



AUGMENTED REALITY IN EDUCATION: A BIBLIOMETRIC ANALYSIS

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ABSTRACT

The application of augmented reality in education has become increasingly important in recent years. This research aims to reveal trends over the last twenty years with bibliometric analysis to examine the results of articles related to the use of augmented reality in education. This research collects data from the Scopus database from 2003 to 2023, uses the Scopus website analysis features, and visualizes the bibliometric network using Vosviewer. A total of 1,772 studies were accessed through various screening processes. This research distributes publications based on year, country, author, and most cited articles. Among the most published articles indexed by Scopus, papers published by researchers in the United States have the highest number of publications (302), followed by Spain (166) and China with 131 publications. Computer science provided the largest contribution by subject area (858 articles). The five most popular journals in AR are *Education and Information Technologies*, *Computers and Education*, *Education Sciences*, *Sustainability Switzerland*, and *the International Journal of Emerging Technologies in Learning*. It has been detected that Wu H.-K. et al. are the most popular authors, with a citation level reaching 3022 citations. The concepts that became clear in the co-occurrence analysis group were "augmented reality," "virtual reality," "education," "teaching," "students," and "e-learning."

Keywords: *Augmented, Reality, Education, Bibliometric, Vosviewer*

1. INTRODUCTION

Augmented Reality (AR) is a technology that can add virtual objects to the real world and can be seen through a camera (Ronald T. Azuma, 1997). AR is a technology where the real world and virtual objects interact simultaneously (in real-time) using electronic devices (Maas & Hughes, 2020). Augmented Reality (AR) has the potential to provide new opportunities for promoting learning, creating constructive learning environments and providing interactive visual experiences (Huang et al., 2016; Klopfer & Squire, 2008).

At the beginning of AR use, users faced many problems, such as technical problems, hardware shortages, and usage costs. This makes it possible that in 2004–2008, researchers had not studied the use of augmented reality in the educational sector in more depth based on Scopus data. However, as technology develops, utilizing AR technology is no longer as difficult as it used to be (Akçayır & Akçayır, 2017). AR applications have increased along with technological advances and ease of use (Talan, 2021). Expensive hardware and complex equipment are no longer required to utilize AR technology, which is one of the most significant factors contributing to the widespread adoption of AR technology (Masalimova et al., 2023). With more accessible AR, users have more opportunities to engage with academic material, thereby improving students' retention of the material (Kaur et al., 2020).

Many research results have tested the effectiveness of using AR in educational environments. The research results reveal that AR can increase students' motivation, learning experience and learning outcomes (Bacca et al., 2018; Di Serio et al., 2013; Georgiou & Kyza, 2018; Ibáñez et al., 2020), improve students' science reading performance from the perspective of cognitive load theory (Lai et al., 2019), and students with high anxiety also have higher self-confidence and satisfaction and lower anxiety when learning using AR (Y. Chen, 2019). Augmented reality technology can also improve storytelling skills, testing elementary school students' narrative skills and creativity (Yilmaz & Goktas, 2017). AR increases engagement, collaboration and participation



(C. Chen et al., 2020). Much research has been conducted on AR implemented in medical education (Baashar et al., 2022; Christopoulos et al., 2022; Gonzalez et al., 2020).

Most studies on AR in education are based on constructivist and situated learning theories (Koutromanos et al., 2015). Previous research on AR generally focuses on the development of the technology and its practical implications in various learning environments (Cheng & Tsai, 2014; Wei et al., 2015). Previous research has also highlighted the importance of using AR in education and its potential impact on learning. However, understanding of research trends related to the use of AR in education remains limited. Therefore, this research will fill this gap by identifying articles related to AR in education and analyzing research trends over the last two decades.

This research uses bibliometric methods to collect, analyze and evaluate articles related to the use of AR in education published over the last twenty years (2003–2023). The research strategy will include identifying relevant databases, developing an analytical framework, and conducting comprehensive bibliometric analysis to reveal significant research trends. Bibliometrics is a type of quantitative analysis that uses various publication patterns. There are evaluative and descriptive methods that can be used in bibliometric methodology. Evaluative methods, such as bibliographic maps, bibliographic networks, and bibliographic coupling, are used to evaluate and compare the impact of publications more complexly than descriptive methods (Karakus et al., 2019).

This research aims to reveal trends over the last twenty years with bibliometric analysis to examine the results of articles related to the use of augmented reality in education. Thus, this study aims to provide in-depth insight into the development, focus and contribution of research in this domain over the specified period. The research questions raised in this study, all related to entries in the Scopus online literature resource, are listed below.

RQ1. What is the distribution of relevant publications by year?

RQ2. What is the distribution of relevant publications by country?

RQ3. What is the citation ranking of related publications, journals, authors, and institutions?

RQ4. What kind of structure emerges in connection with co-occurrence?

