

Bibliometric analysis of augmented reality research in educational sciences

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ABSTRACT

The aim of this study is to determine the distribution of articles on augmented reality in the WOS database in the field of educational sciences by years, keywords and active concepts, active countries, active countries by total number of citations, active countries by citation averages, active authors, active authors by local citation rankings, active researches by global citation rankings, active journals by number of articles, active institutions, country-author-keyword network and popular topics by years. The study used bibliometric analysis, which is one of the quantitative approaches. The data set consisted of 1759 augmented reality articles in the field of educational sciences in the WOS database between 1999 and 1 September 2024. The "Biblioshiny" package program in the "R" programming language was used to analyse the data. The results of the research indicate that the annual growth rate for articles in the field of educational sciences utilizing augmented reality is 24%. The most common keywords are education, augmented reality, students, technology, system, design, science, challenges, performance and virtual reality. The countries with the highest levels of activity in this field are China, the USA, Spain, Turkey, Australia, the United Kingdom, Germany, Serbia, Korea and Japan. China, the USA and Spain are in the first three places in the citation ranking of the countries. According to the citation averages, the ranking is as follows: It was determined that Hwang GJ is the most influential author, Chang HY is the most cited author in the local context, and Wu HK is the most cited author globally. The most influential journal is "Education and Information Technologies," and the most influential institution is National Taiwan Normal University. Popular research topics in augmented reality for 2024 include laboratory skills, virtual reality, and K-12 concepts.

Introduction

The rapid advancement of technology has precipitated a transformation in the field of education, facilitating enhancements in the quality of learning and teaching (Wei et al., 2021). The advancement of information and communication technologies has an impact on the methodologies employed in the field of learning and the environments in which they are

conducted (Marini et al., 2022). The value of employing information and communication technology as an efficacious pedagogical instrument is being increasingly underscored (Lham et al., 2020). It can be reasonably asserted that digital-based learning has become a prevalent pedagogical approach in the present era (Anggrawan et al., 2023). Augmented reality is regarded as a significant technology in the field of education (Rahmadani et al., 2022).

Augmented reality technology serves as a conduit between the virtual and tangible realms, transcending the constraints of physical classrooms at a relatively modest expense while offering an engaging and interactive learning experience (Joon & Kang, 2021). Augmented reality technology affords students the opportunity to engage with learning materials in a manner that incorporates the objects they see in person (Marini et al., 2022). Augmented reality (AR) can be defined as the connection between the real and virtual worlds, providing an immersive and interactive learning experience (Shihab et al., 2023). The use of transparent displays in augmented reality systems enables the user to perceive both the real environment and virtual elements in a consistent manner about user perspective and virtual content dimension (Vertucci et al., 2023).

In recent years, augmented reality has been employed in several fields, including medicine, the military, health, vocational education, teaching at various levels, tourism, and visual media (Uysal & Özdemir, 2024). The utilization of augmented reality technology, particularly within the domain of education, facilitates the enhancement of learning environments and enables the realization of efficacious and enduring learning (Türel & Bayer, 2021). The potential of augmented reality (AR) to assist educators in developing engaging and creative teaching methods is attracting increasing attention (Wei et al., 2021). The accelerated advancement of augmented reality technology has opened new avenues in the domain of education (Joon & Kang, 2021). The use of augmented reality in education has become a significant area of interest (Radu et al., 2022). The incorporation of augmented reality into the educational sphere holds considerable promise, as it promises to enhance pedagogical practices and provide learners with more engaging and attractive learning experiences (Perifanou et al., 2022).

Augmented reality represents a significant instrument for narrowing the discrepancy between theoretical understanding and practical implementation (Lai et al., 2019). The utilization of augmented reality applications has the potential to facilitate collaborative learning experiences that encourage interaction and teamwork (Radu et al., 2022). The utilization of augmented reality applications has been demonstrated to facilitate the development of understanding whilst simultaneously encouraging participation (Shihab et al., 2023). A substantial body of research indicates that augmented reality applications have a positive impact on students' motivation and academic achievement (Demircioğlu et al., 2022; Kul & Berber, 2022). Augmented reality has the potential to significantly enhance active learning (Shihab et al., 2023).

The utilization of augmented reality applications in an educational context represents an efficacious methodology for facilitating learning, whereby the development of students' imagination and creativity is supported, and their interaction with the real world is enhanced (Uysal & Özdemir, 2024). In their research, Türel and Bayer (2021) posit that researchers may favor augmented reality technology due to its straightforward integration into educational settings and the concomitant increase in research activity.

Booyoesen (2023) reached the conclusion that augmented reality has an effective role to play in improving students' understanding of scientific concepts, facilitating collaborative learning experiences, and positively influencing the ability to sustain attention and increase student engagement. In a similar vein, Perifanou and others (2022) explored the perceptions of educators regarding the integration of augmented reality in the educational sphere. The benefits identified

included the potential for more engaging and interactive teaching and learning, heightened interest and engagement, and an enhanced comprehension of complex concepts.

