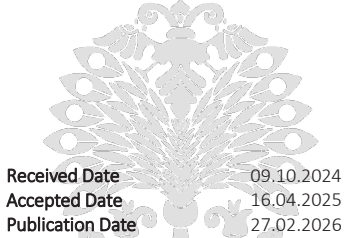


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Received Date 09.10.2024
Accepted Date 16.04.2025
Publication Date 27.02.2026
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Cite this article: Benek, İ., & Dönmez, İ. (2026). Bibliometric analysis of studies on augmented reality in science education. *Educational Academic Research*, 60, 172-181.



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Bibliometric Analysis of Studies on Augmented Reality in Science Education

ABSTRACT

With the rapid advancement of digital transformation in education, the integration of augmented reality (AR) technologies into science education holds great potential to enhance learners' experiences and increase their motivation. However, when the role of AR in science education is well researched, there is a lack of comprehensive insight into the thematic and bibliometric trends shaping this field. This study presents a bibliometric analysis of the research focusing on the use of augmented reality in science education. The concepts of "science education" and "augmented reality" were searched on the Web of Science database on April, 2024 through the VOSviewer program and a total of 210 documents were identified. The documents were quantitatively analyzed and mapped in terms of year, author, citation, country, institution, institution, journal and keywords through the VOSviewer program. The results provided an overview and detailed insights into the evaluation of the research field. The results show a growing interest in AR-based science education research until 2022, followed by a slight decline thereafter. In addition, it was determined that there are intensive research activities related to AR technology in science education in certain countries. Considering related literature, this research contributed to a deeper understanding of the influence of digital technologies in science education.

Keywords: Science education, augmented reality, bibliometrics.

Introduction

Of all the innovative technologies, augmented reality (AR) transforms the ways we interact with the world. An increasing number of AR applications in education is significant due to their impact on learners' cognitive, social, and emotional development. As an extremely beneficial tool for introducing students to complex ideas, AR provides students with hands-on opportunities that suit the practical nature of science education. This study aims to conduct a bibliometric analysis of the research concerning the use of AR technology in science education. Specifically, it examines publication trends, contributions of the authors and institutions, and emerging thematic concerns within this research domain. By mapping this body of research, the study aims to clarify how AR has been integrated into science education and to highlight future directions for scholarly inquiry.

Augmented Reality

There are rapid developments in technology. Developments in technology affect human life and comfort zone in many ways. These developments reshape daily life and professional practices. Thanks to technological advancements, people's quality of life, efforts to use time effectively and efficiently, communication style, entertainment and leisure activities, transportation and

travel options, personal development and opportunities, health and safety are getting better. Many new technologies have a profound impact on human life. One of the technologies that deeply affect human life is augmented reality technology. AR is an emerging technology that enriches digital and virtual content such as graphics, text, sound, music, etc. with real world environments. This technology combines the digital and real world simultaneously, providing users richer and more interactive experiences. AR is a visualization technology that extends sensory perception through digital objects (Buchner & Kerres, 2023). It complements the real world with virtual objects that appear to coexist with the real world (Azuma et al., 2001). This system seamlessly integrates virtual content with the real world and provides users with a sensory experience beyond reality (Qiao et al., 2019). AR can be created by using and linking various innovative technologies (Wu et al., 2013). Azuma et al. (2001) defined augmented reality (AR) as a technology that: 1) integrates real and virtual objects within a real-world environment, 2) operates interactively and in real time, and 3) aligns or registers real and virtual objects with one another. By using this technology, users have instant access to information that enriches their environment. This technology has the potential to affect human life in the future as it does today. AR is used in many fields such as

communication, military, entertainment, shopping and health. One of the key fields where this technology is applied is education. A major factor contributing to the widespread adoption of AR technology is its compatibility with a range of devices, including desktop computers, tablets, smartphones, and laptops (Irwanto et al., 2022).

Augmented Reality in Science Education

In science education, AR serves as an effective tool to simplify abstract and complex concepts while maintaining student engagement. Students engage with digital information visually and interactively with this technology. AR has positive effects on social, cognitive and emotional development as well as the authenticity of the learning environment (Yilmaz & Batdı, 2016). AR is a technology that enriches the learning-teaching process in science education. Students experience by integrating digital information into the real life environment through phones, tablets or augmented reality glasses. Augmented reality enhances our perception of the physical world by integrating ground and network-based information, supporting activities like games, tasks, and explorations that actively immerse students in dynamic learning environments (Bronack, 2011). AR should be used more effectively in science education as it makes the learning process more effective, engaging and interactive. This technology helps students develop the knowledge and skills they can learn more effectively (El Sayed et al., 2011). AR is a technology that can be used in all courses. Especially science is a prominent area for AR technology (Arici et al., 2019).

