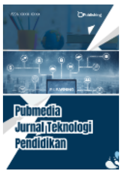

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Trends and Research Issues of Augmented Reality in Education: A Bibliometric Study

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Abstract: This study aims to comprehensively review Augmented Reality (AR) research in education through a bibliometric analysis of 1,850 journal articles and proceedings published between 2015 and 2023. Data were obtained from the Scopus database, which focused on social science subjects. This study focuses on two main aspects: performance analysis and science mapping. The results show a consistent upward trend in AR research, with the United States leading the number of publications, followed by China, Spain, Taiwan, and Turkey. The most influential authors are Akçayır, M. and Akçayır, G., with the highest number of citations. Visualization using VOSviewer yielded seven research clusters, highlighting the role of AR and VR in interactive teaching, simulation, and engineering education. The findings also suggest further research opportunities in the areas of "nursing education," "simulation," and "educational innovation," affirming AR's potential for innovative and sustainable learning. This research contributes to the understanding of the development of AR in education and serves as a useful reference for other researchers interested in studying AR in education.

Keywords: Augmented Reality, Bibliometrics, Education

Introduction

In recent decades, the world of education has become one of the sectors greatly influenced by technological advances. One of the latest learning media resulting from the development of this technology is Augmented Reality (AR) (Asitah et al., 2023; Fatimah et al., 2019). AR technology combines two-dimensional or three-dimensional virtual objects with the real world and then projects them in real-time (Craig, 2013; González et al., 2018). This interactive technology allows users to see and interact with three-dimensional animations that are integrated with the physical environment (Arena et al., 2022; Balakrishnan et al., 2021). Thus, AR can be defined as a technology that combines virtual objects in two or three dimensions into the real world and projects them in real time. The concept of AR combines the boundaries between the virtual world and the real world, provides additional information on the designated natural objects, and makes the boundaries between the two thinner (Craig, 2013).

In addition, AR can help visualize abstract concepts and improve the understanding and structure of an object model; this technology complements reality without replacing it completely (Fombona-Pascual et al., 2022). AR provides an immersive digital experience that cannot be achieved with traditional teaching methods, allowing students to understand complex material more interactively than just through books and lectures (AlGerafi et al., 2023; Zhao et al., 2023). This technology also allows educators to conduct virtual simulations and field trips, providing a more engaging and immersive learning experience (Cheng & Tsai, 2019; Papanastasiou et al., 2019). With AR, students can explore and interact with natural environments without leaving the classroom, creating rich and realistic simulations. In addition, AR can be used to create interactive and engaging content, helping students stay engaged in the learning process (Jesionkowska et al., 2020; Walker et al., 2017). AR has also been shown to positively impact student engagement and learning, increasing motivation and performance in academic tasks (Arisandi et al., 2022; Chang & Hwang, 2018; Ibáñez et al., 2020; Sirakaya & Cakmak2018). In addition, AR provides a safe and engaging learning environment for students with special needs, helping them understand the material with the help of different visuals, audio cues, and simulations (Baragash et al., 2020; Köse& Güner-Yildiz, 2021; Yenioglu et al., 2023).

Significant changes are also seen in how colleges and universities facilitate learning by integrating technologies such as AR into the educational environment (Martín-Gutiérrez et al., 2015). AR allows the integration of digital information into the physical world through devices such as smartphones, tablets, or AR glasses (Arena et al., 2022). Thus, students and learners can access more interactive, immersive, and contextual learning experiences. The development of AR in higher education covers a wide range of aspects, including more realistic scientific demonstrations, advanced medical simulations, and more dynamic language learning (López Belmonte et al., 2019; Mystakidis et al., 2022). This opens up new opportunities to explore how this technology can impact learning in higher education.

Along with this research's growth, several researchers are interested in exploring the use of augmented reality (AR) in education. Several previous studies have been identified, including the Augmented Reality Research in Education: A Bibliometric Study by Karakus et al. (2019). This study identified publications related to AR in education using the Web of Science database. Four hundred thirty-seven publications were selected based on research criteria covering 1999 and 2018. The study results revealed that concepts such as virtual reality, mobile learning, interactive learning environments, and e-learning were the most studied topics in AR research. In addition, another study used a bibliometric study to explore AR in engineering education (Utami et al., 2023). The data for this study were taken from the Scopus database and analyzed using VOSviewer, covering articles published between 2012 and 2022 with a total of 858 articles analyzed. The main findings showed an increasing trend in citations and publications related to AR in engineering education over the past decade. The most frequently used keywords in this study include "augmented reality," "engineering education," and "mobile learning." Recent research in this field focuses on virtual and mobile learning.

In addition, terms that often appear in abstracts are "engineering education," "student," "e-learning," "education," and "teaching." Another relevant study was also conducted by Putri et al. (2021), which analyzed the application of AR in physics laboratories through bibliometric analysis. Data were taken from the Scopus database using the keywords "Augmented Reality and Physics." Data analysis was carried out using VOSviewer, covering keywords, author involvement, country of origin, publication density, and year of publication. The main findings indicate that research on AR-based physics laboratories has never been conducted, especially those focusing on the Higher-Order Thinking Skill (HOTS) aspect. This indicates an excellent opportunity for further research in the context of using AR in physics laboratories, especially in developing students' higher-order thinking skills.