In their 2020 study, Lham and others investigated the use of augmented reality as a learning tool and found that both teachers and students expressed considerable support and positive attitudes towards its use. In their study using augmented reality, Lai and others (2019) observed a notable enhancement in the learning outcomes and motivation of the experimental group in comparison to the control group. In their study, Shihab and others (2023) examined the relationship between augmented reality and active learning. They emphasized that augmented reality supports collaborative activities, problem solving and individualized learning.

Despite the plethora of favorable outcomes documented in the utilization of augmented reality (AR) within the domain of educational sciences, researchers have underscored that, in comparison to other digital technologies, such as multimedia and web-based teaching and learning platforms, AR remains in its nascent stages of investigation (Kljun et al., 2020). In recent years, augmented reality has demonstrated considerable potential as a technology capable of superimposing virtual objects generated by a computer onto the real-world environment surrounding the user (Vertucci et al., 2023).

The challenges associated with augmented reality encompass technology infrastructure, educator training, content quality, and economic considerations (Shihab et al., 2023). Tzima and others (2019) highlight the necessity for sustained teacher training and professional development to ensure the effective integration of augmented reality technologies in the classroom. In their study investigating teachers' views on the integration of augmented reality in education, Perifanou and others (2022) identified several barriers to its implementation. These included the lack of augmented reality educational practices, the cost of purchasing and maintaining augmented reality equipment and resources, the lack of digital skills of teachers and students, classroom management problems, and safety and ethical issues.

A review of the literature reveals a dearth of studies that address augmented reality in its entirety. Radu and others (2022) conducted a thematic analysis of 2023 augmented reality articles, 39 of which were in-depth, and 86 websites and blog posts, 53 of which were in-depth, from a dataset of 86 websites and blog posts addressing public opinion on augmented reality in educational practice between 2010 and 2021. The findings of this study indicate that students demonstrate superior performance when learning with augmented reality (AR) compared to traditional methods. AR enhances motivation and engagement, facilitates more memorable learning experiences, and fosters enjoyment among students. Furthermore, Radu and others (2022) identified the key issues in augmented reality based on their data set of websites and blog posts. These issues were found to be that students learn faster thanks to visualization, increase retention in learning thanks to students' practice, and help to make abstract topics more concrete.

A bibliometric analysis of research on augmented reality in the field of educational sciences is conducted with the objective of elucidating the current state and trends in augmented reality. This research aims to determine the distribution, keywords and active concepts, active countries, active countries according to total number of citations, active countries according to citation averages, active authors, active authors according to local citation ranking, active research according to global citation ranking, active journals according to number of articles, active institutions, country-author-keyword network and popular topics according to the number of years of research in the field of educational sciences in the WOS database between 1999 and 1 September 2024.

Method

Research methodology

This research is a bibliometric analysis study with the objective of elucidating the distribution of augmented reality research in the field of educational sciences by year, distribution by countries, citation ranking, keyword network, effective journals, effective researchers and effective institutions. Bibliometrics is a quantitative method that employs mathematical and statistical analysis of publications (Pritchard, 1969). A bibliometric analysis is a quantitative approach to analysing bibliographic data from research studies, with the objective of identifying publication patterns and trends in specific knowledge areas (Chen et al., 2023). Moreover, bibliometric analysis encompasses a range of summary statistics pertaining to citation data, in addition to network analysis of journals, authors, institutions, countries, and keywords based on citation and frequency analysis methods (Jaradat et al., 2022).

Data set

Criterion sampling, one of the purposive sampling methods, was used to determine the data set. Between 1999 and 1 September 2024, articles in the field of education limited to augmented reality and articles in the WOS database were identified as criteria. The research data were taken from the WOS database, produced by Clarivate Analytics, as it is one of the most powerful platforms among citation indexes related to scientific research and the studies in this database are accepted as having qualified scientific content. The data set was constructed to include the term 'augmented reality' in the title or keywords of the research. In addition, the studies were restricted to the fields of education, interdisciplinary education, social sciences and special education. The dataset included 1759 studies including augmented reality articles in the field of education between 1999 and 1 September 2024.

Analysis of data

The data was analyzed using bibliometric analysis. The aim of bibliometric analysis is to identify researchers, countries, journals, institutions, key concepts and trends in the relevant field (Lim & Kumar, 2024). The 'Biblioshiny' package program in the 'R' programming language was used to analyze the dataset (Aria & Cuccurullo, 2017).

Results

Examining the 1759 Augmented Reality articles in the field of Education between 1999 and 1 September 2024 in the WOS database, it was found that the annual growth rate was 24.47%, the average number of citations per article was 19.78, the total number of references used in the articles was 54853, the total number of authors was 5110, and the number of single-author articles was 177.

The distribution of Augmented Reality research in Education in the WOS database between 1999 and 1 September 2024 is shown in Figure 1.