Some science concepts can be difficult to understand, complex and abstract. Technologies that include visuals can be used to make them easier to understand. Students can understand abstract concepts more easily with three-dimensional visuals. Science lessons enriched with visual technologies are more effective than traditional science lessons (Arici et al., 2019). With AR, students have the opportunity to interact with science concepts. Science subjects generally require hands-on learning. AR provides more interactive and effective learning opportunities for students' hands-on learning. In science courses, students can perform interactive processes such as observing space, performing experiments by presenting a virtual laboratory, examining biological processes, etc. with AR.

In recent years, the number and variety of studies on the use of AR in science education have increased. Yilmaz (2021) showed that AR is the most appropriate tool for teaching abstract topics that do not involve direct observation and investigation in science education. Nielsen et al. (2016) conducted a study with 35 expert science teachers from four different countries and found that AR

application contributed to a range of benefits and challenges to improve learning in science courses. Sahin and Yilmaz (2020) also found that AR technology used in science lessons had a positive effect on attitudes of middle school students. Turan and Atila (2021) determined that AR technology is effective in supporting the learning of students with special learning difficulties. In addition, there are studies conducting content analyses on the use of augmented reality technology in educational sciences (Akçayır & Akçayır, 2017; Masalimova et al., 2023) and science education (Arici et al., 2019; Kayalar & Baran, 2021; Swensen, 2016; Xu et al., 2022). In recent years, many studies have been conducted on the use of augmented reality (AR) technology in science education, especially on the effects of this technology on students' academic achievement, attitudes and motivation. However, when the trend studies in the literature are examined, it is seen that the studies are mostly limited to content analysis and bibliometric elements such as thematic distributions, citation analyses, author, institution and country collaborations are not examined in detail. This situation makes it difficult to fully understand the structural characteristics and developmental directions of academic production in the field. Aiming to overcome this deficiency, this study examines bibliometric data on the use of augmented reality in science education and reveals thematic gaps and trends in the literature with visual maps. In this respect, the study makes a significant contribution to the existing literature in terms of both methodological and content.

Purpose of the Study

This study aims to perform a bibliometric analysis of research utilizing augmented reality technology in the field of science education. In line with this purpose, answers to the following questions were sought:

1. How is the distribution of studies using augmented reality technology in science education according to years?
2. How is the citation-author analysis of studies using augmented reality technology in science education?
3. How is the citation-institution analysis of studies using augmented reality technology in science education?
4. How is the bibliographic link of studies using augmented reality technology in science education?
5. What is the frequency of using keywords together in studies using augmented reality technology in science education?
6. What is the co-citation status of the co-authors of the studies using augmented reality technology in science education?
7. What is the number of journal publications of studies

using augmented reality technology in science education?

Method

Bibliometric analysis refers to a quantitative analysis of scientific literature, revealing trends, patterns and the growth of research areas related to selected themes. Bibliometric analysis is emerging as an important tool among other methods in assessing the productivity and trends of research in various fields of science and technology. Bibliometric analysis is significant in providing insight into research trends, tracking influential studies, and informing future research directions by identifying gaps in the existing literature. One of the most crucial advantages of bibliometric analysis is its ability to provide a very objective and quantitative measure of research outputs. In systematic reviews and meta-analyses, bibliometric analysis provides a useful method for researchers to synthesise large amounts of literature to create an overview of the existing literature. Using visualisation tools such as VOSviewer, researchers can show the relationships between different studies, keywords and authors, thus revealing patterns and connections. This research will result in bibliometric analysis becoming a preferred method for identifying research and trends in the field of augmented reality. The Web of Science database was chosen for this study because it contains high-profile and peer-reviewed studies. Web of Science provides a higher degree of reliability in bibliometric analyses by indexing only reputable sources; therefore, it remains the ideal database for systematic reviews and bibliometric studies.

Data and Analysis Process

In the literature, quantitative analysis of academic studies in the field is carried out with various tools. VOSviewer is a program that is widely used in this process and offers the opportunity to visualize and map data. In this study, the VOSviewer program was preferred for visualizing the data within the scope of the study in line with the purpose of the research. In bibliometric analyses, the database is important because it directly affects the reliability of the study. Web of Science is an advanced database that offers advanced search options. Therefore, in this study, the data were retrieved from the Web of Science database. Through the VOSviewer program, a total of 210 documents were obtained in the general search on the Web of Science database on April 28, 2024 by searching for the concepts of “science education” and “augmented reality”. Of the 210 documents analyzed, the earliest was published in 2008 and the most recent in 2024. In the categorical grouping made in the relevant analysis, 124 journal articles,

61 full-text papers, 19 review articles, 13 early access, 5 book chapters, 3 editorial content and 1 letter were reached. Finally, 210 documents were quantitatively evaluated and mapped on the basis of author-citation-country-institution and keywords through the VOSviewer program. Furthermore, since the study is a bibliometric study, it does not require ethics committee approval. In addition, since the study is a bibliometric study, it does not require ethics committee approval.