2. METHODS

This research uses bibliometric analysis methods to examine the use of AR technology in the education sector. Bibliometric analysis is used in many scientific disciplines, where mathematical and statistical methods are used to measure and analyze scientific publications (Pritchard, 1969). The reason for using bibliometrics is that the tool is widely known and powerful for conducting bibliometric analysis (Aria & Cuccurullo, 2017). The research aims to describe existing phenomena, both currently occurring and those that have occurred in the past, as well as various AR-related topics. This bibliometric study is comprehensive in scope, investigating the existing state and trends regarding AR research from 2003 to 2023 according to the specifications established for the research process. This search was carried out in February 2024, and the Scopus database was used as the main source to obtain bibliographic information.

Data Collection

This research used the Scopus database to obtain bibliometric data to be examined. Scopus is considered the leading citation index in scientific circles and is recognized as the world's leading academic database. Below is the generated code regarding how content is scanned and filtering options in topic areas (article title, abstract, keywords) of the Scopus search engine:

```
TITLE-ABS-KEY ( augmented AND reality AND in AND education ) AND PUBYEAR > 2002  
AND PUBYEAR < 2024 AND ( LIMIT-TO ( LANGUAGE , "English" ) ) AND ( LIMIT-TO ( DOCTYPE ,  
"ar" ) ) AND ( LIMIT-TO ( EXACTKEYWORD , "Augmented Reality" ) )
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The following exclusion and inclusion criteria were applied:

1. Studies published between 2003 and 2023.
2. Document types are limited to articles.



3. Studies must be published in English.
4. Studies are categorized into social sciences and education.

A total of 1,772 studies were found as a direct consequence of searches conducted using the given keywords. In RIS and CSV formats, the bibliometric data of the retrieved studies was downloaded and analyzed.

Data Analysis

Bibliometric and descriptive content analysis is used in data analysis in research. The Scopus database system was used for content analysis. VOSviewer version 1.6.19, a mapping and visualization software, was used for bibliometric analysis. VOSviewer is one of the most popular computer programs designed and developed to present several visualization techniques (Eck & Waltman, 2017). The distribution of studies by year and country was examined first among all the data obtained at the end of the data collection process. After that, the content analysis process included the most published research reference sources, authors, and number of research citations. Bibliometric analysis was carried out to determine trends in AR research that has been carried out in the field of education.

3. RESULTS & DISCUSSION

The research objectives have yielded the following findings: Research findings are presented in the form of tables and figures.

RQ1. What is the distribution of relevant publications by year?

In this study, the distribution of research published in Scopus by year was examined first. The findings obtained are presented in Figure 1.

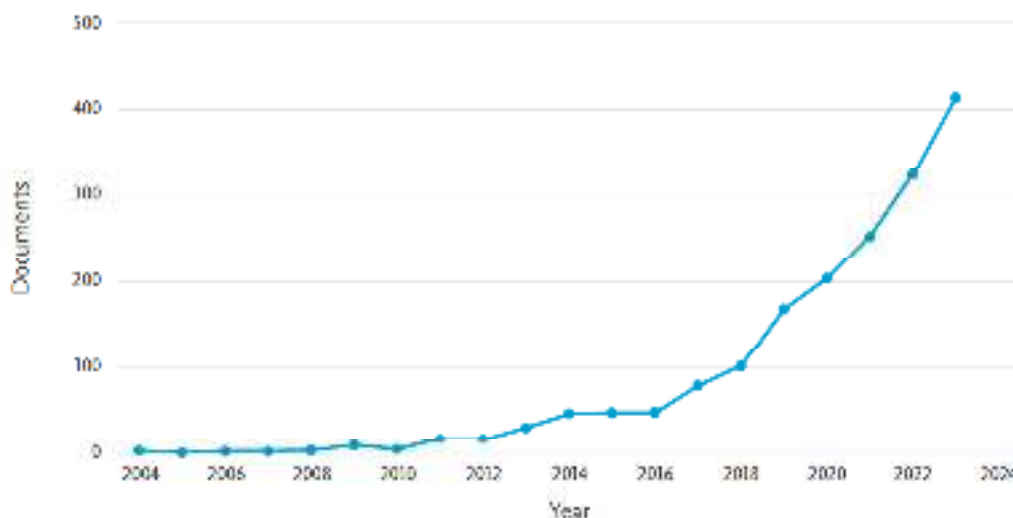


Figure 1. Distribution of Publications by Year