Bibliometric analysis is a quantitative method used to review and analyze scientific publications. This method utilizes various statistical indicators to map research trends, identify collaborations, and assess impact. In recent years, a study has yet to precisely map performance and science mapping related to micro-credentials, mainly focusing on social science subjects, including education. Therefore, this study aims to investigate augmented reality (AR) studies in education from 2015 to 2023 using the Scopus database. Unlike previous bibliometric studies, this study focuses on social science subjects, which include education as its central part. This fills the existing research gap and seeks to provide a deeper understanding of AR research trends in education through bibliometric analysis. The analysis includes performance analysis and science mapping to provide a comprehensive picture of the growth of research in this field. This study is expected to contribute to the understanding of the development of AR in education and serve as a valuable reference for other researchers interested in studying AR in education.

Methodology

This study uses a quantitative approach with bibliometric analysis. Bibliometric studies use quantitative techniques to systematically analyze literature (Donthu et al., 2021; Mukherjee et al., 2022). The database used in this study is Scopus, which is known as one of the most reputable sources of scientific data (Baas et al., 2020; Pranckutė, 2021). Several specific criteria were set to obtain documents that are by the research objectives. First, the title of the document contains the keywords "augmented reality" OR "AR" AND "education." Second, the document must be written in English and its final stage. Third, the document must come from journal sources and conference proceedings published in the subject area of social sciences in the Scopus database, where the field of education is included. Fourth, the documents taken for analysis are limited to 2015-2023. Through these criteria, the search resulted in 1,850 relevant documents for analysis.

TITLE-ABS-KEY ("augmented reality" OR "AR" AND "education") AND PUBYEAR > 2014 AND PUBYEAR < 2024 AND (LIMIT-TO (SUBJAREA , "SOCI")) AND (EXCLUDE (DOCTYPE , "ch") OR EXCLUDE (DOCTYPE , "re") OR EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "bk") OR EXCLUDE (DOCTYPE , "er") OR EXCLUDE (DOCTYPE , "no") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "le") OR EXCLUDE (DOCTYPE , "dp")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (EXCLUDE (SRCTYPE , "k") OR EXCLUDE (SRCTYPE , "d")) AND (LIMIT-TO (LANGUAGE , "English"))

The analysis in this study is divided into two main parts: performance analysis and science mapping. Performance analysis aims to assess research productivity by identifying the number of publications per year, leading authors, and the most influential journals on this topic. Meanwhile, science mapping is used to visualize the intellectual structure, research trends, and relationships between topics in the "augmented reality" field in education. The bibliometric analysis procedure in this study is adapted from the steps proposed by Donthu et al. (2021), which provides a comprehensive framework for systematically and in-depth analyzing literature.

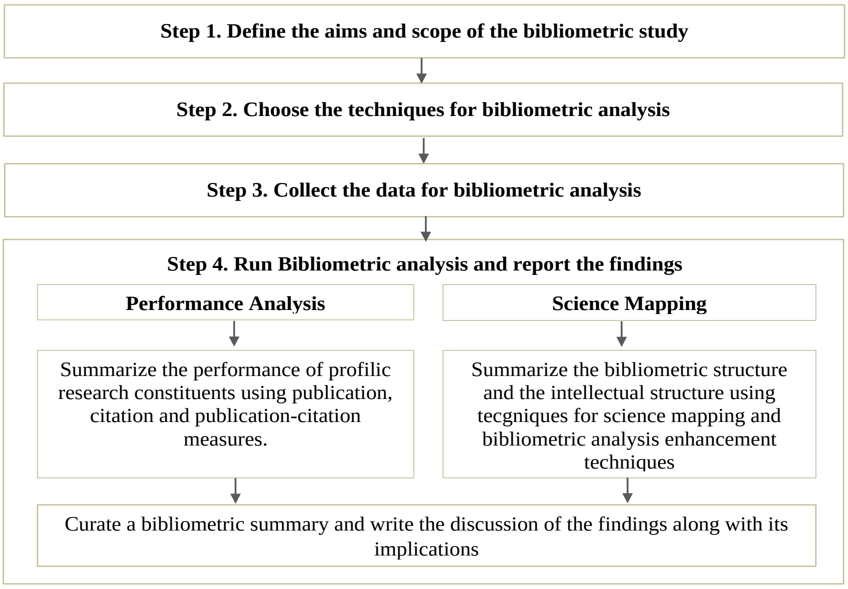


Figure 1. Analysis procedures in bibliometric research (Donthu et al., 2021).

Data analysis used VOSviewer software to produce network, overlay, and density visualizations to facilitate interpretation (Van Eck & Waltman, 2013). This software can provide information related to network metrics and clustering (Rullyana et al., 2024). In addition, VOSviewer provides detailed information on network metrics, such as centrality and betweenness, and identifies clustering patterns or clusters that emerge among the data, thus helping to reveal trends and structures in the study.

Result

Figure 2 shows the growth of educational publications related to augmented reality (AR) from 2015 to 2023, with a consistent and significant upward trend. Initially, the number of publications in 2015 was less than 100, indicating the early exploration stage of AR research for education. A significant increase occurred in 2017, driven by the development of AR technology and the 5.0 era, which encouraged the adoption of advanced technologies in various sectors. From 2017 to 2019, the number of publications grew steadily, peaking between 2019 and 2021, with more than 250 documents in 2021. Although there was a slight decrease in 2022, this trend immediately reversed with a surge in publications in 2023, approaching 400 documents. Overall, this trend reflects a strong and sustained interest in AR in education, indicating the great potential for this field to grow.