Results

This section presents the findings obtained as a result of analyzing the studies included in the scope of the research through the VOSviewer program.

Distribution of Studies by Year

Figure 1

Distribution by Years

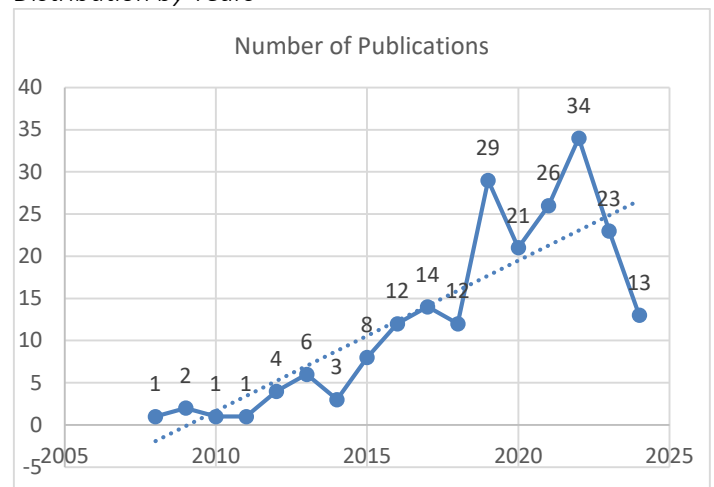
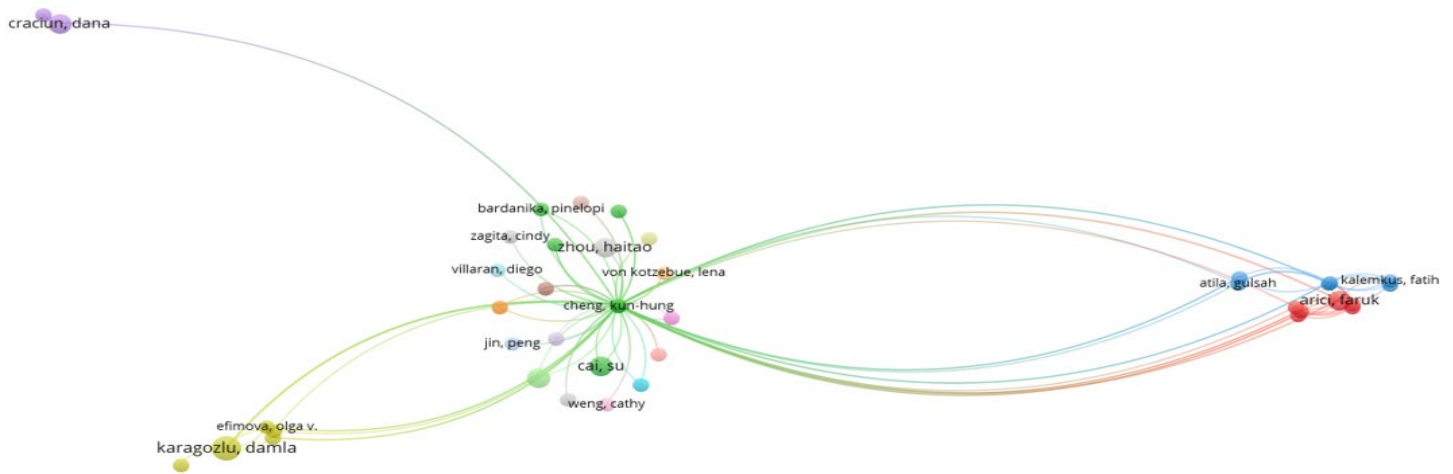


Figure 1 shows the distribution of publications on augmented reality application in science education by years. While the first publication on the topic was only 1 in 2008, there were 13 publications in 2024. The graph shows a generally increasing trend, but after 2022 there is a decline. This decline could be due to various factors, e.g. market conditions, changes in the industry or a decrease in research and development activities. The highest point was recorded in 2022 with 34 publications. The graph also shows a particularly large increase between 2016 and 2022. The increase during this period could indicate a wave of innovation, an increase in funding or a major development in the sector.

