Overall, bibliometric analysis provides a comprehensive understanding of AR's impact, emerging research directions, and the global collaborative network, helping to guide future research and enhance AR's integration in educational practices.

KEYWORDS

Augmented reality; bibliometric; biblioshiny; educational technology; trends

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1. INTRODUCTION

Augmented Reality (AR) technology has emerged as a pivotal technological innovation of the 21st century, notably impacting various fields, particularly education [1], [2]. AR is a revolutionary media innovation that seamlessly integrates digital information into the user's perception of the natural world,

fostering dynamic and informative interactions. [3], [4]. This technology utilizes devices such as smartphones, tablets, or specialized devices like AR glasses to seamlessly insert visual elements, audio, and sensory data into the user's surrounding environment. The uniqueness of AR lies in its capability to enrich the perception of the natural world with real-time, relevant information, thereby enhancing the user's experience across various daily activities.

In education, AR media can facilitate a more immersive and interactive learning experience [5], [6]. Additionally, AR media offers significant opportunities to enhance learners' engagement and comprehension of the subject matter. By integrating visual and interactive elements into the learning process, AR has been shown to make abstract concepts more tangible and easier to visualize, which improves learning efficiency and retention [7], [8]. By clarifying complex concepts, AR media makes them more comprehensible and visualizable, thereby enhancing overall learning outcomes.

In recent years, research on the application of AR in education has undergone rapid expansion. Numerous studies have delved into diverse aspects of this technology, from its efficacy in enhancing learning outcomes to the challenges associated with its integration in classrooms. These investigations have yielded substantial findings, offering valuable insights into the effective utilization of AR in educational settings [9], [10], [11]. For instance, research has explored how AR can improve student motivation and learning performance, particularly in science and mathematics education [12]. Nonetheless, a systematic and comprehensive approach, such as bibliometric analysis, is essential to grasp the global trends and advancements in this field of research.

Bibliometric analysis is a research methodology that employs both quantitative and qualitative approaches to evaluate diverse aspects such as publication year, country of origin, citation frequency, and prevalent keyword usage [13], [14]. According to Kumar [15], bibliometric methods provide a structured approach to examining academic literature, revealing key insights into research trends and identifying influential works within a specific field. This analytical approach aims to create visual representations, identify trends, and observe advancements in research by analyzing data such as publishing patterns, citation trends, and co-authorship networks. By utilizing this method, the study highlights notable research contributions, tracks the evolution of ideas, and explores relationships among groups of researchers.

Additionally, bibliometric analysis is employed to scrutinize scientific literature using publication and citation data. This method enables researchers to discern trends in research, patterns of collaboration, and the scholarly impact within a specific field. In the context of augmented reality (AR) in education, bibliometric analysis offers insights into the evolution of research, prevalent topics of discussion, and influential researchers and institutions. Such insights are crucial for educational researchers and practitioners to navigate the research landscape effectively, pinpoint areas needing further exploration, and foster informed decision-making.

One of the primary advantages of bibliometric analysis is its capacity to track research trends longitudinally. By examining the annual counts of publications and citations, researchers can discern whether interest in employing augmented reality (AR) in education is growing or declining. Moreover, this analysis can illuminate shifts in research emphasis, such as a transition from studies focused on AR technology development to those exploring its practical applications in educational settings. Recent studies Harnal et al. [16] have shown that the increase in publications on AR reflects its growing acceptance and integration into educational practices. Understanding these trends is crucial for researchers to align their focus with current needs and advancements in the field.

Therefore, the primary objective of this research is to identify and visualize various research aspects, including the evolution of publication development, most cited articles, prominent countries, authors, and sources related to the utilization of AR media in education. In addition, this study aims to explore emerging trends and topics on the topic of augmented reality in education. The following list outlines the Research Questions (RQ) that define the main objectives of this investigation:

- RQ1. What are the main information results and publication evolution generated by the overview analysis in bibliometric analysis?
- RQ2. What are the most influential sources, leading authors, and productive countries in the research on augmented reality technology in education?
- RQ3. Which research documents are most often cited by other researchers?
- RQ4. What is the visualization of the co-occurrence analysis of the author's keywords on this topic?

2. METHODS

The methodology employed in this study is bibliometric analysis, a research method that utilizes statistical techniques to examine and evaluate scientific literature [17], [18], [19]. This approach is particularly suitable for studying augmented reality (AR) in education as it allows for a systematic exploration of trends, citations, and authorship patterns within this rapidly evolving field. Bibliometric analysis serves as a powerful tool for understanding and assessing the progression of research within a specific field. First, it facilitates monitoring research development by tracking publication trends over time, providing insights into how interest and activity in a topic, such as augmented reality (AR) in education, have evolved. By using this method, we can identify the years with the highest growth in AR-related publications, pinpointing the moments when AR became a more prominent topic in educational research. This allows researchers to examine the historical trajectory of a field and its dynamic nature.