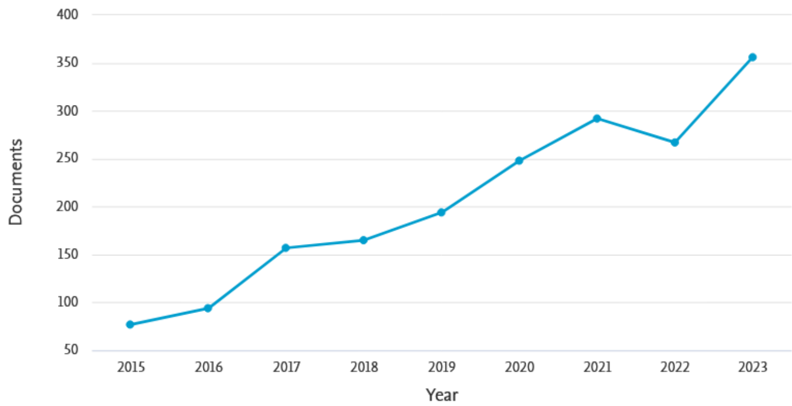


Figure 2. Distribution of the number of publications by year

Next, Figure 3 shows the number of publications related to augmented reality (AR) research in education by country. The United States (US) has the most significant publications, 296 documents, or around 16% of 1,850 publications. This position shows that the US is a leader in AR research in education. This dominance may be due to the significant investment in technology, robust research infrastructure, and collaboration between educational institutions and the technology industry.

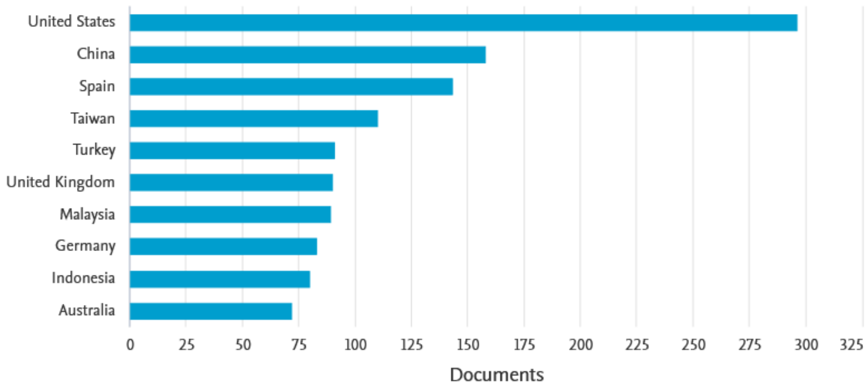


Figure 3. Publication augmented reality on education according to countries

China ranks second with 158 publications, accounting for about 8.54%; Spain ranks third with 143 publications, accounting for about 7.73%. Taiwan ranks fourth with 110 publications, accounting for about 5.95% of the total publications. Turkey ranks fifth with 91 publications, accounting for about 4.92%. Other countries such as the UK, Malaysia, Germany, Indonesia, and Australia contribute significantly to AR research in education, with each country producing more than 50 papers. These contributions show that research on AR in education is not limited to countries with the largest economies but also involves countries with different cultural and economic backgrounds.

Figure 4 displays the top ten authors who are most productive in producing educational publications related to augmented reality (AR). Out of 1,850 publications, their contributions are very significant, although each author's percentage of individual contributions is relatively tiny. Collectively, these authors play an essential role in driving the development of AR research in education. Previous data revealed that countries such as the United States, China, and several European countries are leaders in the number of publications on AR in education. This aligns with data on productive authors from leading educational and research institutions in these countries.

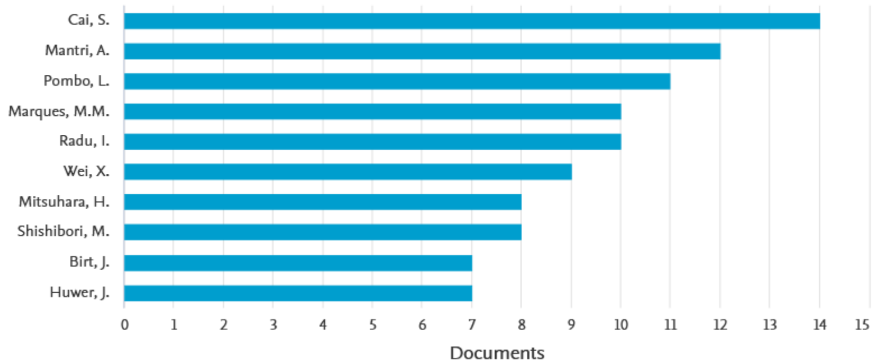


Figure 4. Most productive authors

For example, Cai, S. and Wei, X., who come from universities in China (Beijing Normal University and Northwest Normal University), contribute significantly to the number of publications produced by the country. China ranks second after the United States in terms of the total number of publications, with 158 documents, about 8.54% of the total. On the other hand, the United States, the country with the most publications (296 publications or about 16% of the total), is also represented by authors such as Radu, I. from the Harvard Graduate School of Education. Although only one author from the United States is included in the list of the ten most productive authors, the presence of authors from leading institutions such as Harvard shows the quality and impact of research conducted in this country. Portugal also attracts attention because of the presence of two productive authors, namely Pombo, L. and Marques, M.M. from the Centro de Investigação Didática e Tecnologia na Formação de Formadores (CIDTFF) in Aveiro. Researchers from Japan, such as Mitsuhara, H. and Shishibori, M., show how Japan, although not dominating the total number of publications, has researchers who focus on specific aspects of AR technology in education.

Table 1 presents publications from the most influential researchers in augmented reality (AR) in education, especially in social sciences. With high citation scores, they have made significant contributions to the understanding and practice of using AR in educational contexts. The first article, "Advantages and challenges associated with augmented reality for education: A systematic review of the literature" by Akçayır, M. and Akçayır, G. (2017), is the most cited with 1,304 citations. This study offers a systematic review of the benefits and challenges of AR in education, explaining how this technology can enhance the learning experience while also identifying potential barriers faced by educators and students. This work has become a primary reference for many researchers interested in the application of AR in learning contexts.

