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Review Article

Augmented Reality in Higher Education: A Bibliometric Analysis of Research Trends and Evolution from 1997 to 2024

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Abstract
Augmented reality (AR) is a technology that superimposes digital content onto the physical world, blending virtual components like images, videos, and 3D models with real environments. In the realm of higher education, AR-based learning presents significant benefits. This research seeks to examine and illustrate studies on AR in the context of higher education. Data were obtained from the Scopus database, focusing on AR-related publications, which were analyzed and visualized using Biblioshiny. The article selection process in bibliometric analysis followed the PRISMA diagram. The analysis examined various bibliographic factors, including countries, institutions, journals, authors, publications, and frequently co-occurring keywords. A total of 832 articles meeting the inclusion criteria were analyzed, covering the period from 1997 to 2024. Research in this field has expanded significantly, with a notable rise in publications since 2015. The article by Akçayir M, published by Elsevier in the Educational Research Review journal in 2017, has the highest total citations, with 1309 citations. The United States and China emerged as the leading contributors to this area of study. The university with the most publications is led by the University of Bologna in Italy. Key research themes in AR for higher education include education, computer science, and technology. This article also highlights emerging research trends and the evolution of AR concepts in the educational domain, with a particular focus on higher education.

Keywords: Augmented Reality, Bibliometric Analysis, Higher Education, Research Trends

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1. INTRODUCTION

The advancement of digital technology is an inevitable aspect of life, as it brings significant positive benefits to various aspects of life, including education (Bandara & Jayaweera, 2024; Chasokela, 2025; Handayani, 2024; Ngafifi, 2014; Susanto et al., 2024; Umar & Tilli, 2025; Yulita, 2024). Technological progress has introduced various innovations in teaching and learning activities, such as artificial intelligence (Chasokela, 2025), which enhances understanding tailored to students' needs and abilities and improves learning outcomes (Holmes et al., 2019). Advancements in technology have broadened access to education through e-learning platforms (Means et al., 2013) and enhanced interactivity by integrating augmented reality (AR) technology (Mustaqim, 2016). AR technology makes learning materials more engaging, easier to comprehend, interactive, and efficient (Akçayır & Akçayır, 2017). Consequently, incorporating technology in education fosters a more interactive and collaborative learning environment, effectively addressing the individual needs of students.

Contemporary technologies such as augmented reality (AR) allow for the embedding of digital content into physical surroundings (Castañeda et al., 2018; Mustaqim, 2016). AR bridges the gap between virtual and physical realms, embedding virtual elements like images, videos, and 3D objects into real-world environments. As noted by Dutta et al., (2022), AR enhances interactivity and engagement by displaying 3D virtual objects in a dynamic manner. This rapidly advancing technology has found applications in higher education, where it offers immersive learning experiences. Devices like smartphones and tablets enable the

fusion of virtual elements with the real world, resulting in powerful and memorable learning experiences (Triansyah et al., 2023).

The incorporation of AR in teaching and learning processes improves students' understanding of the material (Akçayır & Akçayır, 2017). It also aids in simplifying complex concepts through interactive and visual learning, sharpening critical thinking, and enhancing skill development (Akçayır & Akçayır, 2017). AR technology provides additional benefits, such as boosting computational thinking, improving concentration, enhancing visualization skills, and creating a memorable learning experience (Hanid et al., 2022; Santos et al., 2016). Moreover, it promotes teamwork and facilitates collaborative discussion skills among students (Sarkar et al., 2020).

As an emerging technology in education, augmented reality (AR) has attracted considerable interest from researchers (Zuo et al., 2025), especially in higher education. Ongoing studies examine how AR improves the learning process, enhances material comprehension, and increases student engagement. Consequently, a thorough analysis of the evolution of topics and research trends surrounding the application of AR in higher education is crucial.

This study seeks to examine articles on augmented reality (AR) in higher education through bibliometric analysis. This method enables researchers to evaluate publication trends, quantitatively analyze articles in the field, assess article citations, examine author contributions to AR research, and identify recurring themes in AR-related studies in higher education (Donthu et al., 2021; Zhang et al., 2019; Zyoud et al., 2023). By conducting this analysis, the progression of AR research can be mapped, offering valuable insights for future studies and benefiting researchers, educational institutions, and educators alike.

To highlight the progress of research on augmented reality (AR) in higher education, several key questions are addressed:

1. What are the key information and recent developments in the literature on augmented reality?
2. Who are the researchers involved, and what are the titles of the sources in the augmented reality literature?
3. What are the reviews of the most cited articles, the geographical distribution of publications, and the trends in international collaboration within AR research?
4. Which countries and institutions are the most productive contributors to the field of augmented reality?