Additionally, bibliometric analysis aids in measuring impact by evaluating citation frequencies and other bibliometric indicators. This is especially relevant for AR in education, as it helps identify the most influential studies that have shaped the integration of AR into pedagogical frameworks. This helps researchers determine the influence of individual studies or research bodies, identify seminal works, and recognize influential authors who have significantly contributed to the field. However, it is important to note that citation analysis may have biases, such as the tendency to favour more established authors or older studies, which can overlook emerging contributions.

Moreover, bibliometric analysis excels in visualizing trends through graphical representations and data visualization techniques. For AR in education, this method can generate visual maps of co-authorship networks and keyword co-occurrence, helping to identify collaborative clusters and prevalent research themes in the field. These methods enable researchers to observe patterns and shifts in research topics, keywords, and collaboration networks over time. Lastly, one of the most valuable aspects of bibliometric analysis is its ability to identify emerging research themes. By analyzing frequently occurring keywords and topics, it uncovers new and promising areas of interest, guiding researchers toward emerging trends that can shape the direction of future research. This is particularly valuable in the context of AR in education, as it helps pinpoint areas of research that have recently gained traction, such as the use of AR for remote learning or its impact on specific educational outcomes.

Despite its advantages, bibliometric analysis does have limitations. For instance, it may be limited by biases in keyword selection or by the scope of the databases used. Keyword choices might not fully encompass all related areas of AR in education, and certain databases might not capture all relevant

publications. Overall, bibliometric analysis provides critical insights into the evolution, impact, and future potential of research within a given domain.

Figure 1 illustrates the four main stages involved in conducting bibliometric analysis: 1) Identification: Gathering relevant publications from bibliographic databases such as Scopus, 2) Filtering: Cleaning and preparing the data for analysis, including extracting bibliometric indicators like publication year, authors, citations, and keywords, 3) Analysis: Applying statistical methods to analyze the data, which may include citation analysis, co-citation analysis, keyword analysis, and network analysis, 4) Conclusion: Presenting the results through visual representations such as graphs, charts, and maps to illustrate trends, patterns, and relationships among research entities.