Tabel 1 : the most influential researchers in augmented reality (AR) in education

Document Title	Authors	Source	Year	Citations
Advantages and challenges associated with augmented reality for education: A systematic review of the literature	Akçayır, M., Akçayır, G.	Educational Research Review	2017	1,304
Metaverse beyond the hype: Multidisciplinary perspectives on emerging challenges, opportunities, and agenda for research, practice and policy	Dwivedi, Y.K., Hughes, L., Baabdullah, A.M., ... Wamba, S.F.	International Journal of Information Management	2022	1,028
Virtual laboratories for education in science, technology, and engineering: A review	Potkonjak, V., Gardner, M., Callaghan, V., ... Jovanović, K.	Computers and Education	2016	602
Augmented reality for STEM learning: A systematic review	Ibáñez, M.-B., Delgado-Kloos, C.	Computers and Education	2018	556
Virtual technologies trends in education	Martín-Gutiérrez, J., Mora, C.E., Anorbe-Díaz, B., González-Marrero, A.	Eurasia Journal of Mathematics, Science and Technology Education	2017	485

The article "Metaverse beyond the Hype: Multidisciplinary Perspectives on Emerging Challenges, opportunities, and Agenda for Research, Practice and Policy" by Dwivedi et al. (2022) received 1,028 citations. This publication broadens the scope of the topic by exploring the concept of metaverse and its relation to AR, providing a multidisciplinary perspective on the emerging challenges and opportunities. This article discusses AR in education and positions it in a broader context, namely how metaverse and related technologies may influence future education policy and practice. This work has become an essential reference for researchers interested in current developments in educational technology.

Furthermore, the article "Virtual Laboratories for Education in Science, technology, and Engineering: A Review" by Potkonjak et al. (2016) with 602 citations highlights the role of virtual laboratories, including AR, in science, technology, and engineering education. This article discusses how virtual laboratories can enrich the learning experience, providing access to experiments that would otherwise be difficult to conduct in a physical environment. This research provides an essential foundation for developing experiment-based learning methods, especially in STEM fields. "Augmented reality for STEM learning: A systematic review" by Ibáñez & Delgado-Kloos (2018), with 556 citations, evaluates explicitly the effectiveness of AR in STEM learning. This work reviews various AR applications that support learning in science, technology, engineering, and mathematics and assesses how this technology can enhance student understanding and motivation. This research provides a strong foundation for educators and curriculum developers who want to integrate AR into STEM learning, emphasizing the role of AR in making complex concepts more understandable. The article "Virtual Technologies Trends in Education" by Martín-Gutiérrez et al. (2017), with 485 citations, provides insight into virtual technology trends in education. This study includes AR as one of the critical technologies transforming learning methods. By identifying virtual technology trends and implications, this article helps shape an understanding of how technologies such as AR can be effectively integrated into educational curricula.

Figure 5 shows the collaboration network among authors with at least three educational publications related to augmented reality (AR). This network map illustrates the interactions and collaborations among authors, where colored node indicate collaboration clusters and lines connect those who have worked together. The dots' size indicates the authors' productivity, while their proximity indicates the intensity of the collaboration.

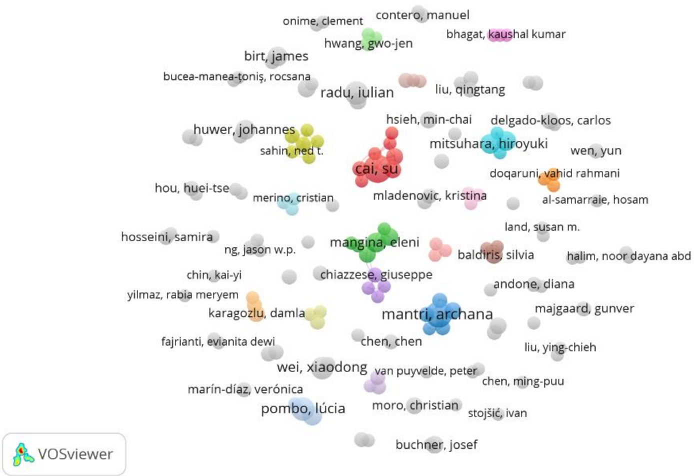


Figure 5. Collaborative network between authors

Cai, Su appears to be one of this network's most prominent and central authors. The larger dot size and her strategic position in the center indicate that Cai Su is a very productive author who is involved in many collaborations. This finding suggests that Cai worked with various authors from different clusters, building bridges between groups of researchers in AR research in education. Mantti, Archana also stands out in this network with a relatively large dot size, indicating that she is an author who has connections with various researchers and plays a vital role in bridging different clusters. Pombo, Lúcia appears in the blue cluster, indicating solid connections with a specific group of authors. Pombo may have a more specific research focus, such as AR applications in STEM education or distance education, thus creating close collaborations with researchers with similar interests. Other authors such as Mitsuhara, Hiroyuki, and Radu Ilian also appear to have substantial positions in the network. Both seem to serve as connectors between different clusters, indicating their involvement in cross-disciplinary collaborations that enrich the perspectives and methodologies of AR research in education.

This study yielded 7,966 keywords from 1,850 educational documents related to augmented reality (AR). Of these keywords, only those that appeared 12 times or more were analyzed further. With this threshold, 189 keywords were identified that met the criteria for visualization in the network. Setting the threshold at 12 keyword occurrences serves to filter and focus the analysis on the most relevant and frequently occurring terms in the literature. Keywords with high frequency indicate concepts, topics, or themes that are the main focus of research on AR in education. Thus, the 189 keywords that passed this threshold provide a more structured and meaningful picture of the emerging research trend.