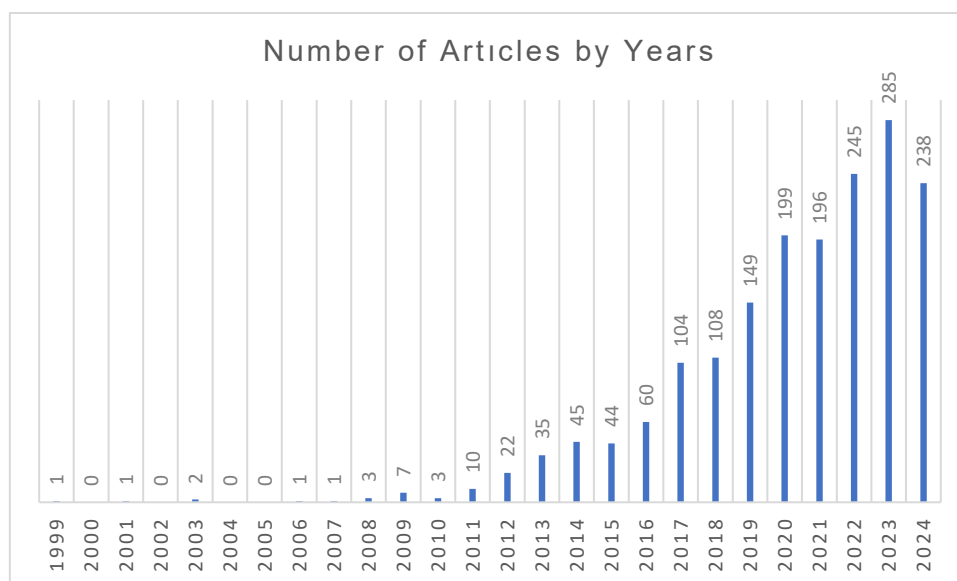


Figure 1 Distribution of augmented reality research by years

Looking at Figure 1, we can see that augmented reality research in the field of educational sciences, which started with one study in 1999, showed a significant increase especially after 2017 and gained momentum with 285 studies in 2023 and 238 studies in the first eight months of 2024.

The word cloud according to the keywords of augmented reality research in the field of education between 1999 and 1 September 2024 in the WOS database is shown in Figure 2.



Figure 2 Word cloud of keywords related to augmented reality research

When analyzing Figure 2, education, augmented reality, students, technology, system, design, science, challenges, performance and virtual reality are among the keywords used in augmented reality research.

Figure 3 shows the top 10 keywords and their frequency of use in augmented reality research.

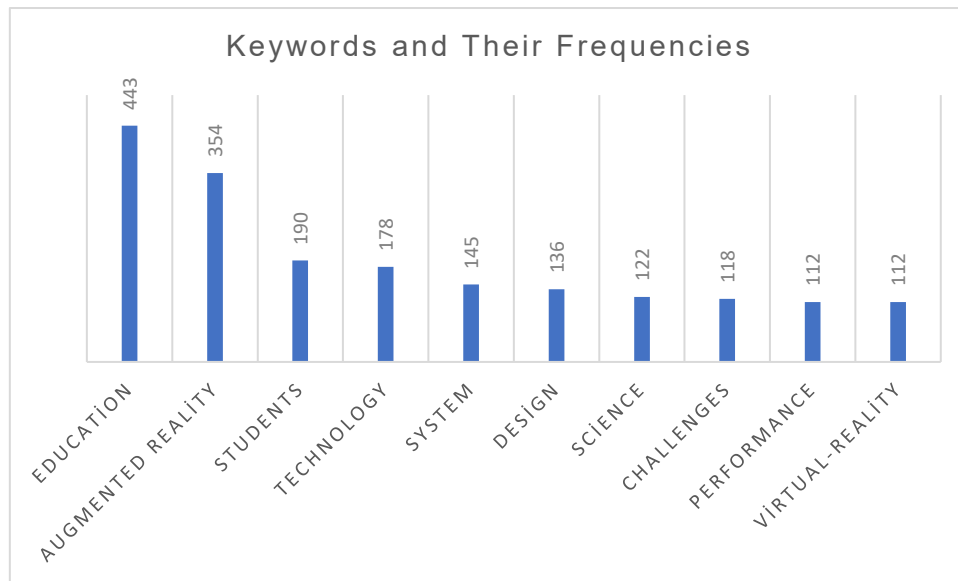


Figure 3 Top 10 keywords and frequency of use in augmented reality research

When analyzing Figure 3, education is the most popular keyword in augmented reality research with 443 occurrences, augmented reality is the second most popular keyword with 354 occurrences and students is the third most popular keyword with 190 occurrences. The keyword frequency ranking in augmented reality research is 178 technology, 145 system, 136 design, 122 science, 118 challenges, 112 performance and 112 virtual reality.

The distribution of augmented reality research in the field of educational sciences in the WOS database between 1999 and 1 September 2024 according to the top 10 active countries is shown in Figure 4.