If you look at Figure 1, it can be seen that the first research related to augmented reality in the field of education was carried out in 2004 with two articles. There is a visible increase in the number of studies conducted in general. It was found that the number of publications was low from 2004 to 2010 but reached the highest number in the last three years (2021-2023). 2023 is the year with the most publications on this subject, with 413 research articles on AR in education. This is because the research results of (Bujak et al., 2013) stated that AR is just starting to surface in educational applications (Bujak et al., 2013). Therefore, (Bacca Acosta et al., 2014) recommended more research on AR in education (Bacca Acosta et al., 2014).

RQ2. What is the distribution of relevant publications by country?



When the distribution of studies conducted on this subject by country is examined, the graph below (Figure 2) shows the top 10 countries with the most publications.

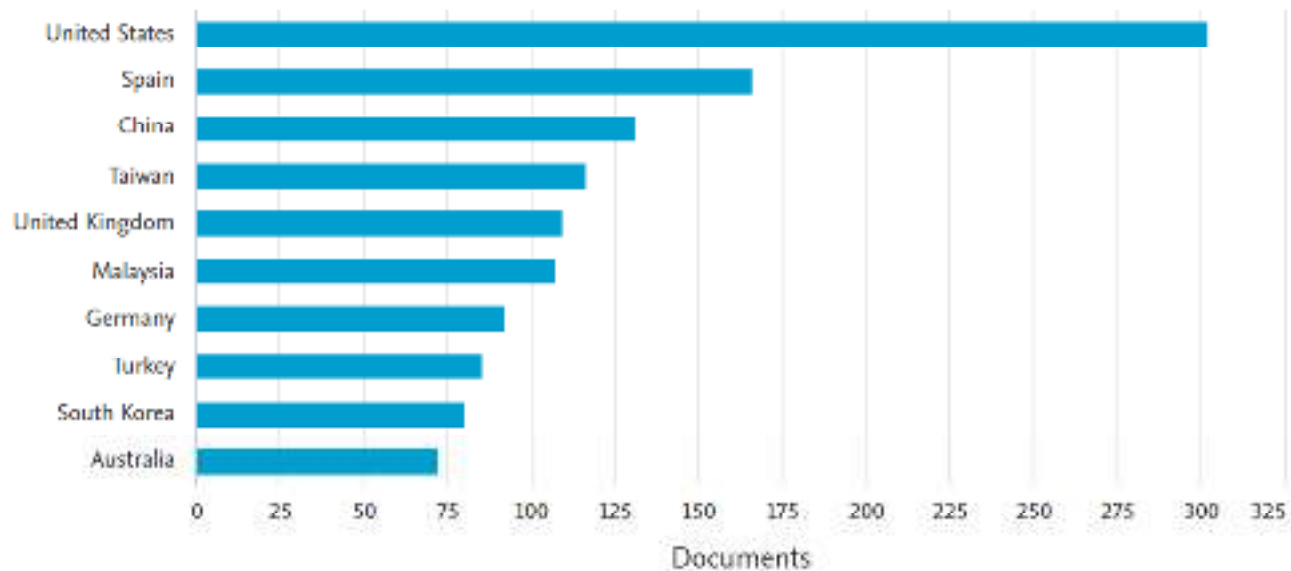


Figure 2. Distribution of Publications by Country

Based on this distribution, the United States ranks first with 302 papers, Spain ranks second with 166 papers, and China ranks third with 131 papers. Taiwan ($f = 116$) follows the list, followed by the followed by the United Kingdom ($f = 59$), Malaysia ($f = 107$), Germany ($f = 92$), Turkey ($f = 85$), South Korea ($f = 80$), Australia ($f = 72$), and other countries. The United States ranks first in terms of the total number of publications. This aligns with bibliometric research findings (Karakus et al., 2019; Masalimova et al., 2023) that the United States is at the top of the list based on total publications. Researchers researching AR are more open to collaborating and publishing joint works (Masalimova et al., 2023).

RQ3. What is the citation ranking of related publications, journals, authors, and institutions?

The distribution of papers according to the research areas in the Scopus data is checked first. Relevant data are presented in Figure 3.

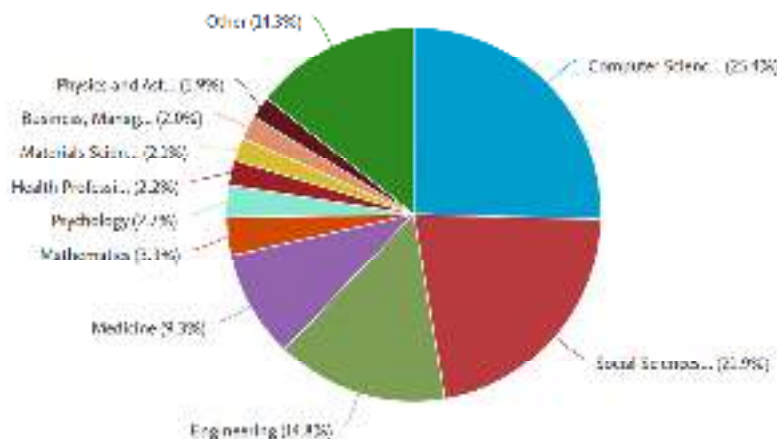




Figure 3. Relevant Data

Journals that publish AR papers are highly diversified. Based on Scopus data, it was found that the distribution of papers based on areas related to the use of AR is: computer science (858 articles), social sciences (740 articles), engineering (499 papers), medicine (315 papers), mathematics (111 papers), psychology (91 papers), health professions (73 papers), materials science (70 papers), business, management and accounting (69 papers), physics and astronomy (65 papers), arts and humanities (60 papers), and environmental science (58 papers). This analysis shows that AR is a technology that will be involved in many fields because it is useful for users (Arici et al., 2019). Furthermore, a comparison of the number of articles based on their sources can be seen in Figure 4.

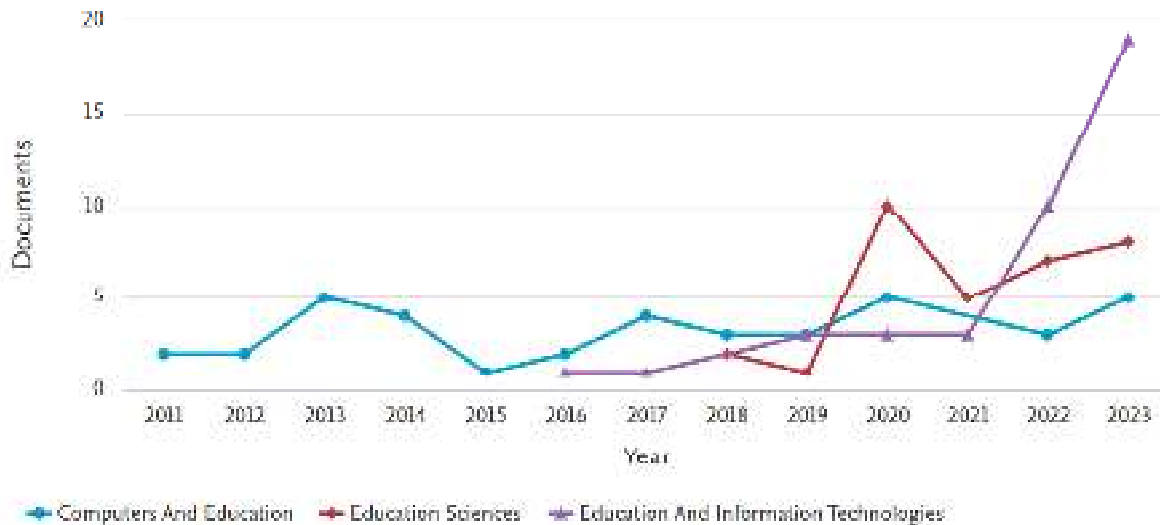


Figure 4. Documents per Year by Source

Computer and Education is in first place with a total of 40 documents. The second is Education Sciences, with a total of 39 documents. Third is Education and Information Technologies, with a total of 33 documents. Several bibliometric studies (Garzón, 2021; Karakus et al., 2019; Masalimova et al., 2023) stated that Computer and Education were the most cited sources. The author prefers Computer and Education because the AR subject covers technology intensively and is compatible with the scope of Computer and Education (Masalimova et al., 2023).

Next, analysis of articles with the highest number of citations based on Scopus data is presented in Table 1 below.

Table 1. Most Cited Articles

Cited by	Authors	Title	Year	Journal