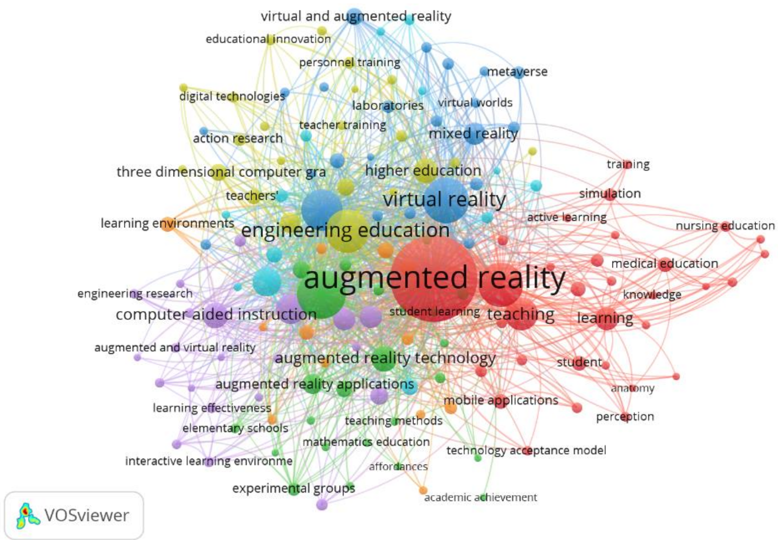
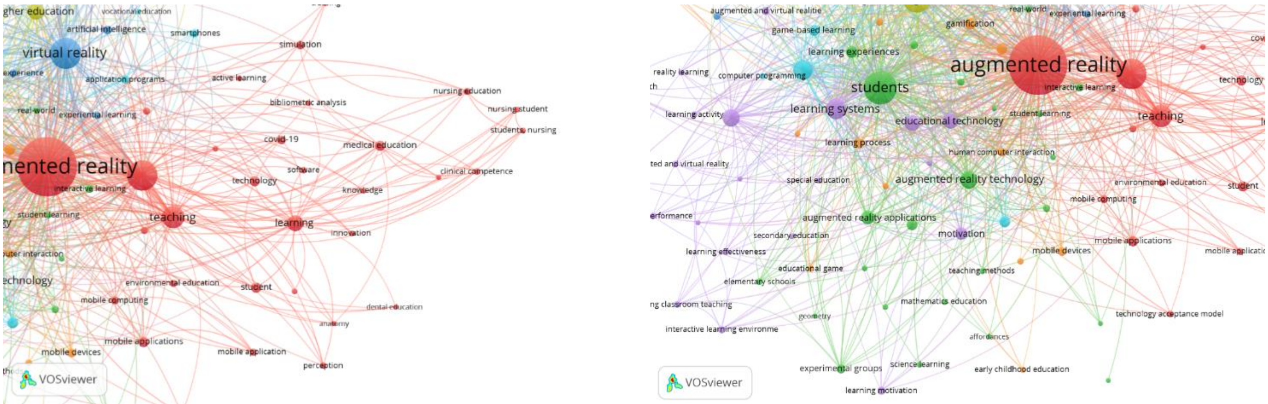


Figure 6. Network visualization map of keywords' co-occurrence

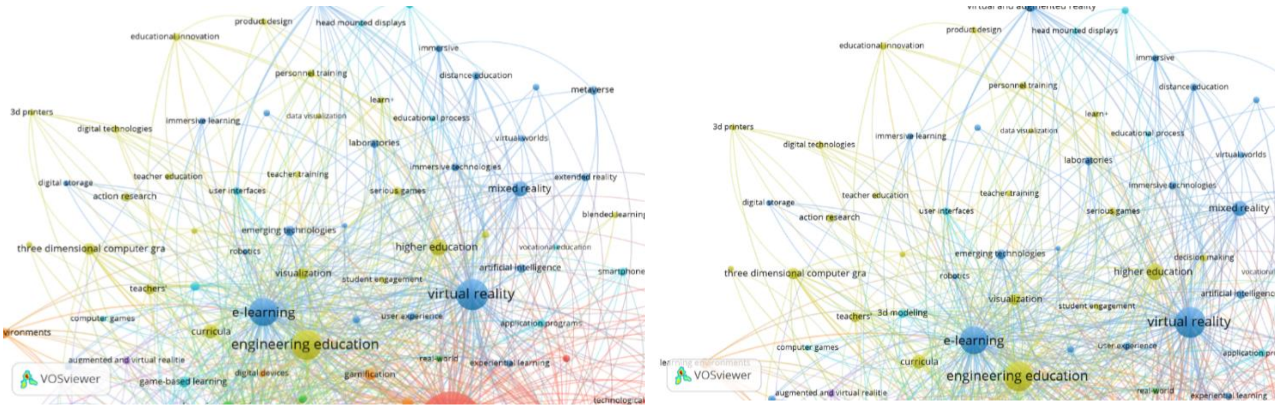
Cluster 1 focuses on "augmented reality" (AR) and its relationship to "teaching," "learning," "medical education," and "technology." AR is central to many educational connections, demonstrating its essential role in enhancing the learning process at various levels. This technology enables interactive learning, creating a more engaging learning environment for students. In the medical field, AR is used for procedure simulations, clinical training, and providing a safe learning environment for medical and nursing students, including in nursing and dentistry. In addition to medical applications, this cluster includes research on AR software development, mobile applications, and integrating AR into educational curricula. Keywords such as "student learning" and "interactive learning" indicate a focus on the user experience and how AR can be tailored to meet the various needs of students.