2. METHODS

This study utilizes a bibliometric analysis approach, which is a systematic examination of scientific literature designed to reveal patterns, trends, and impacts within a specific field (Passas, 2024). Bibliometric analysis is employed to evaluate research (Mongeon & Paul-Hus, 2016). Through this method, it is possible to assess the productivity (publications) and influence (citations) of research (articles), as well as the contributions of authors, institutions, countries/regions, funders, and research fields within a discipline (Lim & Kumar, 2024).

The initial step in conducting a bibliometric analysis involves utilizing a bibliographic database that provides relevant information about scientific publications, including titles, authors, abstracts, keywords, and references. Two prominent databases frequently used by researchers for discovering and indexing scientific journals are WoS (Web of Science) and Scopus. Scopus was selected for this study because it is widely recognized as one of the largest citation and abstract databases, offering extensive coverage of scientific journals, conference proceedings, books, citations, institutions, and h-index results. Scopus is particularly valuable due to its broad journal coverage and up-to-date data, especially in rapidly evolving fields such as computer science, information technology, and medicine. It also enables searches in various languages beyond English, allowing for the inclusion of journals from multiple countries. Furthermore, Scopus features an intuitive interface designed for beginners and allows for customizable sorting of search results (Aghaei Chadegani et al., 2013; Archambault et al., 2009; Bhat, 2023; Mongeon & Paul-Hus, 2016; Salisbury, 2009). Additionally, Scopus supports various formats and platforms for bibliometric data analysis, facilitating the examination of publication trends, citation analysis, and international collaborations (Ball, 2017).

Between Scopus and WoS, the choice depends on the specific needs of the researcher. Scopus was selected because it offers broader coverage, faster indexing processes, and is considered more user-friendly, especially for researchers outside the natural sciences or those requiring access to non-English journals.

2.1. Process and Method of Article Selection

The article selection process in bibliometric analysis follows the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) flow diagram (Figure 1). The PRISMA framework is used for systematic literature reviews, guiding data collection and applying keyword restrictions to narrow the literature (Khan & Wyrwa, 2024). Key elements of the PRISMA flow diagram include the number of studies identified through database searches, those excluded, and the studies ultimately included in the analysis (Page et al., 2021). The PRISMA flow diagram includes the following stages: identification, screening, eligibility, and inclusion (Albhirat et al., 2024).