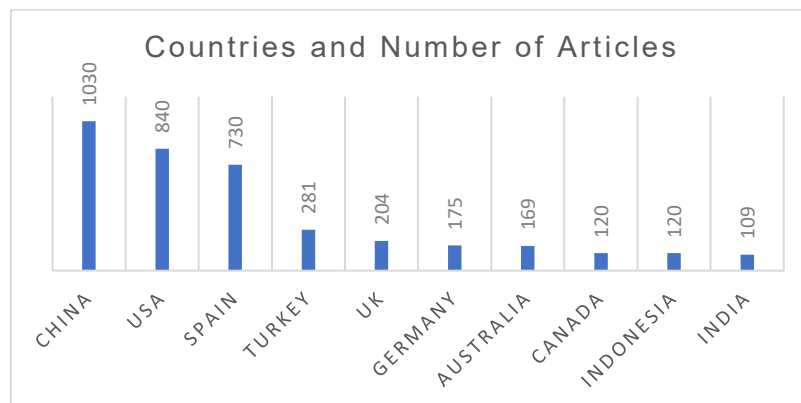


Figure 4 Distribution of augmented reality research by top 10 active countries

Figure 4 shows that China, USA, Spain, Turkey, Australia, UK, Germany, Serbia, Korea and Japan are the top 10 countries active in augmented reality research in education. In terms of the number of articles, China is in first place with 1030 articles, the USA is in second place with 840 articles and Spain is in third place with 730 articles. Another finding is that Turkey ranks fourth with 281 articles.

Figure 5 shows the active countries according to the total number of citations in augmented reality research in the field of educational sciences between 1999 and 1 September 2024 in the WOS database.

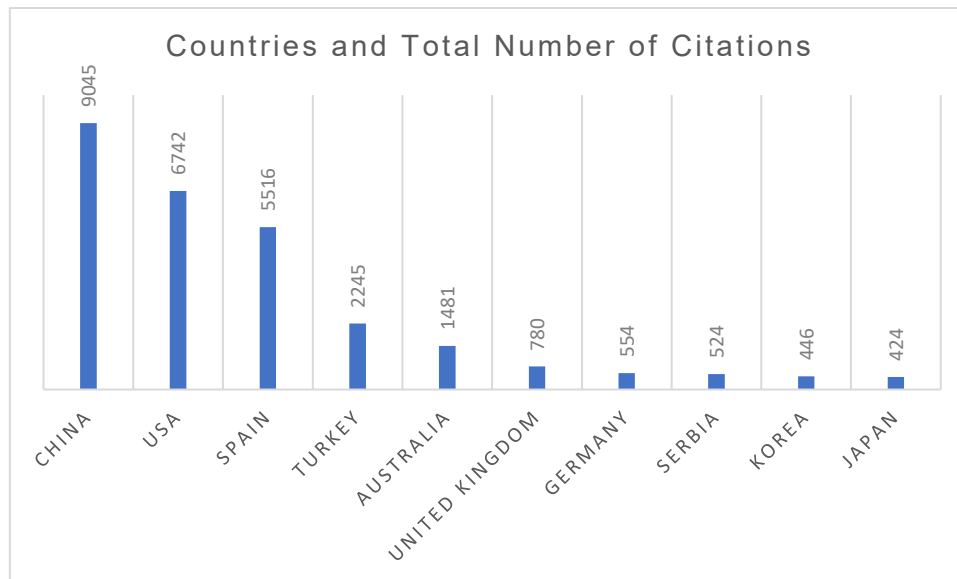


Figure 5 Active countries in augmented reality research by total number of citations

When analyzing Figure 5, according to the total number of citations in Augmented Reality research in the field of Education, China with 9045 citations, the USA with 6742 citations and Spain with 5516 citations are in the first three places. The overall citation ranking is as follows Turkey 2245, Australia 1481, England 780, Germany 554, Serbia 524, Korea 446 and Japan 424.

Figure 6 shows the active countries according to the average number of citations in Augmented Reality research in the field of Education between 1999 and 1 September 2024 in the WOS database.

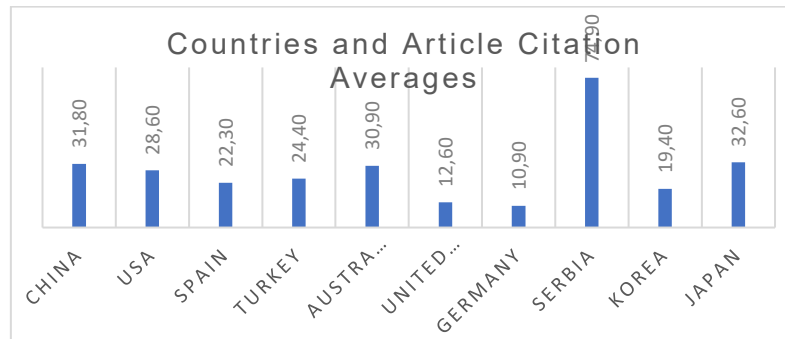


Figure 6 Active countries according to citation averages in augmented reality research

When analyzing Figure 6, Serbia ranks first among the active countries according to the average number of citations in Augmented Reality research in the field of Educational Sciences, with an average number of citations of 74.90. The citation ranking is 32.60 for Japan, 31.80 for China, 30.90 for Australia, 28.60 for the USA, 22.40 for Turkey, 22.30 for Spain, 19.40 for Korea, 12.60 for England and 10.90 for Germany.