Cluster 1 Cluster 2

Figure 7. Cluster 1 and 2 augmented reality research in education generated in VOSviewer

Cluster 2 focuses on the relationship between "augmented reality" (AR) and various aspects of learning, specifically "students," "learning systems," and "educational technology." The keyword "students" takes center stage, indicating how AR impacts students' learning experiences, increases engagement, and supports different learning styles. The interconnection with "learning experiences" and "motivation" suggests that the research also focuses on how AR can motivate students and enhance learning effectiveness. "Learning systems" and "educational technology" reflect the view that AR is integral to modern learning. Research in this cluster involves developing AR-based learning systems and exploring the integration of AR into the curriculum and student interactions with the technology. The focus on "augmented reality technology" and "augmented reality applications" highlights the practical applications of AR in a variety of areas, including science, mathematics, and early childhood education. The use of AR to create interactive learning environments is also reflected in terms such as "educational games" and "game-based learning." In addition, the connection with "mobile devices" and "mobile applications" shows a research trend that focuses on accessible and flexible AR-based learning, both inside and outside the classroom. The connection with keywords such as "teaching methods" and "learning effectiveness" shows that this cluster also evaluates how AR can improve teaching methods and learning outcomes through an empirical approach.

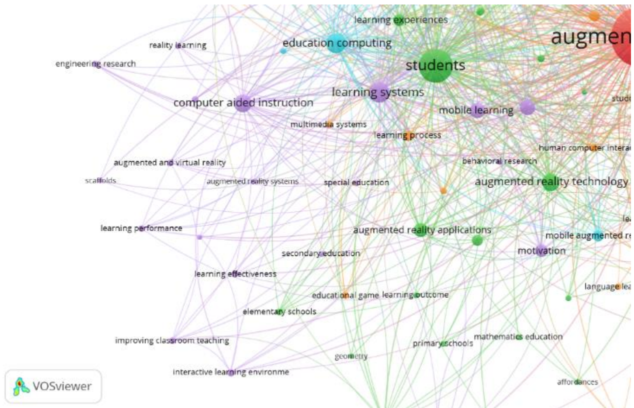


Cluster 3 Cluster 4

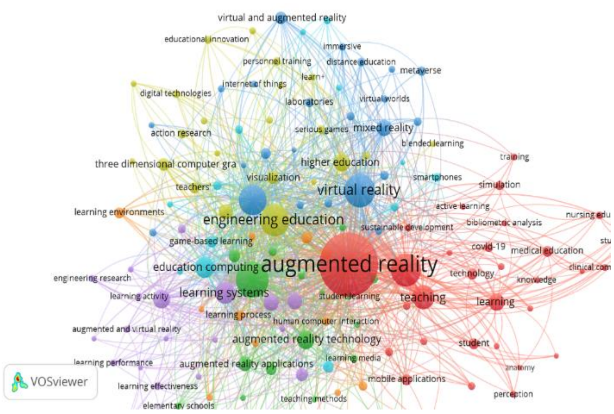
Figure 8. Cluster 3 and 4 augmented reality research in education generated in VOSviewer

Cluster 3 in this network visualization focuses on the relationship between "virtual reality" and "e-learning" and their various associated technologies and learning methods. The keyword "virtual reality" emerges as the center of this cluster, indicating its significant role in educational contexts, especially in engineering education and online learning. "Virtual reality" has strong connections with terms such as "mixed reality," "immersive technologies," and "extended reality," indicating the research focus on developing immersive and interactive learning environments. Using these technologies in education aims to create more realistic and immersive learning experiences, allowing students to understand complex concepts through simulations and hands-on practice.

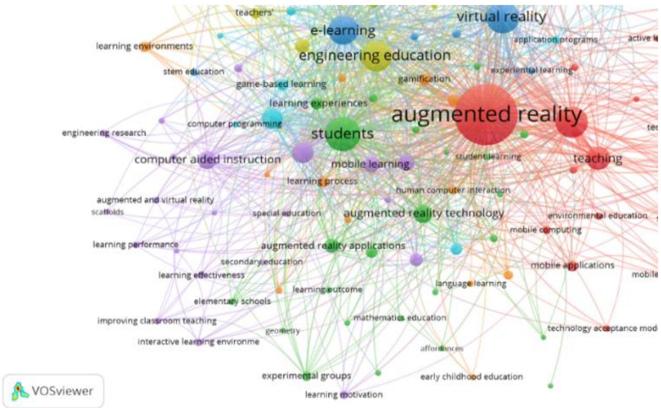
Cluster 4 focuses on the integration of "emerging technologies," "teacher education," and "three-dimensional computer graphics" in education. 3D graphics are important because they provide deep and interactive visualizations, helping students understand complex concepts through simulations and immersive learning environments. In addition, "teacher education" is a crucial element, emphasizing the importance of teacher training to integrate these technologies into teaching. The connection with keywords such as "teacher training" and "action research" indicates a focus on effectively developing teachers' skills to use technologies such as virtual reality and 3D graphics.



Cluster 5



Cluster 6



Cluster 7

Figure 9. Cluster 5, 6 and 7 augmented reality research in education generated in VOSviewer

This cluster also includes the development of other digital technologies, such as "3D modeling," "computer games," and "digital technologies," which create interactive learning environments. Computer games with 3D graphics teach concepts more engagingly, increasing student engagement and motivation. In addition, "educational innovation" and "immersive learning" focus on how these technologies can lead to innovative educational approaches. The association with "laboratories," "robotics," and "digital storage" highlights the technical aspects of implementing technology in education, such as the use of virtual laboratories and robotics to support broader learning, especially in the context of engineering and STEM education.