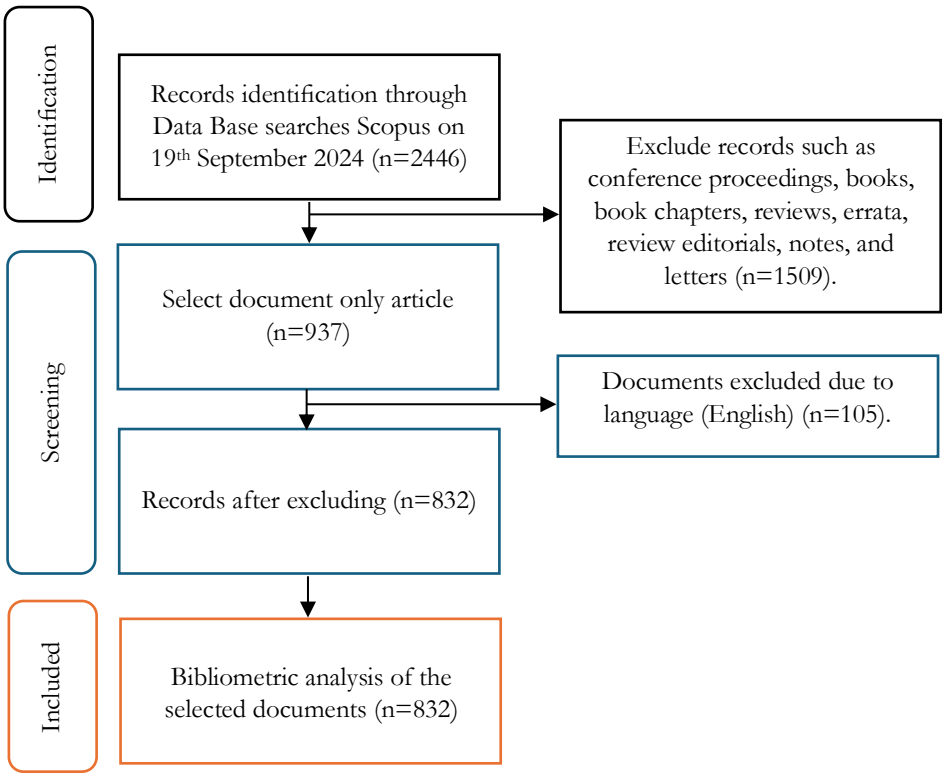

Figure 1. Process and Method of Article Selection

The bibliographic data extraction from Scopus took place on September 19, 2024, initially identifying 2,446 documents related to augmented reality using the specified keywords "augmented reality" AND "higher education" OR "university." Based on Moreno et al. (2024), the selection process started by filtering publications within the years 1997 to 2024, focusing exclusively on articles. This choice was made because articles are the most prevalent and representative form of scientific publication, often containing original research findings suitable for analysis and comparison using bibliometric methods and indicators. The process further narrowed the selection to articles written in English (n=832) from an initial pool of 937. Following the screening, a bibliometric analysis was performed on the final set of 832 articles.

2.2. Data Analysis

The extracted documents were saved in an Excel (.csv) file and subsequently exported for bibliometric analysis. The file was analyzed descriptively in line with the research questions posed. The data were visualized using Biblioshiny software, version R 4.4.1. The use of R software includes various information such as author names, document titles, journals, publication years, page numbers, citation counts, author affiliations, abstracts, author keywords, references, document types, and author addresses

(Bhat, 2023). Afterward, the file was imported into R Studio. Functions available within the application were applied to generate descriptive and graphical bibliometric results (Aria et al., 2022).

3. RESULTS AND DISCUSSION

3.1. Key Information

Table 1 provides key information from the augmented reality literature sourced from the Scopus database. Research in this field has been published by various publishers between 1997 and 2024. The study included 832 articles from 484 sources for bibliometric analysis. A total of 2,973 authors contributed to these 832 articles on augmented reality. The average number of citations per document is 20.67, and the total number of keywords used amounts to 2,513.

As shown in Figure 2, the number of publications on augmented reality has significantly increased each year. Augmented reality research continues to develop across various fields, using diverse keywords to drive innovation and open new opportunities for more creative discoveries within the scientific community.

Tabel 1. Main Information of Bibliometric Data

Description	Results
Main Information About Data	
Timespan	1997:2024
Sources (Journals, Books, etc)	484
Documents	832
Annual Growth Rate %	20.3
Document Average Age	3.85
Average citations per doc	20.67
References	33774
Document Contents	
Keywords Plus (Id)	3214
Author's Keywords (DE)	2513
Authors	
Authors	2973
Authors of single-authored docs	101
Authors Collaboration	
Single-authored docs	104
Co-Authors per Doc	3.92
International co-authorships %	20.19
Document Types	
Article	832

3.1.1 Publication Trends

The beginning of publications is shown in Figure 2 (year 1997), but in the following year, 1998, the number of publications was 0 (zero). Then, from 2003 to 2015, the number of publications fluctuated, with several years showing relatively high publication numbers (2009 with 8 publications, 2012 with 16 publications, and 2014 with 20 publications). Finally, from 2016 onward, the number of publications on augmented reality experienced a notable rise, continuing through 2024. This reflects an increasing interest in the topic among researchers and scientists.

Price's Law is used as a metric to assess research productivity in a particular field by examining the exponential growth of scientific output (Egghe, 1994; López-Muñoz et al., 2015). The bibliometric analysis reveals that a small group of authors contributes to half of all the literature on augmented reality, despite the larger total number of authors in the field (Nicholls, 1988). Price's Law is applied to validate the distribution of author publications (Thirumagal et al., 2020). The growth of AR publications shows an exponential value (r-square value) from the analyzed data. In Figure 2, an R^2 value of 0.6522 was obtained, indicating a slight increase in the number of publications on augmented reality over the past 26 years (López-Muñoz et al., 2015).