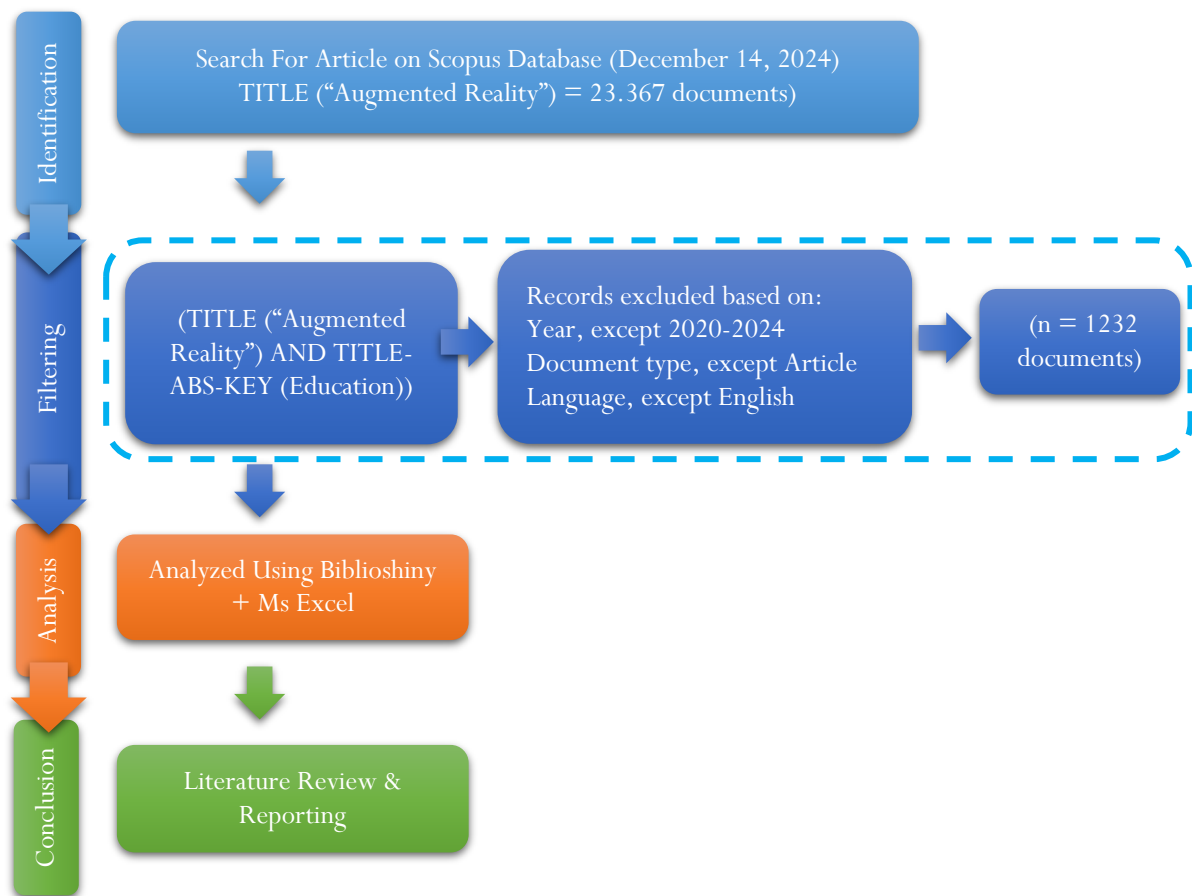


Figure 1. Stages of the bibliometric analysis method

In the initial stage, this research conducted identification by searching for documents relevant to the topic to be analysed using Scopus as the primary data source [20], [21]. Scopus was chosen based on its excellent features, including breadth of coverage, accuracy and reliability of information, a robust citation system, and consistent data standards, enabling continuous in-depth analysis [22], [23]. The search was carried out on December 14, 2024, by writing the research title about "Augmented Reality". Obtained as many as 23,367 documents found on the keyword use of Augmented Reality technology published on the Scopus database. Next, in the second stage, data filtering is performed using queries specifically designed to isolate documents that match specific criteria, namely (TITLE ("augmented reality") AND TITLE-ABS-KEY (education)) AND PUBYEAR > 2019 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")), focus on topics related

to the use of augmented reality media in the field of education. In addition, it also restricts the year in the range of 2020–2024, with the type of article document and the language used being only English. As a result, 1232 documents were identified that met the search criteria.

In the third stage, 1232 filtered documents from the Scopus database were analyzed. Biblioshiny and Microsoft Excel software were used to analyze and visualize the data. Biblioshiny effectively visualizes and analyses descriptive and conceptual data [24]. The fourth or final stage of the research involved a thorough literature review and the conclusion of various research questions, particularly regarding the use of augmented reality media in education.

3. RESULTS AND DISCUSSION

3.1. Overview

RQ1. What are the main information results and publication evolution generated by the overview analysis in bibliometric analysis?

RQ1 aims to identify the main information results and publication developments resulting from the analysis of the general overview. The analysis begins by providing an overview covering three main aspects: key information and publication developments. The results of the key information provide insights into key elements, such as the number of publications, prominent authors, and the most influential journals in research related to augmented reality in education. Meanwhile, publication developments show a trend of publication growth over time, reflecting the increasing attention to this topic, especially with the widespread adoption of AR technology in education. Table 1 presents vital information from the Scopus metadata search results. The explanation includes the period, sources, documents, annual growth rate, and several authors contributing to research using augmented reality technology in education:

Table 1. The main information on bibliometric analysis

Decription	Result
Timespan	2020-2024
Sources (Journals, Books, etc)	562
Documents	1232
Annual Growth Rate %	23.15%
Authors	4607

The descriptive bibliometric analysis focused on augmented reality (AR) technology in education, conducted using data extracted from the Scopus database. Between 2020 and 2024, a total of 1232 publications were identified, sourced primarily from journals, books, and other academic outlets, totalling 481 sources. The analysis revealed an average annual growth rate of 23.18% in publications on this topic. The extensive interest is reflected in contributions from 4607 authors, underscoring significant engagement among researchers and academics in exploring AR's application in educational contexts.

In addition, the results of an annual analysis of publications that use augmented reality technology in education. The results of the analysis show that the number of publications is increasing every year. Figure 2 shows the number of publications per year in the time from 2020 to 2024 related to the use of

augmented reality technology in education. Figure 2 shows the number of publications per year in the 2020-2024 timeframe related to using augmented reality technology in education.