3022	Wu H.-K.; Lee S.W.-Y.; Chang H.-Y.; Liang J.-C.	Current status, opportunities and challenges of augmented reality in education	2013	Computers and Education
2261	Akçayır M.; Akçayır G.	Advantages and challenges associated with augmented reality for education: A systematic review of the literature	2017	Educational Research Review
1685	Bacca J.; Baldiris S.; Fabregat R.; Graf S.; Kinshuk	Augmented reality trends in education: A systematic review of research and applications	2014	Educational Technology and Society



1560	Di Serio Á.; Ibáñez M.B.; Kloos C.D.	Impact of an augmented reality system on students' motivation for a visual art course	2013	Computers and Education
1369	Klopfer E.; Squire K.	Environmental detectives-the development of an augmented reality platform for environmental simulations	2008	Educational Technology Research and Development
1049	Radu I.	Augmented reality in education: A meta-review and cross-media analysis	2014	Personal and Ubiquitous Computing
933	Li X.; Yi W.; Chi H.-L.; Wang X.; Chan A.P.C.	A critical review of virtual and augmented reality (VR/AR) applications in construction safety	2018	Automation in Construction
886	Ibáñez M.-B.; Delgado-Kloos C.	Augmented reality for STEM learning: A systematic review	2018	Computers and Education
863	Moro C.; Štromberga Z.; Raikos A.; Stirling A.	The effectiveness of virtual and augmented reality in health sciences and medical anatomy	2017	Anatomical Sciences Education
779	Ibáñez M.B.; Di Serio Á.; Villarán D.; Delgado Kloos C.	Experimenting with electromagnetism using augmented reality: Impact on flow student experience and educational effectiveness	2014	Computers and Education

Based on Table 1 above, it was found that the most frequently cited article titles were Current Status, Opportunities, and Challenges of Augmented Reality in Education, written by (Wu H.-K. and Lee S.W.-Y.; Chang H.-Y.; and Liang J.-C.2013) in the Computer and Education journal with 3,022 citations. This study recommends that future research consider how Augmented Reality (AR) environments support learning so that they can help transform important concepts in education, such as contextualization, authenticity, and engagement. Additionally, learning approaches that emphasize students' roles in AR environments can increase students' sense of presence and engagement. Likewise, location-based learning approaches can link formal and informal learning, which can change the concept of contextualization. AR can also enhance learning tasks by allowing students to view content from different points of view. However, further research is needed to understand the learning effects of AR in more depth, including the development of substantial educational content and the integration of AR into school curricula (Wu et al., 2013).

Table 2. Top 5 Documents by Author

Authors	Number of Study	Example Paper
Mantri, A.	14	(Tuli, Mantri, et al., 2022); (Pathania et al., 2023); (Tuli, Singh, et al., 2022); (Kumar et al., 2021); (Singh et al., 2019)
Yilmaz, R.M.	9	(Salar et al., 2020); (Sahin & Yilmaz, 2020); (Yilmaz & Goktas, 2017); (Yilmaz, 2016); (Küçük et al., 2014); (Topu et al., 2023)
Navab, N.	8	(Ma et al., 2016); (Barmaki et al., 2019); (Martin-Gomez et al., 2021); (Bork et al., 2021)



Behzadan, A.H.	7	(Shirazi & Behzadan, 2015); (Dong et al., 2013); (Behzadan & Kamat, 2013); (Turkan et al., 2017)
Billinghurst, M.	7	(Billinghurst & Duenser, 2012); (Herbert et al., 2018); (Feng et al., 2023); (Herbert et al., 2022); (Dalim et al., 2020)

RQ4. What kind of structure emerges in connection with co-occurrence?

Keywords co-occurrence analysis