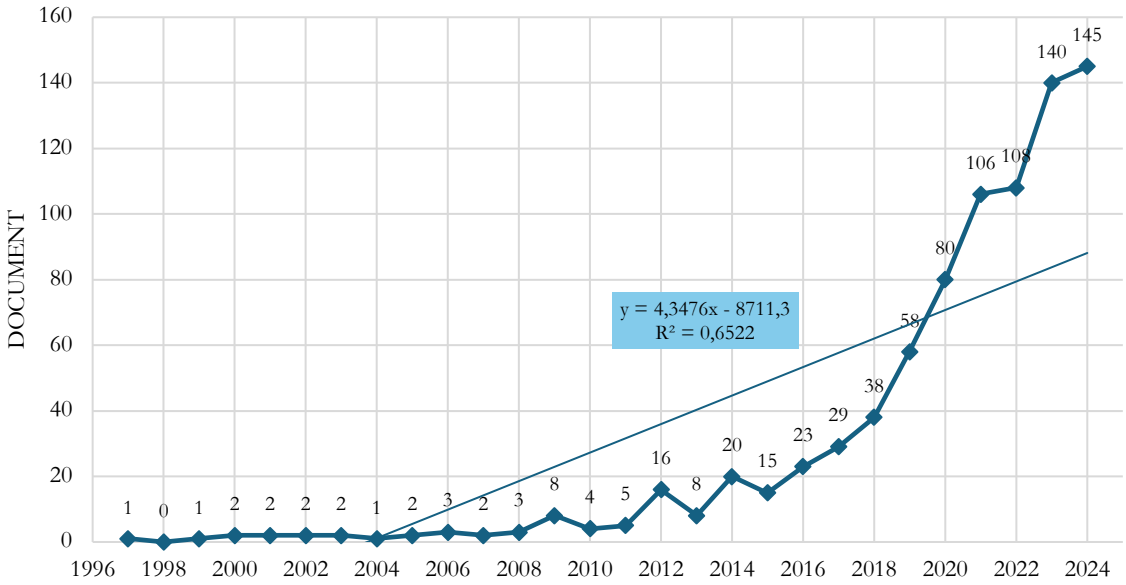

Figure 2. Annual Publications of Articles on Augmented Reality

Figure 3 shows the average number of citations per year for research on augmented reality from 1997 to 2024. The graph indicates that annual citations sharply increased from 1997 to 2000, peaking in 2000 with an average citation count of over 125.5. Afterward, it rapidly decreased in 2002. The graph then shows a gradual increase, peaking again in 2010 with an average citation count of over 85.75, followed by a gradual decline in annual citations. Annual citations have been on the rise since 2015, but citations in 2024 are much lower compared to those in 2000.

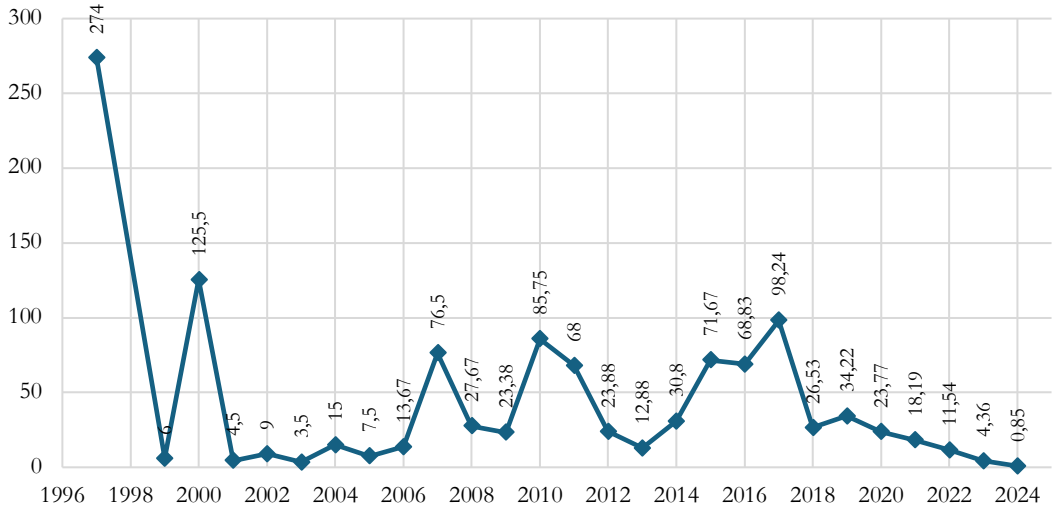

Figure 3. Average Annual Citations Related to Augmented Reality (1997-2024)

However, this graph only shows the average, so there is a possibility that the decline in average citations is due to several factors, such as a decrease in research interest in augmented reality because new trends have emerged in the technology field, the quality of research in augmented reality has declined, leading to fewer citations, changes in citation methods making it harder to track citations accurately, and a decrease in the need to refer to previous research (Adiprasetio, 2022; Shen et al., 2024).