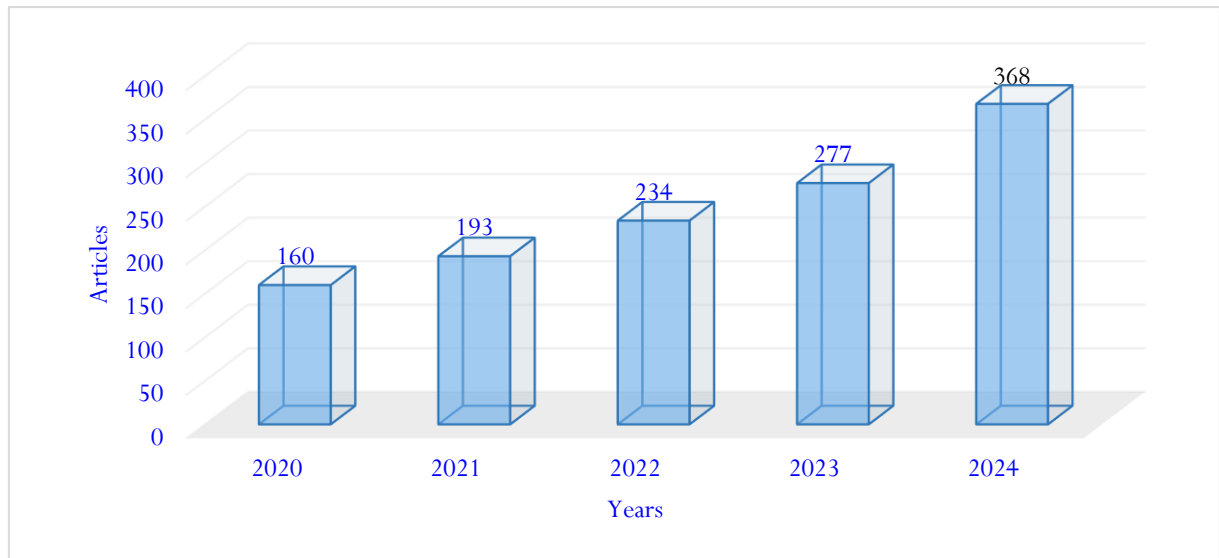


Figure 2. Evolution of publication (2020-2024)

Figure 2 illustrates the annual publication trends from 2020 to 2024 focused on augmented reality (AR) technology in education. The graph reveals a notable increase in the number of research articles over this period. Starting at 160 articles in 2020, the count rose significantly to 368 articles by 2024, indicating consistent growth and heightened interest in AR within the educational context.

The surge in publications underscores the rising popularity of AR as a research topic in education. This trend reflects the recognition of AR's potential to enhance learning through innovative and interactive methods, thereby improving engagement and educational outcomes. In the earlier years (2019-2020), growth was driven by the exploration of new technologies and initial applications of AR in educational settings. Subsequently, from 2021 to 2024, there was a sharp increase, reflecting broader adoption and practical implementation of AR in response to technological advancements and the increasing demand for adaptive and engaging learning approaches. This acceleration was further propelled by the COVID-19 pandemic, which underscored the necessity for effective distance-learning solutions.

3.2. Impact Sources, Authors, and Countries

RQ2. What are the most influential sources, leading authors, and productive countries in the research on augmented reality technology in education?

To answer RQ2 regarding the most influential sources, prominent authors, and productive countries in research on augmented reality technology in education, bibliometric analysis identifies key elements that provide an overview of the greatest contributions in this field. The results of this analysis highlight the various dominant publication sources, the most influential authors, and the countries with significant research contributions on the topic. Figure 3 shows a diagram of the five most productive sources in producing publications related to this topic. This analysis can help in selecting journals for future publication of research results. If the research matches a topic widely covered in a particular journal, then that journal can be a good choice for paper submission. The total number of journals obtained from the analysis amounted to 562. In Figure 3, we filtered them into ten journals that are most productive in producing research on using augmented reality technology in education.