VOSviewer software analyzed 1,772 articles to extract the most researched AR-related topics in education. The keywords most frequently used are AR, VR, education, human, AI, student, teaching and learning. All keywords were categorized into four logical groups (Figure 5). The node's size indicates the keyword's frequency: the larger the node, the more often the keyword is researched. The close relationship between the two phrases affects the thickness of the line. The study found 1,858 links for 55 items, giving an average link strength for co-occurrence of 33.8 (across all keywords).

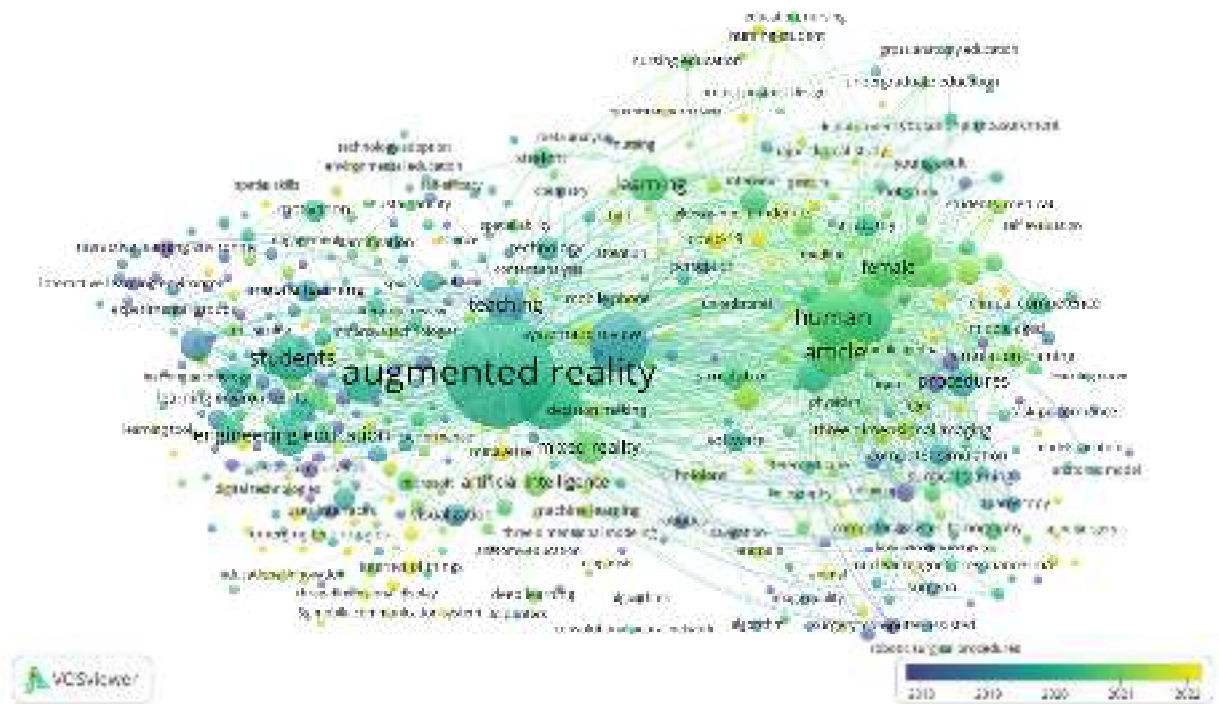


Figure 5. Keywords Network Based on Co-Occurrence

The network structure of relationships between keywords is shown in Figure 5. Larger circle sizes indicate more frequently discussed subjects, while yellow areas indicate recent subjects. As can be seen in Figure 5, the words “augmented reality,” “virtual reality,” “education,” “teaching,” “student,” and “e-learning” are located in the center of the map. These words are concepts that have been studied together with other clusters and have been identified as the most frequently used keywords.

The co-occurrence of author keywords is presented with a network visualization. The number of occurrences and the total strength of their links with other keywords are calculated for all keywords. The



keywords with the greatest total link strength are selected. Augmented reality was the most frequently found keyword, with 1,772 occurrences and a total link strength of 11,579. For others, the first number represents the occurrence, and the second is the total link strength. Virtual reality is in second place (498; 4,526), and education is in third place (438; 4,473). Other terms are human (373; 5,739), students (276; 2,428), engineering education (188; 1,475), teaching (185; 2,055), e-learning (176; 1,619), and learning (173; 2,104).

Figure 5 shows that the largest cluster comprises AR, student, teaching, and engineering education. The second cluster comprises humans, articles, procedures, females, and 3D imaging. The third cluster comprises education, learning, student, COVID-19, curriculum, anatomy, student medical, and major clinical study. The fourth cluster comprises human experiments, knowledge, pilot studies, and nursing education. Most augmented reality literature studies have been conducted at all levels and in all in all scientific disciplines.

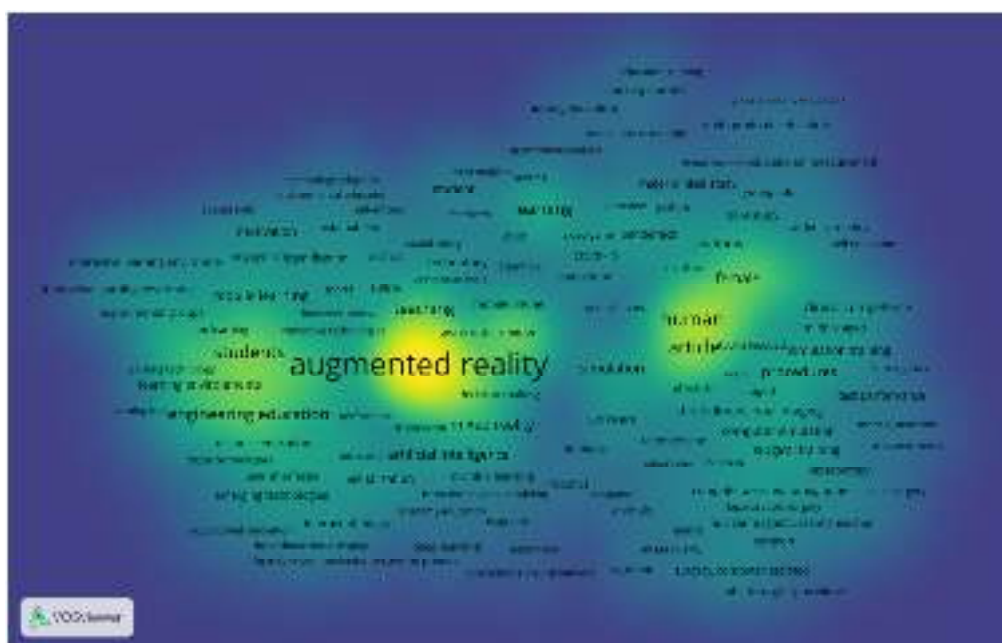


Figure 6. VosViewer Cluster Analysis

Table 3. Cluster Keywords and Cluster Topics

Cluster	Cluster keywords	Cluster topic / Example papers
1	AR, student, teaching, engineering education, artificial intelligence, interactive learning, motivation, mixed reality, mobile learning, gamification, emerging technologies, iot, etc.	AR, motivation: (Santos et al., 2013); (Huang et al., 2016); (Ibáñez et al., 2020)
2	Human, article, procedures, female, 3D imaging, simulation training, clinical competence, medical education, software, computer simulation, etc.	3D imaging, simulation training: (Anton et al., 2018); (Goh et al., 2021); (Christopoulos et al., 2022)



3	Education, learning, student, covid-19, curriculum, anatomy, student medical, major clinical study, adolescent, young adult, undergraduate education, etc.	Education, student medical: (Moro et al., 2017); (Martín-Gutiérrez et al., 2015)
4	Human experiment, knowledge, pilot study, nursing education, nursing student, health education, radiology, etc.	Nursing education: (Uymaz & Uymaz, 2022)

Cluster 1