3.1.2. Thematic Development

The Sankey diagram in Figure 4 illustrates the development related to keywords (right area), authors (middle area), and publication sources (left area). The characteristic of the Sankey diagram is that it depicts

the quantitative relationships of various information flows with the main themes (de-Córdoba & Molinari, 2022). The likelihood of success is seen from the width of the flow, such as the keyword "augmented reality" (first right area), which is more prominent compared to other keywords used in the publications.

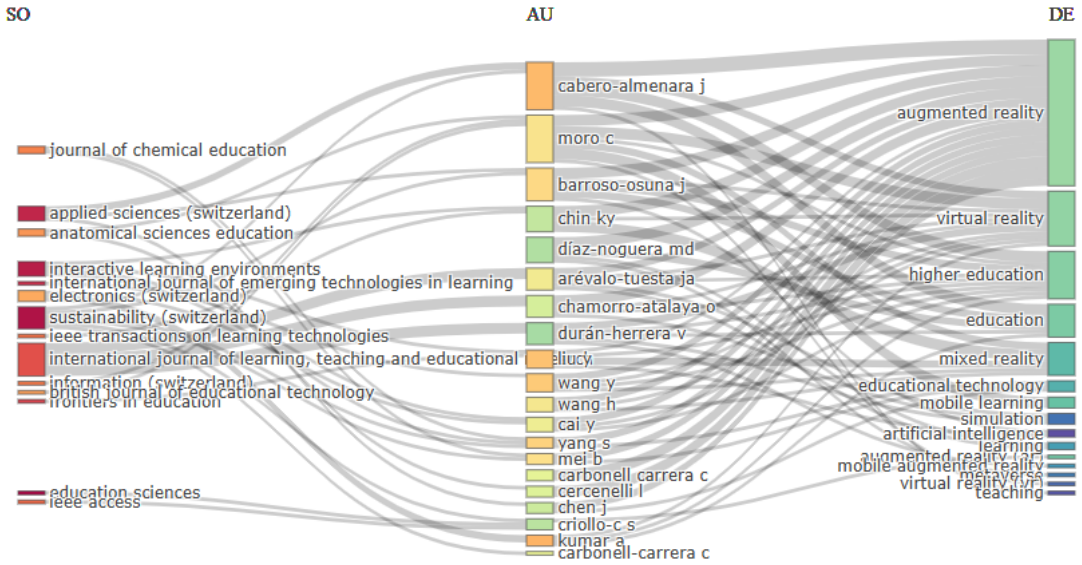

Figure 4. Thematic Development of Augmented Reality Research using Sankey Diagram

3.2. Researcher Profile and Source Titles

3.2.1. Top Authors

In research, an author's productivity can be evaluated by examining the number of works they have produced over a given period, whether individually or in collaboration with other authors (Rohanda & Winoto, 2019).

Table 2. List of Top Authors and Their Impact in Augmented Reality Research

Authors	Articles	Articles Fractionalized	h_index	TC
Kumar A	7	1.01	5	47
Cabero-Almenara J	5	1.75	5	305
Liu Y	5	1.24	3	17
Wang Y	5	1.01	3	104
Yang S	5	2.08	4	145
Barroso-Osuna J	4	1.17	4	295
Li J	4	1.83	1	22
Mei B	4	1.83	4	144
Moro C	4	0.95	3	769
Arévalo-Tuesta Ja	3	0.31	1	3

Author productivity and impact are typically measured through the number of publications and citations, represented by the h-index (Hirsch, 2005). Table 2 lists the top ten authors in augmented reality literature. Kumar, A is identified as the most productive author, with 7 articles, and has a notable impact with an h-index of 5 and a total of 47 citations. Following Kumar, Cabero-Almenara J published 5 articles, garnering more citations than Kumar, with a total of 305 citations and an h-index of 5. However, Moro, C stands out for having the highest citation count, with a total of 769 among the ten authors.

The article written by Moro C has a high citation count of 769. According to De Groote et al., (2023), factors contributing to the high citation count include the author's collaboration with other researchers, the high quality of the research leading to greater interest from other authors, and the novelty or theme being analyzed having a significant impact (Tahamtan et al., 2016).