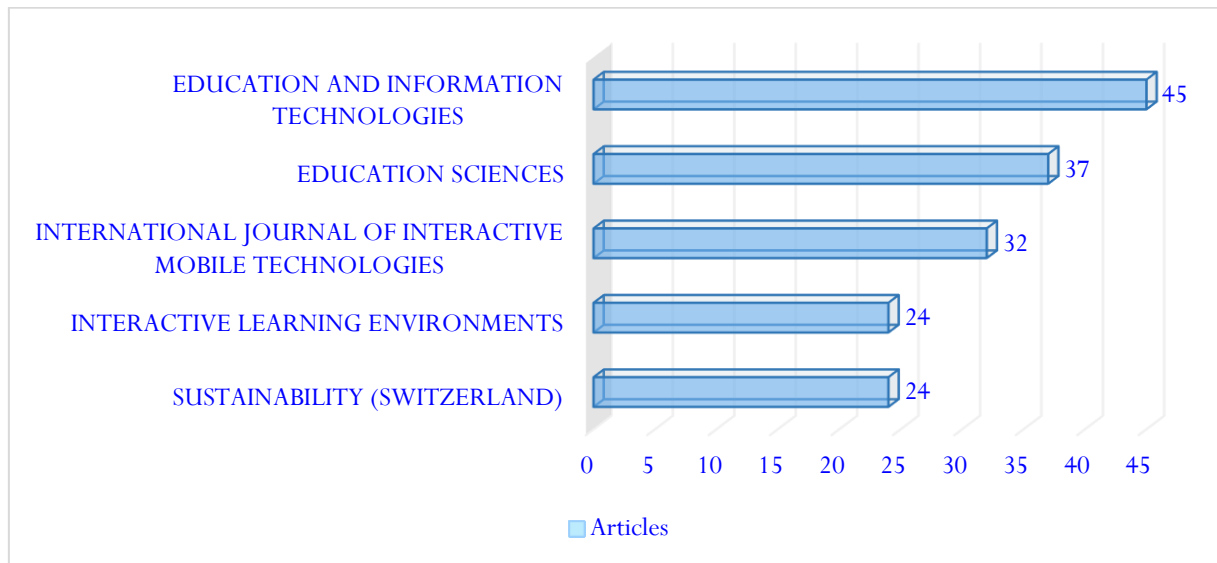


Figure 3. Top five most relevant and productive sources

Figure 3 shows the ten most prolific publication sources in augmented reality (AR) research for education. This pie chart depicts the distribution of articles published in various journals, providing an overview of the journals at the centre of research activity in this field. Understanding these key publication sources can assist researchers and academics in identifying the most relevant and reputable journals to publish their research.

The journal “Education and Information Technologies” emerged as the most productive source with 45 articles. It shows that integrating information technology in education is a significant area of research. The articles in this journal explore how AR can be integrated with other technologies, such as learning management systems and e-learning platforms, to create more interactive and practical learning environments.

The journal “Education Sciences” with 37 articles, took second place, indicating that the field of education generally recognizes the importance of AR research in developing new learning methodologies and technologies. The journal publishes a wide range of studies exploring the application of AR in various educational contexts, from primary to higher education, as well as in various disciplines.

The International Journal of Interactive Mobile Technologies, with 32 articles, took third place, underscoring the relevance of mobile technology in AR development and implementation. The journal highlights how mobile devices can expand access to AR in education, making learning more flexible and adaptive, which can be done anywhere and anytime.

Overall, this analysis of publication sources shows that research on AR in education is widespread across journals focusing on education, technology, and sustainability. This reflects the diversity of AR approaches and applications in education and the importance of interdisciplinary collaboration to develop innovative solutions to address challenges and meet educational needs in the digital age. This bibliometric analysis guides researchers on which journals are most relevant and influential in this field, helping them plan their research publications more strategically.

Furthermore, the focus will be on prominent authors who have made significant contributions to the advancement of AR research in education. Table 2 presents five authors who produced many

publications related to using augmented reality technology in education. This analysis can help researchers make the most contributing authors as references. The total number of authors obtained from bibliometric analysis is 4607. Table 2 displays five authors who have been filtered as the most productive in conducting and publishing research on using augmented reality technology in education.

Table 2. Top five most productive authors

Authors	Documents	Affiliations
Mantri, Archana	12	Chitkara University, India
Chen, Liru	7	Southeast University, China
Huwer, Johannes	7	University of Konstanz, Germany
Wang, Xi	7	University of Science and Technology, China
Andrade-Arenas, Laberiano	6	Universidad de Ciencias y Humanidades, Peru

Table 2 presents the five most prolific authors in the investigation of augmented reality (AR) technology in education. Archana Mantri is the most prolific author from Chitkara University, Punjab, Rajpura, India, with 12 publications. This illustrates Archana Mantri's substantial contribution to augmented reality research in education, serving as a vital reference for other scholars in this domain. The inclusion of two writers from Chitkara University indicates the institution's robust emphasis on augmented reality research in teaching.

The second most prolific author in the current data is Liru Chen from Southeast University, China, with seven publications. Chen's contributions highlight augmented reality research initiatives in China, illustrating the nation's active engagement in investigating the potential of augmented reality in education. Chen's research centres on the application of augmented reality to improve learning experiences and its impact on student engagement and outcomes.

Johannes Huwer, affiliated with the University of Konstanz, Germany, has authored seven published documents. In conjunction with Wang, Xi from the University of Science and Technology, China, they emphasise substantial global contributions to augmented reality research in education. The existence of numerous highly productive authors from various locations signifies a worldwide dedication to enhancing the function of augmented reality in education. Moreover, Archana Mantri, with the most publications (12), enhances Chitkara University's standing as a distinguished research centre in augmented reality and educational technology, possibly indicating a robust research program at the institution.