Cluster 5 focuses on “computer-aided instruction” and its role in enhancing learning. The association with keywords such as “learning performance,” “learning effectiveness,” and “interactive learning environment” suggests that the study highlights how computer technology can support more effective teaching. Using computers and software in instruction allows for deep interaction, enhanced visualization, and access to various educational resources. “Augmented and virtual reality” (AR and VR) are essential components, enabling interactive and immersive learning environments. These technologies help students understand abstract concepts and enhance the classroom learning experience. In addition, the study covers the development of computer-aided learning systems, including interactive multimedia, simulations, and educational games that can be applied at various levels of education, such as special education, secondary, and elementary schools. Keywords such as “scaffolds,” “behavioral research,” and “learning process” suggest a focus on the pedagogical aspects of using these technologies. The study explores how computer-aided instruction can provide adaptive support, enhance students’ understanding and performance, and influence their learning behaviors and cognitive processes.

Cluster 6 focuses on “educational computing” and “game-based learning,” as well as related technologies such as “3D modeling,” “application programs,” “computer games,” and “head-mounted displays.” This research explores how computing technologies and digital applications can create more interactive, immersive, and compelling learning experiences. “Educational computing” encompasses software, learning applications, and interactive simulations, while “game-based learning” emphasizes game elements to enhance student engagement. Technologies such as “3D modeling” and “head-mounted displays” enable the visualization of complex concepts and immersive learning experiences through virtual reality. “mobile augmented reality” and “smartphones” demonstrate the trend toward flexible and accessible learning, allowing students to learn anywhere and anytime. Technical aspects such as “user interfaces” and “computer programming” are also in focus, with research exploring the design of user-friendly interfaces to enhance learning effectiveness.

Cluster 7 focuses on “teaching and learning,” “learning environments,” “mobile devices,” and “gamification.” This cluster highlights innovative learning approaches that use digital technologies, especially mobile devices, multimedia systems, and human-computer interaction. “Digital devices” and “mobile devices” are central to this cluster, emphasizing the importance of mobile devices in supporting modern learning, enabling students to learn anytime and anywhere. Mobile devices are also platforms for learning applications, including educational games and augmented reality.

Next is the density visualization. Density visualization in bibliometric studies is a technique used to provide an overview of the intensity and distribution of keywords, authors, or research topics in a field of study. Density visualization displays dense areas with brighter or more intense colors, indicating the high frequency and importance of a particular keyword or topic in the literature analyzed. Conversely, areas with more muted colors indicate a lower frequency of occurrence, which may indicate less explored or more specific issues in that field of research.

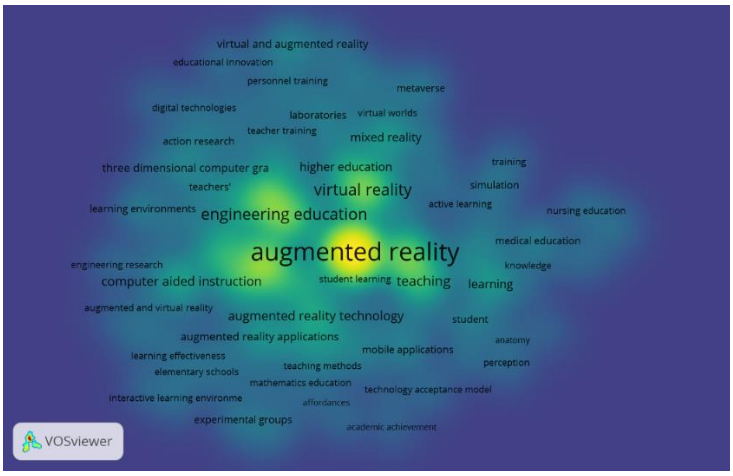


Figure 10. Density visualization map of keywords’ co-occurrence

In this visualization, the keywords most studied by researchers are marked with brighter colors, mainly centered around "augmented reality," "virtual reality," and "engineering education." Bright colors indicate that these areas have been a significant research focus in recent years. "Augmented reality" and "virtual reality" are in the center with the brightest colors, indicating that these topics have become dominant research areas in the educational context. Both of these technologies have been widely explored, especially in how they can be applied to enhance the learning process, whether through interactive teaching, simulations, or immersive learning environments. In addition, "engineering education" also has a bright color, indicating that this field has become one of the primary beneficiaries of AR and VR technologies, enabling more realistic simulations and practices in engineering education.

Around the bright center, keywords such as “teaching,” “learning,” “augmented reality technology,” “augmented reality applications,” and “student learning” are also quite bright. This indicates that these aspects have received considerable attention in educational AR research. Researchers have extensively explored how AR can be integrated into teaching and learning methods to improve student effectiveness, engagement, and motivation. In addition, "teaching methods," "mobile applications," and "interactive learning environments" also appear in the bright area, indicating extensive research in the development of technology-based teaching methods and mobile applications that support more interactive and flexible learning. On the other hand, areas with dimmer colors located somewhat further away from the bright center indicate areas with great potential for further research. Some of these keywords include "nursing education," "simulation," "virtual worlds," "metaverse," and "educational innovation." For example, "nursing education" and "simulation" indicate that while AR-based simulation and learning have been explored, their application in nursing education may not have received as much attention as other fields, such as engineering. This area has excellent potential for further development, especially in creating more realistic simulation environments for nursing training.