The top 10 authors and the number of articles active in augmented reality research in the field of educational sciences between 1999 and 1 September 2024 in the WOS database are shown in Figure 7.

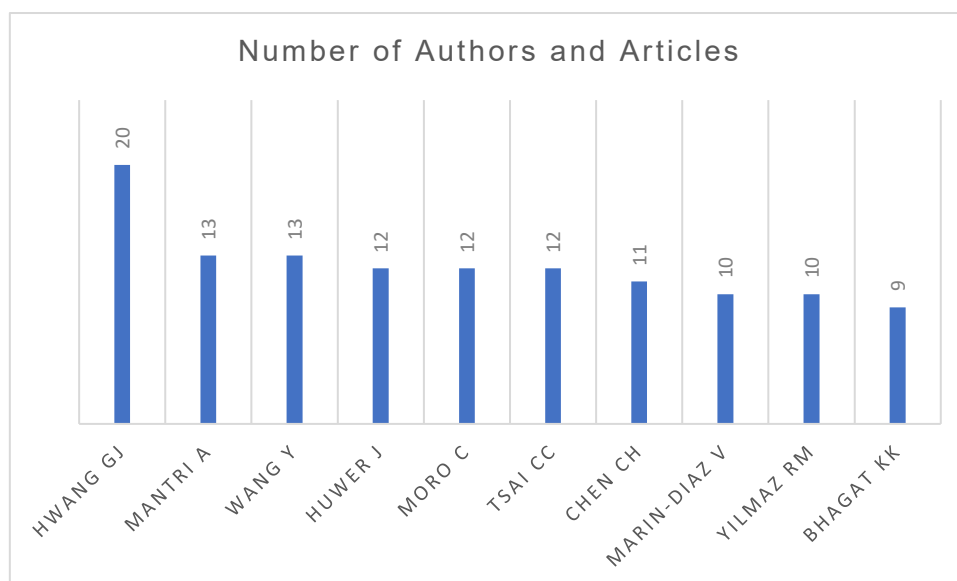


Figure 7 Top 10 authors active in augmented reality research and number of articles

When analyzing Figure 7, the active authors in augmented reality research are Hwang GJ with 20 articles, Mantri A with 13 articles, Wang Y with 13 articles, Huwer J with 12 articles, Moro C with 12 articles, Tsai CC with 12 articles, Chen CH with 11 articles, Marin-Diaz V with 10 articles, Yilmaz RM with 10 articles and Bhagat KK with 9 articles.

The ranking of the effective 10 authors according to the local citation ranking of augmented reality research in the field of educational sciences between 1999 and 1 September 2024 in the WOS database is shown in Figure 8.

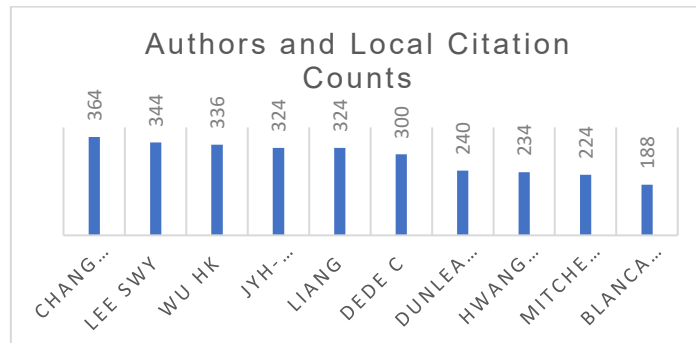


Figure 8 The 10 most influential authors of augmented reality research by local citation rankings

An analysis of Figure 8 shows that Chang H is in first place with 364 citations, Lee SWY is in second place with 344 citations and Wu HK is in third place with 336 citations. Jyh-Chong JC follows with 324 citations, Liang with 324 citations, Dede C with 300 citations, Dunleavy M with 240 citations, Hwang GJ with 234 citations, Mitchell R with 224 citations and Blance Ibanez M with 188 citations.

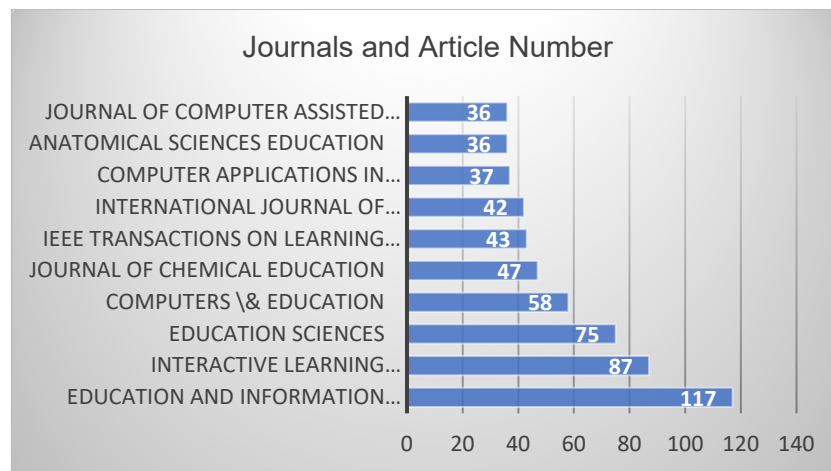
The top 10 articles and their information according to the total global citation ranking of augmented reality research in the field of educational sciences between 1999 and 1 September 2024 in the WOS database are shown in Table 1.