This revised study highlights essential authors, like Mantri, Chen, and others, whose publications are vital references for scholars investigating the applications of AR in education. Utilising these fundamental studies and promoting inter-institutional cooperation, future research can yield transformative advances, guaranteeing that AR perpetuates the enhancement of educational quality and accessibility worldwide.

In addition, an analysis of the most productive countries in producing AR-related research, as well as the role of these countries in developing and advancing augmented reality technology in the context of education. Figure 4 presents data from countries worldwide that contribute to this research. The total number of countries obtained from the analysis is 73. In Figure 4, the author filters into the five most productive affiliations in producing research on using augmented reality technology in education.

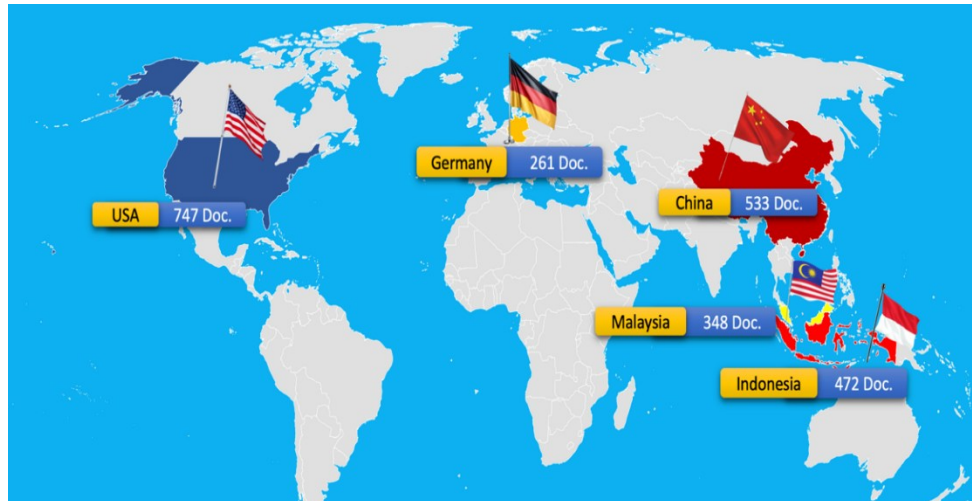


Figure 4. Top five most productive countries

Based on [Figure 4](#), the United States (USA) leads in research productivity concerning augmented reality (AR) in education, with 747 documents and 2,035 citations. This indicates that the USA not only leads in the volume of documents but also exerts considerable influence on global research in this field. The USA's dominance in AR research can be attributed to its robust technological infrastructure, substantial investment in educational innovation, and the presence of leading research institutions like MIT and Stanford, which consistently produce high-impact research. This elevated production signifies the existence of premier research institutions and robust academic collaboration, which facilitate the advancement of augmented reality innovations for 21st-century education.

China ranks second with 533 documents and 1,435 citations, illustrating the nation's proactive involvement in advancing AR technologies for education. China's substantial investment in digital technology and its government-driven focus on educational modernization have positioned the country as a key player in educational technology research [\[25\]](#). China's substantial investment in digital technology and technology-driven education substantially influences the worldwide trend. Research in China frequently centres on augmented reality applications that incorporate adaptive learning, self-directed learning, and enhanced student engagement.

Indonesia secured the third position with 472 documents, however with a comparatively lower citation total of 449. This indicates that although Indonesia's productivity is elevated, the efficacy of its research need enhancement. The lower citation rates in Indonesia can be attributed to challenges in global research visibility, limited international collaboration, and the regional focus of many studies [\[26\]](#). Indonesia may enhance its research effect by augmenting international collaboration and concentrating on technologies that are more relevant to local contexts, such as augmented reality-based learning to elevate the quality of education in distant regions. Strengthening these international ties and focusing on localized educational challenges could increase the global recognition and citation of Indonesian AR research [\[27\]](#).

Malaysia ranks fourth, possessing 348 documents and 578 citations. The nation exhibits consistent advancement in augmented reality for educational research, mostly through initiatives from prominent universities and international collaborations. Similar to Indonesia, Malaysia's research productivity is bolstered by strategic partnerships with global institutions, particularly in the integration of AR with STEM (Science, Technology, Engineering, and Mathematics) education [\[28\]](#). Malaysia's research emphasis frequently encompasses the fusion of augmented reality with STEM education, aligning with

contemporary educational requirements and addressing the global demand for more dynamic, technology-driven learning models.

Germany completes the top five with 261 documents and 618 citations, demonstrating its substantial impact in AR research despite a smaller document count relative to other nations. Germany's significant role in AR research can be attributed to its emphasis on foundational research, a strong focus on collaborative European research initiatives, and its investment in the intersection of technology and education. Germany prioritises foundational research and extensive international academic collaboration, leading to AR technology developments that are frequently cited worldwide. This research underscores the significance of international cooperation in recognising trends and effects of augmented reality in 21st-century education, possessing substantial potential to yield more innovative and inclusive educational solutions.