In addition, "metaverse" and "virtual worlds" are in a more muted area, indicating that although these concepts are beginning to emerge in the literature, there is considerable room for further research. With the development of technology and the increasing interest in virtual worlds, the metaverse may become one of the main focuses of future research, especially in creating truly immersive and interactive learning environments. "Educational innovation" is also in a muted area, indicating that although educational innovation is a broad topic, in-depth exploration of how AR can drive more radical and transformational innovation in education may still be limited. This underlines the urgency and importance of further research in this area.

Overall, these visualizations show that while areas such as "augmented reality," "virtual reality," and "engineering education" have been extensively explored, there are still many research opportunities open. The potential of AR and VR technologies to be applied in broader and more diverse contexts to support education across disciplines is particularly striking. Future researchers can leverage these areas to develop more in-depth studies, focusing on how these technologies can be applied in diverse contexts to support education.

Discussion

The research trend related to augmented reality (AR) in education has shown significant and diverse developments in recent years. These studies focus on integrating AR into various aspects of education, from teaching and learning to increasing student engagement. One of the main trends is the exploration of the use of AR in medical education, which aims to improve students' clinical competence and practical skills. For example, a study by Portman et al. (2015) highlighted the potential of using virtual reality to support education and training, especially in areas requiring complex visualization and interaction. The use of AR in this area not only enhances the immersive learning experience but also provides an opportunity to practice in a safe and controlled environment.

In addition, the use of AR in supporting student learning and engagement is also an important focus. Huang et al. (2016) showed how animation and AR can be used in environmental education to improve students' understanding and awareness of ecological issues. This approach reflects how AR can be integrated into learning systems to support richer, student-centered learning experiences. In this context, AR serves as a tool that enriches learning content through more realistic visualization and interaction, allowing students to understand complex concepts more intuitively.

The development and evaluation of the impact of AR on motivation and learning effectiveness is also a prominent trend. Mystakidis et al. (2022) identified that AR research in education often focuses on how this technology can enhance students' learning experiences and motivation. The emphasis on interactivity and student engagement suggests that AR is an innovative educational tool capable of creating dynamic learning environments. In addition, a study by Abad-Segura et al. (2020) also discussed the sustainability of educational technologies, including AR, and how these technologies can be effectively integrated into education systems in the long term. This reflects the need to evaluate the impact of AR not only in terms of learning effectiveness but also from the perspective of sustainability and integration into everyday educational practices. Research in e-learning and engineering learning also shows how immersive technologies such as AR and virtual reality (VR) can create more effective learning experiences. Bozzelli et al. (2019) developed an integrated framework for using VR and AR in user-driven design, emphasizing how these technologies can support online learning and engineering education. This reflects a broader trend in higher education and engineering, where immersive technologies are being used to provide interactive simulations and immersive, hands-on experiences that are otherwise difficult to achieve in traditional physical environments. Overall, the research suggests that augmented reality in education is not focused on one specific area or approach but encompasses multiple dimensions of education, from improving learning effectiveness and student motivation to integrating technology into existing learning systems. These studies highlight the great potential of AR to create more innovative, interactive, and sustainable learning approaches while addressing practical challenges in its implementation. As such, AR is considered one of the critical technologies that will continue to shape the future of education

The findings from this density visualization reveal critical trends in augmented reality (AR) and virtual reality (VR) research in education. Keywords such as “augmented reality,” “virtual reality,” and “engineering education” appear in bright colors, indicating a significant focus of research on integrating these technologies to enhance learning. AR and VR have been widely applied in interactive teaching, simulations, and the creation of immersive learning environments, especially in engineering education, where they are used to create realistic hands-on experiences. In addition, areas such as “teaching,” “learning,” “augmented reality technology,” and “augmented reality applications” are also highlighted in bright colors, indicating extensive research on the use of AR to enhance student effectiveness and engagement. This focus includes the development of teaching methods and mobile applications that support interactive learning. However, areas with more muted colors, such as “nursing education,” “simulation,” “metaverse,” and “educational innovation,” indicate significant opportunities for future research. While AR has been used in engineering simulations, its application in nursing education is still limited. Likewise, "metaverse" and "virtual worlds" have great potential to create more immersive learning environments, and "educational innovation" can lead to new, more transformative learning models. While some areas have been extensively explored, there is still room for further research.

Conclusion

Based on the findings in this study, research related to augmented reality (AR) in education shows a consistent upward trend from 2015 to 2023, reflecting the growing interest and investment in this field. The United States leads in the number of publications, followed by China, Spain, Taiwan, and Turkey, indicating that AR research in education is developing in various countries with diverse economic and cultural backgrounds. The top ten most productive authors are from these countries, confirming their essential contributions to advancing AR research. The most influential authors during the period 2015-2023 are Akçayır, M. and Akçayır, G., with the highest number of citations of 1,304. In addition, Cai Su is also known as a very productive author and is involved in many collaborations, indicating his significant role in the AR research community in education.

Visualization with VOSviewer produces seven clusters that reveal various research focuses in this field. The main trends show that AR and virtual reality (VR) have been widely applied in interactive teaching, simulations, and immersive learning environments, especially in engineering education and e-learning. Keywords such as "augmented reality," "virtual reality," and "engineering education" emerged as primary focuses, indicating that these technologies have been used to enhance learning effectiveness and student engagement. In addition, significant attention has been paid to integrating AR in medical education, game-based learning, and developing interactive teaching methods. However, the density visualization also shows areas with more muted colors, such as "nursing education," "simulation," "metaverse," and "educational innovation," which offer great opportunities for further research. While some areas have been explored extensively, there is still room for in-depth studies in more specific contexts, such as nursing education, advanced simulation, and more transformative educational innovations. Thus, AR research in education continues to grow, offering great potential for creating more innovative, interactive, and sustainable learning approaches.

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