Table 1 Top 10 articles and information of augmented reality research according to total global citation ranking

| Author, Year, Journal Name | Doi | Total Citation |
|--|-------------------------------|----------------|
| Wu HK, 2013, Comput Educ | 10.1016/j.compedu.2012.10.024 | 1082 |
| Dunleavy M, 2009, J Sci Educ Technol | 10.1007/s10956-008-9119-1 | 696 |
| Di Serio A, 2013, Comput Educ | 10.1016/j.compedu.2012.03.002 | 563 |
| Potkonjak V, 2016, Comput Educ | 10.1016/j.compedu.2016.02.002 | 435 |
| Moro C, 2017, Anat Sci Educ | 10.1002/ase.1696 | 417 |
| Lee K, 2012, Tech Trends | 10.1007/s11528-012-0559-3 | 410 |
| Klopfer E, 2008, Etr&D-Educ Tech Res Dev | 10.1007/s11423-007-9037-6 | 403 |
| Gavish N, 2015, Interact Learn Environ | 10.1080/10494820.2013.815221 | 367 |
| Heradio R, 2016, Comput Educ | 10.1016/j.compedu.2016.03.010 | 325 |
| Bower M, 2014, Educ Media Int | 10.1080/09523987.2014.889400 | 315 |

When analyzing Table 1, Wu HK, with his article published in the journal 'Computers & Education' in 2013, is in first place according to the total global citation ranking with 1082 citations. This is followed by Dunleavy M with 696 citations, Di Serio A with 563 citations, Potkonjak V with 465 citations, Moro C with 417 citations, Lee K with 410 citations, Klopfer E with 403 citations, Gavish N with 367 citations, Heradio R with 325 citations and Bower M with 315 citations.

The top 10 journals active in augmented reality research in the field of educational sciences between 1999 and 1 September 2024 in the WOS database and the number of articles is shown in Figure 9.

**Figure 9** Top 10 journals active in augmented reality research and number of articles

Analyzing Figure 9, the first effective journal in augmented reality research is 'Education and Information Technologies' with 117 articles. This is followed by 'Interactive Learning Environments' with 87 articles, 'Education Sciences' with 75 articles, 'Computers & Education' with 58 articles, 'Journal of Chemical Education' with 47 articles, 'IEEE Transactions on Learning Technologies' with 43 articles, 'International Journal of Emerging Technologies in Learning' with 42 articles, 'Computer Applications in Engineering Education' with 37 articles, 'Anatomical Sciences Education' with 36 articles and 'Journal of Computer Assisted Learning' with 36 articles.

The top 10 institutions active in augmented reality research in the field of educational sciences between 1999 and 1 September 2024 in the WOS database and the number of articles is shown in Figure 10.

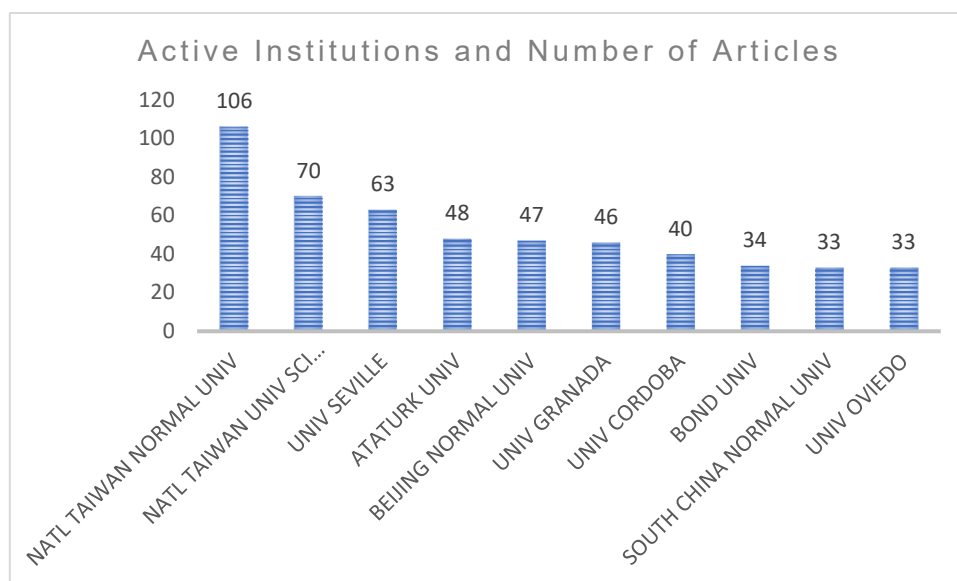


Figure 10 Institutions active in augmented reality research and number of articles