3.3. Top 10 Most Cited Article

RQ3. Which research documents are most often cited by other researchers?

To answer RQ3 regarding the research documents most frequently cited by other researchers, this analysis identifies publications that have had a significant influence in the field of augmented reality (AR) technology in education. The results of the analysis show documents that are often used as the main reference, reflecting their contribution to the development of AR theory and applications in the context of education. Table 2 shows the documents with the most citations worldwide. The table lists ten articles out of 1232 related to using augmented reality technology in education, detailing the article title, DOI (Digital Object Identifiers), number of citations received, and a column labelled TC (Total Cited) per year or average total citations.

Table 3. Top five most cited articles

Title	DOI	Cited	TC
"The effect of Augmented Reality Technology on middle school student's achievements and attitudes towards science education" [29]	10.1016/j.compedu.2019.103710	248	41.33
"Virtual reality and augmented reality in social learning spaces: a literature review" [30]	10.1007/s10055-020-00444-8	227	45.40
"Augmented reality and mixed reality for healthcare education beyond surgery: an integrative review" [31]	10.5116/ijme.5e01.eb1a	173	28.83
"Augmented Reality and Virtual Reality for Learning: An Examination Using an Extended Technology Acceptance Model" [32]	10.1109/ACCESS.2020.3048708	158	31.60
"Integrating TTF and UTAUT2 theories to investigate the adoption of augmented reality technology in education: Perspective from a developing country" [33]	10.1016/j.techsoc.2021.101787	145	29.00
"Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective" [34]	10.1016/j.stueduc.2020.100876	145	24.17

Table 3 shows the ten most cited articles in research on augmented reality (AR) in education. This data shows which articles have had the most significant impact within the academic community, guiding global research trends in using AR for education. These articles reflect various important aspects of AR applications, from increasing student motivation, STEM learning support, gamification in education, and adoption challenges in developing countries, to applications in sports training.

Augmented reality (AR) has become one of the key technologies in 21st-century education, as shown by the data in the table. The article “The Effect of Augmented Reality Technology on Middle School Student's Achievements and Attitudes Towards Science Education” was the most cited with 248 citations, showing that AR has a significant impact on improving student achievement and attitudes towards science education [29]. This is in line with recent trends showing that AR can create a more interactive and immersive learning experience, thus increasing student engagement. Research like this emphasizes the role of AR as a catalyst in improving students' understanding of complex subject matter [39].

Key themes emerging in AR-related research, as seen in the table, include the role of AR in health education, STEM learning, and sports training. The article “Virtual Reality and Augmented Reality in Social Learning Spaces: A Literature Review” with 227 citations, for example, highlights how AR can create more effective collaborative learning environments [30]. This is supported by recent research showing that AR can integrate theoretical knowledge with practical applications, especially in professional fields such as healthcare and STEM [40].

AR adoption also shows geographical and contextual variations, as revealed in the article “Challenges and Prospects of Virtual Reality and Augmented Reality Utilization among Primary School Teachers: A Developing Country Perspective” which has 145 citations. The article underscores the infrastructure and teacher training challenges of adopting these technologies in developing countries [34]. Recent research supports these findings, suggesting that successful AR implementation is highly dependent on infrastructure readiness and local education policies [41].

The AR integration model in education is also an important focus, as outlined in the article “Augmented Reality for Learning: An Examination Using an Extended Technology Acceptance Model” with 158 citations. This study shows that frameworks such as the Technology Acceptance Model (TAM) are essential for understanding AR adoption among users [32]. This is reinforced by other literature that emphasizes that user-friendly interface design and relevant content are key to the successful implementation of AR in the classroom [42].

Specific applications of AR in STEM education and sports also stand out. The article “A Systematic Mapping Review of Augmented Reality Applications to Support STEM Learning in Higher Education” with 134 citations shows that AR can facilitate the understanding of complex STEM concepts. In addition, the article “Augmented Reality Tools for Sports Education and Training” with 131 citations shows that AR-based simulations can improve students' physical skills as well as theoretical understanding of sports [43], [44].

In addition, the trend of gamification and collaborative learning using AR is growing, as reflected in the article “EmoFindAR: Evaluation of a mobile multiplayer augmented reality game for primary school children” which has 136 citations. This study highlights how a gamified AR environment can improve students' collaboration, critical thinking, and creativity. Other research also supports that AR-based multiplayer platforms provide significant benefits to students' cognitive and social learning outcomes [45].