Citation-Author Analysis

Figure 2

Citation-Author Distribution



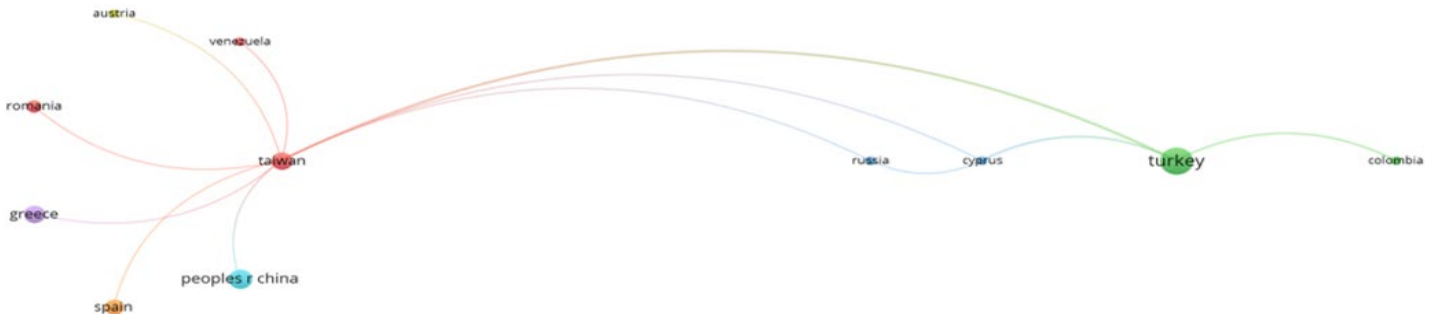
In Figure 2, the studies indicates the networks of their authors. Cheng and Tsai appear to have 394 citations and

35 different link strengths. Faruk Arici's two documents have 45 citations and 13 link strengths.

Citation- Country Analysis

Figure 3

Citation - Country Analysis



In Figure 3, the citation networks of the countries are presented. The results show that Taiwan with 4 documents and 418 citations (impact power=12); Turkey with 9

documents and 143 citations (impact power=8); Cyprus with 1 document and 8 citations (impact power=4) stand out respectively.

Citation-Institution Analysis

Figure 4

Citation-Institution Analysis

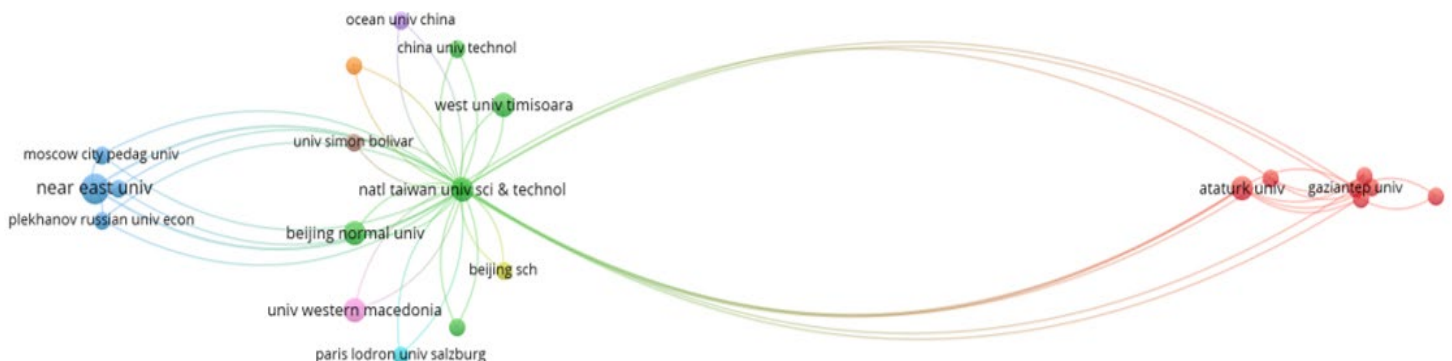


Figure 4 shows that National Chiao Tung University has one document with 394 citations and 21 citation power. National Taiwan University of Science and Technology has

2 documents 414 citations and 21 citation power while Atatürk University has 2 documents 72 citations and 8 citation power.

Bibliographic Linking of Documents

Figure 5

Bibliographic Link to Documents



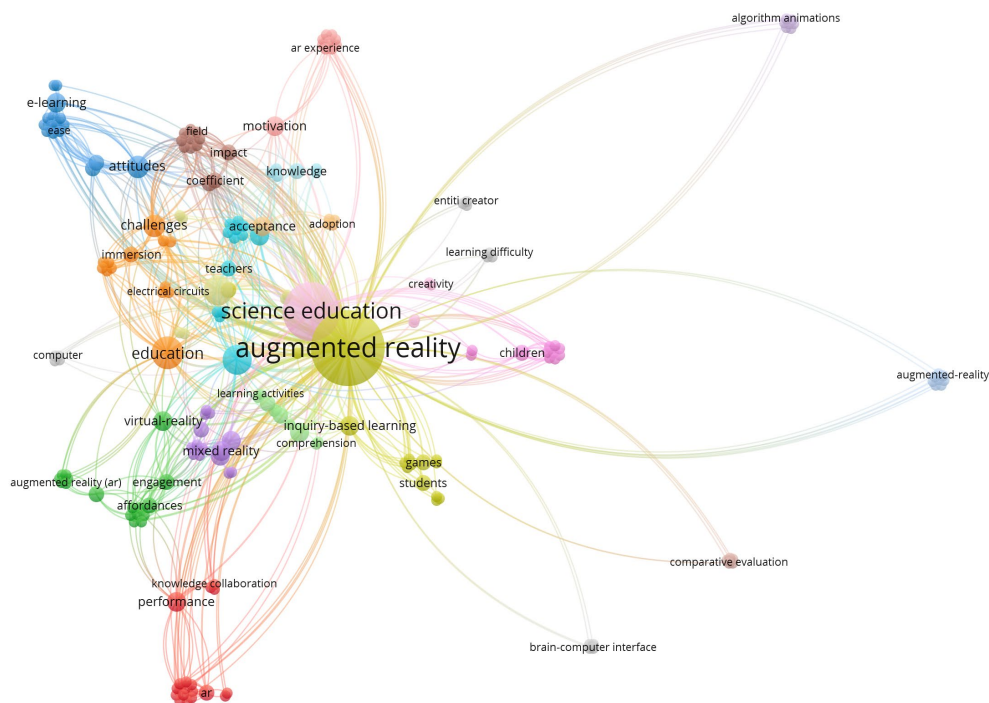
In Figure 5, the bibliographic matching networks of the documents were determined. In the analysis, Cheng and Tsai (2013) with 394 citations (impact power=41); Enyedy