Analyzing Figure 10, the top 10 active institutions in augmented reality research are National Taiwan Normal University with 106 articles, National Taiwan University Science and Technology with 70 articles, University of Seville with 63 articles, Atatürk University with 48 articles, Beijing Normal University with 47 articles, University of Granada with 46 articles, University of Cordoba with 40 articles, Bond University with 34 articles, South China Normal University with 33 articles and University of Oviedo with 33 articles.

Figure 11 shows the relationship between active countries, active authors and active keywords in Augmented Reality research in Education between 1999 and 1 September 2024 in the WOS database.

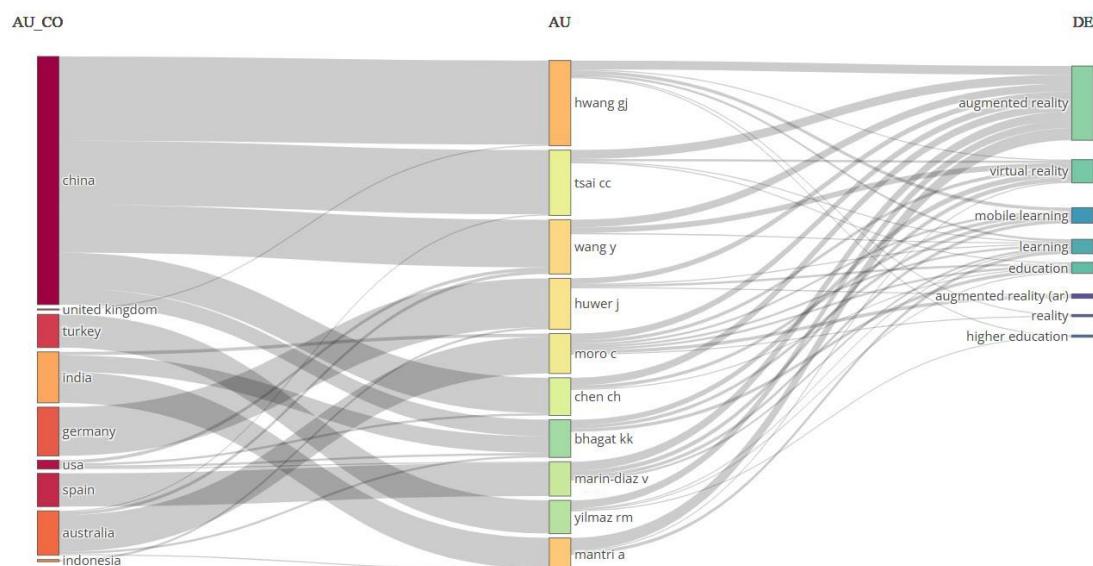


Figure 11 Three field diagrams; country (left), author (centre) and keyword (right)

If we analyze Figure 11, which shows the relationship between countries, active authors and active keywords, we see that China as a country, Hwang GJ as an author and Augmented Reality as a keyword are at the top and have the highest frequency. In Figure 11, the active authors in the middle summaries their use of the keywords on the right and their collaboration with the

countries on the left. For example, Moro C from Australia has conducted augmented reality studies using almost all the keywords on the right (except the keyword higher education).

The most popular Augmented Reality research topics in the field of education between 1999 and 1 September 2024 in the WOS database are shown in Figure 12.