Santos et al., (2013) discussed that Augmented Reality Learning Experiences (ARLEs) have unique advantages that can influence the learning experience. Development of ARLEs involves hardware, software, and content creation. The current use of ARLEs has an average effect of 0.56 on student performance, but there is wide variation due to different ways of using ARLEs and differences in experimental design. AR technology transforms the learning experience and can provide exciting new experiences that lead to better learning.

Huang et al., (2016) also showed that using AR in field learning and eco-education can enhance students' learning experiences and stimulate positive emotions while helping them develop stronger bonds with the natural environment.

In their research, Ibáñez et al., (2020) stated that augmented reality technology positively impacts the learning outcomes of secondary school students in Mexico. However, the impact varies depending on whether the student is enrolled in a public or private school. The research results show that: (1) there is an interaction between the type of technology, type of school, and assessment time when student achievement scores are measured; (2) students who used augmented reality-based learning environments scored higher in post-tests compared to those who used web-based applications; (3) augmented reality learning environments are more effective in learning compared to web-based learning environments in public schools, but not in private schools; (4) there is no interactive effect between type of technology, type of school, and assessment time when student motivation is measured; (5) students from private schools reported higher levels of motivation compared to those from public schools when using augmented reality learning environments.

Cluster 2

Anton et al., (2018) stated that Augmented Reality (AR) and Virtual Reality (VR) technologies have become more affordable with cheap 3D cameras, mixed reality headsets and 3D displays available in the consumer market. Although this technology has been adopted in the video gaming and entertainment industries, its use for professional purposes, such as in industrial and business settings, healthcare, and education, still lags. 3D systems for communication have been proposed to overcome these limitations; however, very little research has examined performance and interaction with such technologies.

Goh et al., (2021) reviewed the existing literature on applying augmented reality technology to practice planning and intraoperative navigation in knee arthroplasty. This study concludes that augmented reality technology has great potential to improve orthopedic surgical practice, but further research is needed to understand its impact more deeply and evaluate the cost-effectiveness of its use in training and clinical practice. Various potential applications in orthopedic surgery include training and improving surgical skills.

Christopoulos et al., (2022) contribute by guiding how AR-supported interventions can be integrated into medical education and providing empirical evidence on the benefits such approaches can provide to students' academic performance and knowledge acquisition.

Cluster 3

Moro C., Stromberg Z., Raikos A., and Stirling A. (2017) researched to assess whether learning structural anatomy using VR or AR is as effective as tablet-based applications and whether this mode allows for increased