et al. (2012) with 135 citations (impact power=3); Salar et al. (2020) with 45 citations (impact power=69) came to the fore respectively.-

Frequency of Key Words Used Together

Figure 6

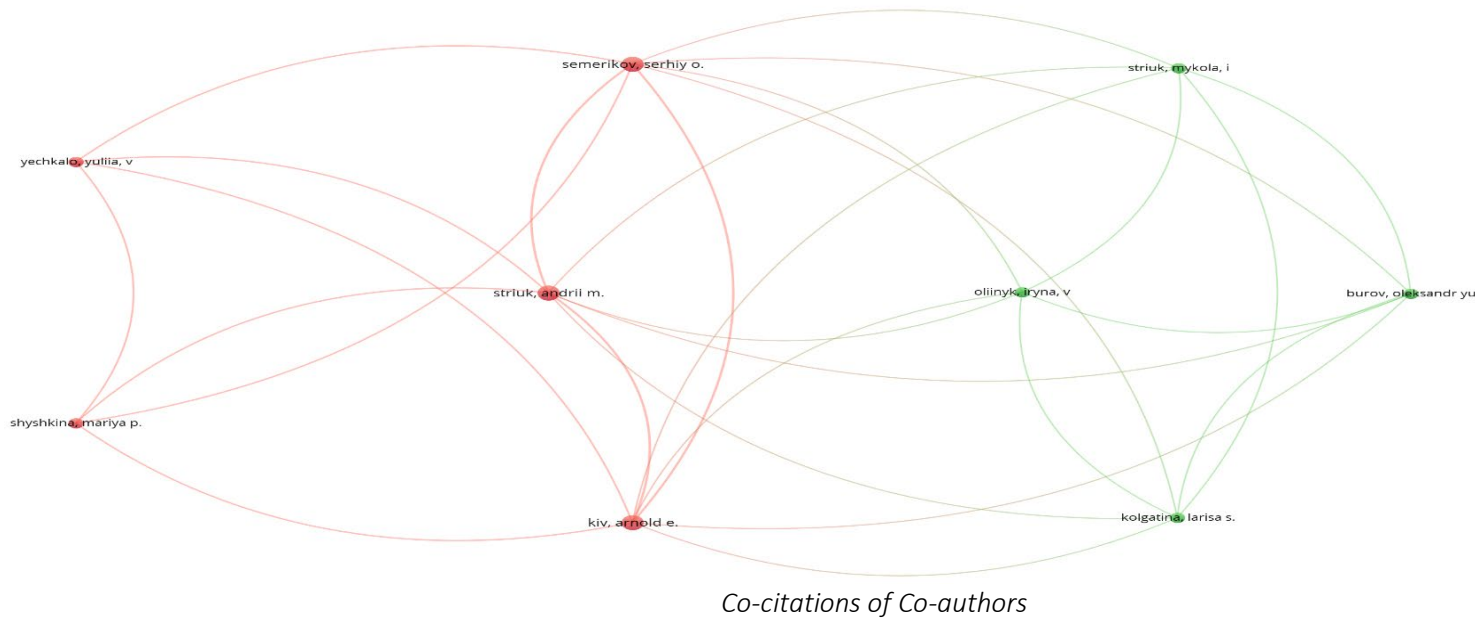
Co-occurrence of All Keywords



In Figure 6, it is seen the networks of the most frequently used keywords. The analysis revealed the most frequently occurring keywords including “augmented reality” with 42 uses (impact power=161); “science education” with 26 uses (impact power=100); “meta-analysis” with 3 uses

(impact power=13); “augmented reality in gamification” with 2 uses (impact power=13); “augmented reality in professional development” with 2 uses (impact power=12); “social and technical issues in augmented reality” with 2 uses (impact power=12).