The keyword “students,” which is also close to “augmented reality,” indicates that many studies are exploring the impact of AR on students' learning experiences. Research includes how AR can improve student motivation, comprehension, and retention of information. This is important because the success of educational technology relies heavily on student response and acceptance [50]. These findings echo earlier work by Alvarez-Marín et al. [51], who examined how AR enhances student learning by providing a more immersive and interactive educational experience.

The terms “virtual reality” and “visualization” also appear as essential keywords connected to “augmented reality.” This shows that research often compares or combines AR with VR to enhance visual experiences in education. Visualization enhanced with these technologies can help learn complex and abstract concepts [52], [53]. Previous research has explored the synergy between AR and VR, noting that both technologies can complement each other in creating more engaging and realistic learning environments, particularly in subjects like engineering and medicine [54].

Keywords such as “mobile applications” and “e-learning” indicate the trend of using mobile devices and online platforms in implementing AR. This aligns with the increasing adoption of mobile technology in education, providing broader and more flexible access to AR-based learning materials [55]. These findings are in line with studies that have shown the growing role of mobile AR applications in education, particularly as mobile devices become more pervasive and integral to everyday learning [56].

The network's keyword “engineering education” indicates that AR is widely used in engineering education. This is due to AR's ability to provide realistic and interactive simulations essential for practical training in these fields. With AR, engineering students can visualize complex structures, while medical students can practice clinical procedures in a safe and controlled environment [57], [58], [59]. This aligns with earlier research by Danmali et al. [60], which emphasized AR's potential in fields requiring hands-on training, where visualization plays a crucial role in improving understanding and skill acquisition.

The terms “motivation” and “teaching” relate to “augmented reality” and indicate that many studies have explored how AR can be used to improve student motivation and teacher teaching methods [61], [62]. This research is essential to understand how technology can be effectively integrated into curriculum and daily teaching practices. Previous studies have underscored the potential of AR to boost motivation and enhance teaching strategies by offering dynamic and interactive learning opportunities, which contribute to improved learning outcomes [63], [64].

Overall, this keyword network visualization provides insight into the main focus and sub-themes in AR for education research. The analysis aligns with existing research networks, as previous studies have identified similar patterns of interest in terms like mobile applications, engineering education, and visualization. Through this bibliometric analysis, researchers can identify emerging research trends, underexplored areas, and potential collaborations between fields. The co-occurrence of keywords also reveals collaboration patterns, highlighting the interdisciplinary nature of AR research in education, which involves contributions from fields such as computer science, engineering, and pedagogy. This helps direct future research and ensure that the use of AR in education can have the maximum impact on students and teachers worldwide.

4. CONCLUSION

This study aims to analyze the application of Augmented Reality (AR) technology in education using a bibliometric analysis approach. Based on the results of data analysis from Scopus, it was found that the

United States dominates publications on AR in education, followed by China, Indonesia, Malaysia, and Germany. In addition, the development of AR publications shows a significant upward trend from 2020 to 2024, with a focus on the use of AR in STEM education and the integration of AR with other technologies such as Virtual Reality.

This study makes an important contribution to understanding the evolution of AR research in education and demonstrates the importance of international collaboration in the development of this technology. However, this study has limitations in terms of data coverage, which is limited to documents available on Scopus. For further research, it is advisable to expand the data sources and focus on the application of AR in more specific educational contexts, as well as investigate in greater depth the challenges of AR adoption in developing countries.

DECLARATIONS

Author Contributions

Afdal Luthfi: Writing – Review & Editing, Writing – Original Draft, Visualization, Software, Resources, Conceptualization. **Mukhlidi Muskhir:** Writing – Review & Editing, Resources, Formal Analysis, Data Curation. **Hansi Effendi:** Writing – Review & Editing, Writing – Original Draft, Visualization, Validation, Supervision, Methodology, Investigation, Formal Analysis, Conceptualization. **Nizwardi Jalinus:** Writing – Review & Editing, Resources, Formal Analysis, Data Curation. **Goncharova Maria Nikolaevna:** Writing – Review & Editing, Visualization, Supervision, Data Curation.

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Ethical Approval

This study did not involve human or animal participants; therefore, ethical approval was not required

Data Availability Statement

The data supporting this study's findings are available upon reasonable request.

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Competing Interests

The authors declare that they have no competing interests.

Generative AI and AI-Assisted Technologies Statement

During the preparation of this work or manuscript, the author(s) used Grammarly and Quilboot to assist in improving the readability, language, and overall structure of the manuscript. Following the use of this tool, the author(s) thoroughly reviewed and edited the content, ensuring its accuracy and integrity. The author(s) take full responsibility for the content and conclusions presented in the published article.

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