student learning, engagement and performance. The results showed no significant difference between the average VR, AR, or TB assessment scores. However, VR participants were more likely to experience side effects such as headaches, dizziness, or blurred vision during lessons. Nonetheless, VR and AR have the same value in teaching anatomy as tablet devices and promote intrinsic benefits such as increased immersion depth and learning engagement. This shows great potential for the use of virtual and augmented reality as a means to complement course content in anatomy education.

Martín-Gutiérrez et al., (2015) have proven the effectiveness of Augmented Reality (AR) in learning to improve learning quality, overcome practical lab overcrowding, and update teaching methods. AR enables independent learning, reduces lecturers' teaching time, and provides a motivational tool for students. The integration of AR in the curriculum has been successful in an electrical machines course in an electrical engineering program, and the positive results of this research suggest expanding the use of this technology to other programs that teach the same course. It is hoped that AR can increase student motivation and academic performance. Additionally, AR is considered a cost-effective solution for presenting engaging content, and expansion of AR is proposed for other engineering laboratories.

Cluster 4

Uymaz & Uymaz (2022) stated that nursing students believe AR technology will improve their academic performance. Although this study only involved nursing students, the results provide insight into AR technology's potential use in general health education. AR technology that can be accessed via mobile phone provides flexibility and active engagement, which can motivate students. Demand for AR applications is predicted to be high due to their ability to provide holistic teaching and be an alternative to textbooks. Additionally, teachers can use AR for interactive online education, improving students' clinical skills and assisting in training health workers. However, it is important to remember that strong mentorship remains important in nursing education. By utilizing AR technology, teachers can provide a better learning experience for students.

Countries Co-occurrence Analysis

Figure 7 represents the co-occurrence analysis in a country for at least ten documents per country. The total number of countries detected was 44, with 425 links. Six clusters were found, including the United States, Spain and China, representing the largest papers.

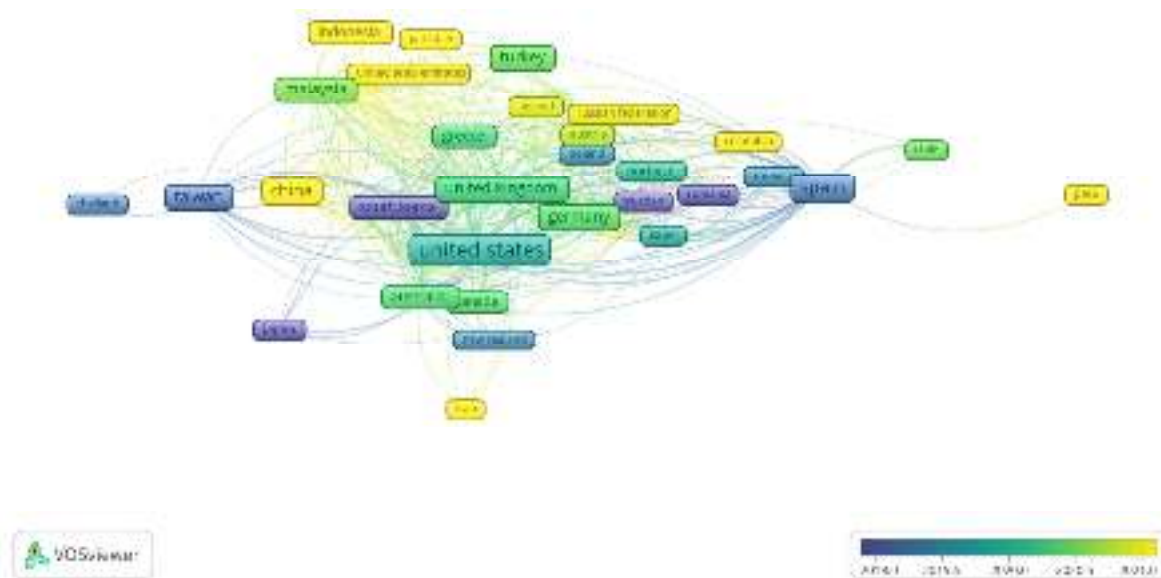




Figure 7. VosViewer Countries Co-Occurrence Analysis

Based on the Vos Viewer analysis, the countries co-occurrence analysis presents the countries where the author's institution is located. Cluster 1 mostly contains Asian countries except the Russian Federation and Serbia. Cluster 2 is mostly from American countries except Switzerland. Cluster 3 shows a more diverse mix of Australia, America (Canada, Hong Kong, Ireland, New Zealand, and South Korea), North America (the United States), East Asia (Japan), and West Asia (Iran). Cluster 4 is made up of European countries (Austria, Cyprus, Finland, Greece, the Netherlands, and the United Kingdom). Cluster 5 is mostly South American countries except Spain. Cluster 6 is East Asian countries (China, Taiwan) and Southeast Asia (Thailand). Most countries with a minimum of 10 documents per country are from America. However, the composition of the cluster shows that there is strong international collaboration between authors from various countries. For more details, see table 4 below.

Table 4. Cluster Countries (Countries with 10 or More Documents)