Figure 7



Co-Citations of Co-Authors

Figure 7 presents the bibliographic matching networks of the authors. The results indicate that, Kiv Arnold (impact power=10) with 2 documents and 12 citations; Semerikov,

Serhiy O. (impact power=10) with 2 documents and 12 citations; Striuk, Andrii (impact power=10) with 2 documents and 12 citations each contributed publications

Number of Journal Publications

Figure 8

Number of Journal Publications

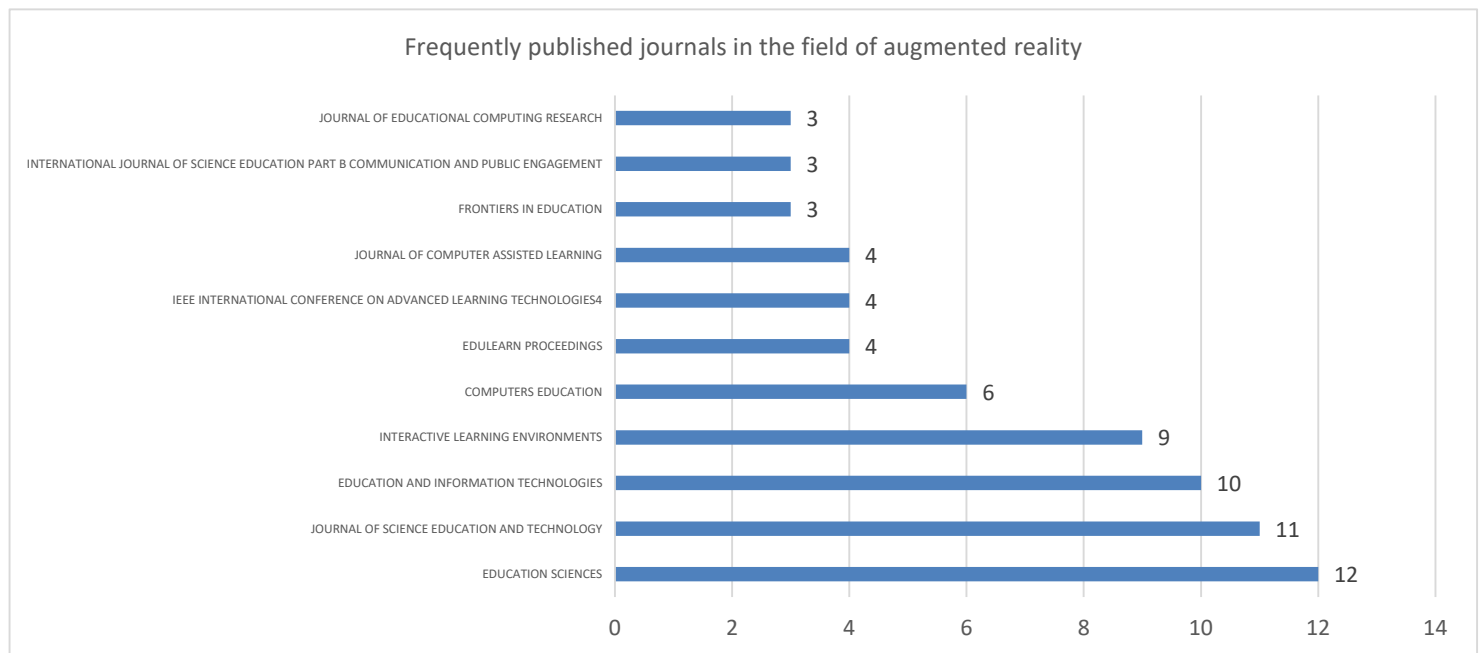


Figure 8 shows the journals that frequently publish in the field of augmented reality. The graph presents the names of the journals and the number of articles published in these journals. The journal “Education Sciences” has the highest number of publications with 12 articles, the second journal is the Journal of Science Education and Technology, the third journal is “Education and Information Technologies” and the last three journals (“Frontiers in Education”, “International Journal of Science Education Part B Communication and Public Engagement” and “Journal of Educational Computing Research”) have the lowest number of publications with 3 articles each. It is understood that these journals specialize in augmented reality and make a significant academic contribution in this field.