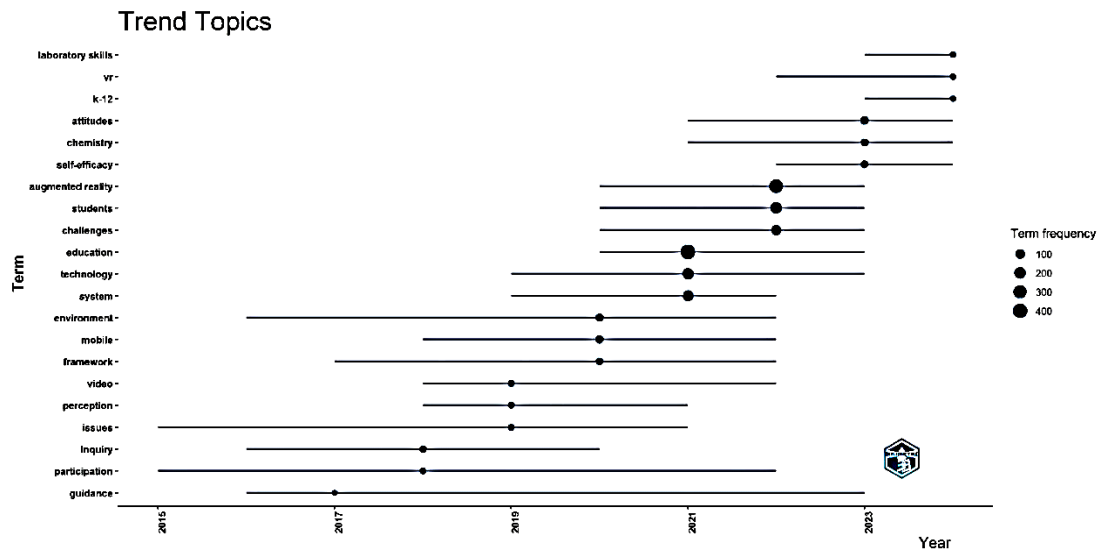


Figure 12 Popular topics in augmented reality research by year

Figure 12 shows that the Augmented Reality research terms on the left are more popular in the years bordering the lines. The year that covers the circle on the lines reflects the year in which it is most popular, and the size of the circle reflects the popularity status of that topic. Similarly, an analysis of Figure 12 shows that the years 2021 and 2022 cover the most popular topics. While these topics are education, technology and system for 2021, augmented reality, students and challenges for 2022. In 2024, laboratory skills, VR and K12 concepts are popular in augmented reality research.

Discussion and conclusion

In this study, 1759 Augmented Reality articles in the field of Education in the WOS database between 1999 and 1 September 2024 were examined, and it was found that the annual growth rate was 24.47%. Kljun and others (2020) emphasize in their study that research on augmented reality in digital technologies is still at an early stage and needs to increase. Radu and others (2022), Taalaybek and Özerbaş (2023), Keleş and Yavuz (2022), Bal and İçten (2017) and Boz (2019) used descriptive content analysis in their studies. When reviewing the literature, there are almost no studies that deal with augmented reality studies.

Considering the distribution of Augmented Reality research in the field of Education by years, it was concluded that the number, which started with one research 25 years ago in 1999, gradually increased with 285 research in 2023 and 238 research in the first eight months of 2024. Among the keywords, education is in first place with 443 searches, augmented reality is in second place with 354 searches and students is in third place with 190 searches. The top 10 active countries are China, USA, Spain, Turkey, Australia, UK, Germany, Serbia, Korea and Japan. According to the average number of citations, Serbia ranks first among the active countries with an average of 74.90 citations.

The citation ranking is 32.60 for Japan, 31.80 for China, 30.90 for Australia, 28.60 for the USA, 22.40 for Turkey, 22.30 for Spain, 19.40 for Korea, 12.60 for the United Kingdom and 10.90 for

Germany. Although Serbia is eighth in the ranking of active countries, it stands out for its first place in the average number of citations. The active authors in augmented reality research are Hwang GJ with 20 articles, Mantri A with 13 articles, Wang Y with 13 articles, Huwer J with 12 articles, Moro C with 12 articles, Tsai CC with 12 articles, Chen CH with 11 articles, Marin-Diaz V with 10 articles, Yilmaz RM with 10 articles and Bhagat KK with 9 articles.

In the local citation ranking, Chang HY ranks first with 364 citations, Lee SWY ranks second with 344 citations and Wu HK ranks third with 336 citations. Jyh-Chong JC follows with 324 citations, Liang with 324 citations, Dede C with 300 citations, Dunleavy M with 240 citations, Hwang GJ with 234 citations, Mitchell R with 224 citations and Blance Ibanez M with 188 citations. In terms of total global citations, Wu HK is in first place with 1082 citations for his article published in *Computers & Education* in 2013. Global citations are Dunleavy M 696 citations, Di Serio A 563 citations, Potkonjak V 465 citations, Moro C 417 citations, Lee K 410 citations, Klopfer E 403 citations, Gavish N 367 citations, Heradio R 325 citations and Bower M 315 citations.

The first effective journal in augmented reality research is 'Education and Information Technologies' with 117 articles, the second is 'Interactive Learning Environments' with 87 articles, and the third is 'Education Sciences' with 75 articles. The top 10 active institutions are National Taiwan Normal University with 106 articles, National Taiwan University Science and Technology with 70 articles, University of Seville with 63 articles, Atatürk University with 48 articles, Beijing Normal University with 47 articles, University of Granada with 46 articles, University of Cordoba with 40 articles, Bond University with 34 articles, South China Normal University with 33 articles and University of Oviedo with 33 articles.

It was concluded that the most popular concepts in augmented reality research were explored more in 2021 and 2022. While these concepts were education, technology and system for 2021, augmented reality, students and challenges for 2022. In 2024, the most popular concepts in augmented reality research were laboratory skills, VR and K12 concepts.

This study, which summarizes the point reached by the bibliometric analysis of augmented reality research in the field of educational sciences between 1999 and 1 September 2024, and addresses situations such as countries, keywords, authors, articles, institutions, popular topics that are active in this research, is expected to form a useful basis for future studies. In addition, it is suggested that researchers should also conduct bibliometric analyses in augmented reality studies outside the field of education and compare the results.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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