Cluster	Cluster countries
Cluster 1	India; Indonesia; Kazakhstan; Malaysia, Pakistan, Russian Federation; Saudi Arabia; Serbia; Singapura; Turkey; United Arab Emirates
Cluster 2	Brazil; France; Germany; Israel; Italy; Poland; Portugal; Romania; Sweden; Switzerland
Cluster 3	Australia; Canada; Hong Kong; Iran; Ireland; Japan; New Zealand; South Korea; United States
Cluster 4	Austria; Cyprus; Finland; Greece; Netherlands; United Kingdom
Cluster 5	Chile; Colombia; Mexico; Peru; Spain
Cluster 6	China; Taiwan; Thailand

4. CONCLUSION

Based on the research results, several main findings can be concluded, namely: 1) Distribution of Publications by Year: Research related to augmented reality (AR) in education has experienced a significant increase over time, with the number of publications being low in the early 2000s and increasing rapidly in the following years. Recent years, especially in 2021–2023, This finding is, according to the opinion of previous researchers, that AR has begun to appear significantly in educational applications in the last decade. 2) Distribution of Publications by Country: The United States dominates in the number of educational publications related to AR, followed by Spain and China. These findings reflect the United States' preeminence in AR research and the strong international collaboration between researchers from different countries. 3) Co-occurrence Structure: Analysis of co-occurrence keywords shows that the most frequently discussed topics in the context of AR in education include AR, VR, education, teaching, students, and learning. These findings indicate a strong interest in using AR to enhance learning and teaching experiences. 4) Cluster Analysis: The clustering of research shows that studies of AR in education cover a wide range of topics, including student motivation, interactive learning, student engagement, clinical training, and curriculum development. This shows that AR has great potential to be applied in various educational contexts and scientific disciplines. 5) Co-occurrence Analysis by Country: Co-occurrence analysis by country shows strong international collaboration between researchers from various countries, with the United States dominating the number of publications. This international collaboration reflects the complexity and importance of AR research in education as a global topic.

In connection with the research results and conclusions above, the recommendations from this research are:

- 1) Research shows a significant increase in interest and publications related to AR in education, so it is recommended that this research be further developed. This could include research on the application of



AR in more specific educational contexts, the development of innovative learning methods using AR, and the exploration of AR's potential to improve student learning outcomes.

- 2) Given the diversity of countries involved in AR research in education, it is advisable to encourage more collaboration and international cooperation between researchers from different countries. This can increase the exchange of knowledge and experience and expand the scope of research carried out.
- 3) AR can be an effective tool for enhancing students' learning experiences in various fields of study. Therefore, it is recommended that AR be integrated into formal and informal education curricula at the school and college levels. This will help create a more engaging and technology-oriented learning environment for students.

5. ACKNOWLEDGMENTS

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