Discussion

Image-based and location-based AR technology can offer new possibilities to support science learning (Cheng & Tsai, 2013). AR has been shown to have a moderate to large significant positive effect in science-related courses (Xu et al., 2022). Therefore, we found it important to examine the research using augmented reality technology in science. In this study, studies conducted on augmented reality application in science education were revealed through bibliometric analysis. Depending on the purpose of the study, the concepts of “science education” and “augmented reality” were searched on the Web of Science database and a total of 210 documents were reached. According to the results obtained, it was seen that there was an increasing trend in the number of publications over the years, but a decrease occurred after 2022. In a similar study, Irwanto et al. (2022) analyzed trends in research on augmented reality applications in science education and found that the number of studies has grown consistently since 2007, reaching its highest point in 2020 and 2021. Masalimova et al. (2023) conducted a bibliometric analysis of augmented reality studies in education and social sciences and stated that the rate of increase between 2019-2020 was lower than other years, the rate of increase between 2018-2019 was higher than other years, and there was an increase in AR publications after 2020. The result we reached in our study is that augmented reality studies in science education tend to decrease after 2022. Similarly, Özbey and Arıcı (2024) emphasise the increasing trend of AR research in education. These differences suggest that although AR is widely investigated in science education, the methodological focus and research objectives differ between studies. In the early years, AR technology was seen as a major innovation in science education and intensive research was conducted on science education. In

recent years, new areas of research may be needed.

Even within the positive impact of AR in the education of science, there are some challenges still arising. Whereas a few free AR applications have been built, a lot of AR used in education will demand a few investments in hardware, software development, and training for teachers (Bacca et al., 2014; Cheng & Tsai, 2013). Contributions devoted to such AR experiences combined with science education are expensive because of the specialized software, 3D modeling, and content creation required (Wu et al., 2013). Access to these advanced AR tools may also be severely limited in developing areas where schools lack the requisite technology (Akçayır & Akçayır, 2017). This may have made it difficult for researchers to conduct studies in the field. The decline of studies on augmented reality in science education in recent years can be explained in a nutshell. These include the change in interest in augmented reality to other technologies, face-to-face training post-pandemic, difficulty in accessing technology, market conditions, and changing funding priorities.

Bibliometric analyses generally examine the citation rates of authors and studies. With these analyzes, it is determined which author/authors or studies have more impact on the subject. In this study, the authors' networks were also analyzed through VOSviewer software to determine their networks, and it was found that Cheng and Tsai have 1 document, 394 citations and 35 different link strengths. In addition, Arici, Faruk has two documents, 45 citations and 13 link strengths and Karagözlü, Damla has 3 documents, 33 citations and 8 link strengths. This finding is also consistent with studies in the literature. For example, Arici et al. (2019) stated that a limited number of authors determine the direction of studies in the field of augmented reality and science education and that these authors are in a central position in co-authorship networks. Similarly, Irwanto et al. (2022) stated that some researchers are frequently the first authors in augmented reality studies and are key actors in citation networks. Academic production in the field is concentrated around certain authors, and these individuals stand out as pioneers in determining both the content orientation and collaboration networks in the literature. This is significant in terms of identifying influential actors in the literature and determining possible future collaborations. Bibliometric analysis of studies on augmented reality in science education in the context of countries' citation networks can yield effective results.

The analysis reveals the research performance of countries on this topic, highlights their collaborative interactions,

identifies those that play a central role in scientific output, and maps their international cooperation networks. The findings of our study show that the country with the highest impact rate on the subject is Taiwan (4 documents, 418 citations and 12 impact powers). Taiwan is followed by Turkey (9 documents, 143 citations and 8 impacts), Cyprus (1 document, 8 citations and 4 impacts) and Colombia (1 document, 12 citations and 2 impacts). Irwanto et al. (2022) reported that the majority of first authors in AR research studies come from the USA, with Taiwan and Turkey following closely behind. Irwanto et al. (2022) conducted a search on the subject in the Scopus database, one of the prestigious databases.

The discrepancy between our study's finding-Taiwan being the country with the highest impact score-and that of Irwanto et al. (2022), who reported that the majority of first authors were from the United States, may be attributed to the use of different databases in the respective studies. Moreover, the fact that countries such as Taiwan stand out with high citation impact in AR research indicates that qualified studies in this field should be evaluated not only according to the number of publications but also according to the citation power.

Therefore, it is useful to reveal the bibliographic matching networks of institutions and documents that conduct research on the subject. The academic productivity and effectiveness of institutions on the subject yields remarkable results as a result of bibliometric analyses. In such analyses, it is revealed which universities, research institutes or other institutions contribute to cited works. In our study, when the institutions are considered in terms of productivity; National Chiao Tung University (1 document 394 citations and 21 citation power) and National Taiwan University Science & Technology. (2 documents 414 citations and 21 citation power) are in the lead in terms of number of publications, number of citations and impact power. These institutions were followed by Atatürk University (2 documents, 72 citations and 8 citation power) and Ben-Gurion University of the Negev (2 documents, 12 citations and 8 impact power). The bibliographic matching networks of the documents are that they refer to the same reference foci. This is a frequently used method to analyze the relationship between scientific documents. As a result of the analysis we conducted in the study; Cheng and Tsai (2013) with 394 citations (impact power=41); Enyedy et al. (2012) with 135 citations (impact power=3); Salar et al. (2020) with 45 citations (impact power=69) stand out in terms of bibliographic matching, respectively. Studies on augmented reality in science education are concentrated in certain universities and these institutions have become leading centres that shape the literature. In particular, the

fact that universities in Taiwan stand out with high citation numbers reveals that they have a strong position in terms of both quality and visibility in research in this field.

Analyzing concepts or phrases that appear frequently in scientific publications or academic texts plays an important role in understanding trends or changes in the subject matter. These analyses help to identify trends in research and thus identify new potential areas of study. Key concept analysis helps to understand the discovery processes and strategies of scientific research. Our research findings show that words and phrases such as "augmented reality" with 42 uses (impact power=161); "science education" with 26 uses (impact power=100); "meta-analysis" with 3 uses (impact power=13); "augmented reality in gamification" with 2 uses (impact power=13); "augmented reality in professional development" with 2 uses (impact power=12); "social and technical issues in augmented reality" with 2 uses (impact power=12) are prominent in the research on the subject. Arici et al. (2019) stated that the most used keywords were "augmented reality", "mobile learning", "science education", "science learning" and "e-learning". In addition, Arici et al. (2019) concluded that studies on the use of keywords have focused on mobile learning in recent years.

Uncovering the bibliometric matching networks of authors in a research field plays a key role in determining the interactions, information flow and structural characteristics of research in the research field. Authors' bibliometric matching networks reveal the relationship between authors referencing the same sources. When the studies included in the scope of the research were analyzed, it was determined that Kiv Arnold (impact power=10) with 2 documents and 12 citations; Semerikov, Seyhiy O. (impact power=10) with 2 documents and 12 citations; Striuk, Andrii (impact power=10) with 2 documents and 12 citations produced publications. This finding is consistent with similar studies in the literature. For example, Arici et al. (2019) stated that authors in publications on augmented reality cluster around certain sources and this creates a knowledge network in the field. Similarly, Masalimova et al. (2023) emphasized that studies in the field of augmented reality focus on certain sources and that these sources strengthen the connection between studies.

Revealing the journals that frequently publish on augmented reality in science education and the number of articles published on the subject in these journals can have results in understanding the scientific development and publication dynamics of this subject. Journal publication analysis plays an important role in understanding how knowledge production, knowledge distribution and impact

occur in the research field. In the light of the findings we obtained in our research, it was understood that the journal with the highest number of publications on the subject was "Education Sciences" with 12 articles. This journal was followed by "Journal of Science Education and Technology" and "Education and Information Technologies". As a result, it is understood that these journals specialize in augmented reality in science education and make a significant academic contribution to the literature in this field. Masalimova et al. (2023) stated in their study that the majority of technology journals are among the top ten. Arici et al. (2019) identified the most frequently cited journals as Computers & Education, Journal of Science Education & Technology, Educational Technology and Society, Computers in Human Behavior, and the British Journal of Educational Technology. This finding may be a guide for researchers in determining the right broadcasting channels to direct their studies.

Conclusion and Recommendations

In the study, 210 studies published in the Web of Science database in the field of augmented reality and science education between 2008 and 2024 were analyzed. It was determined that the most publications were produced in 2022, and then a decrease occurred. It was determined that the most cited authors were Cheng and Tsai. The the most influential country was Taiwan, and the most influential institution was National Taiwan University. The most frequently used keywords were "augmented reality" and "science education". These findings clearly identify the most influential people, institutions, countries and themes in the field. The study contributes to researchers both in seeing past trends and in determining the direction for future studies. We believe that facilitating researchers' access to augmented reality technology, providing funding support to researchers who want to work in this field and supporting researchers' project applications on the subject can be beneficial.

This study has some limitations that need to be recognised. First, the analysis is limited to the Web of Science database. Future research could expand the dataset by including multiple databases to provide a view of AR research in science education. Second, this study relied on only quantitative bibliometric methods regarding the effectiveness of AR in science education. A mixed methods approach can offer deeper information into the pedagogical impact of AR. Finally, this study does not assess the content quality of the selected articles, i.e. citation frequency does not indicate the importance or rigour of the research. Future studies could include content analysis to

assess the thematic depth and contributions of highly cited studies.

Ethics Committee Approval: Since the study is a bibliometric study, it does not require ethics committee approval.

Peer-review: Externally peer-reviewed.

Author Contributions: Concept – İB, İD; Design – İB; Supervision – İD; Resources – İB, İD; Materials – İB, İD; Data Collection and/or Processing – İD; Analysis and/or Interpretation – İD; Literature Search – İB; Writing Manuscript – İB; Critical Review – İB, İD

Conflict of Interest: The authors have no conflicts of interest to declare.

Financial Disclosure: The authors declared that this study has received no financial support.

Note: A detailed list of the 210 research documents analysed in this study is not provided in the main text of the study. However, upon request, the authors would be pleased to share this information with the readers/researchers.

Use of Artificial Intelligence: In this article, artificial intelligence has been used for simple language editing purposes.

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