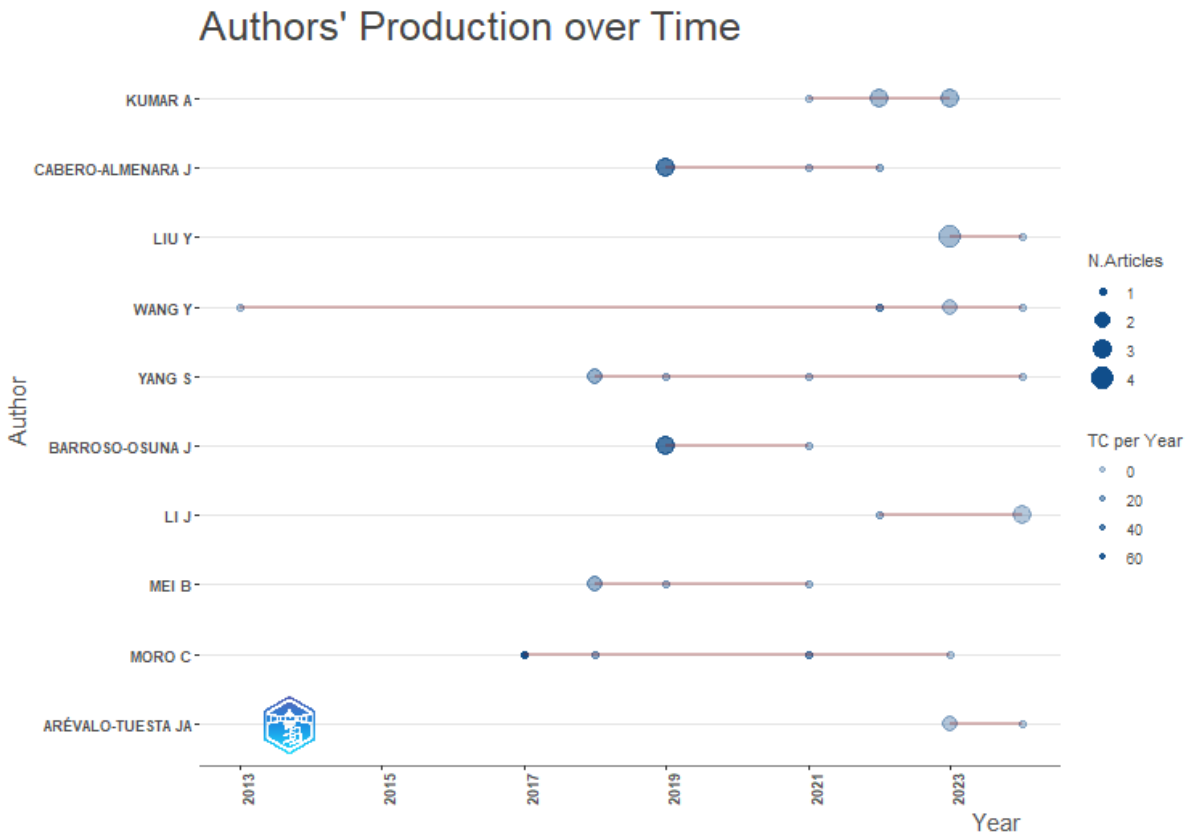

Figure 5. Top Author Production Over Time

Figure 5 presents the publications of top authors over a specific period. Wang, Y appears consistent as an author publishing works on augmented reality since 2013. The article disscussion about explores how augmented reality (AR) can enhance learning by making it more interactive and personalized to meet the individual needs of each student, not just in primary and secondary education but also in higher education, with the ARICE framework utilizing AR to improve learning outcomes (Wang et al., 2013). This was followed by Moro et al., (2017), the article explores how learning anatomy using VR, AR, and tablets yields similar knowledge outcomes while offering additional benefits such as increased student engagement and great potential as a tool for anatomy education. Subsequently, the author Yang & Mei (2018) the article explores the use of AR in language learning, providing insights into learners' perceptions and experiences throughout the process. It is important to note, however, that the majority of leading authors started their research on augmented reality in 2018, reflecting an increasing interest in this subject within the educational sector.

Figure 6 shows that few authors write many articles, while the majority of authors write only a few articles. This is demonstrated by author productivity following Lotka's law, which asserts that the number of authors producing n articles is inversely proportional to $1/n^2$ (Coile, 1977), describes a mathematical relationship that explains how authorship is distributed across a population of researchers, with fewer authors contributing a large number of works (Shen et al., 2024). Applying Lotka's Law effectively identifies the 'core authors' who consistently produce a large volume of works (Coile, 1977). This figure shows that there are approximately 2,743 authors, representing 92.3% of the total, who each published only one research article. There are 187 authors, representing 6.3% of the total, each publishing two articles. Next, 34 authors, representing 1.1% of the total, each published three articles. Then, around 4 authors each published 4-5 articles, and finally, one author published seven articles.

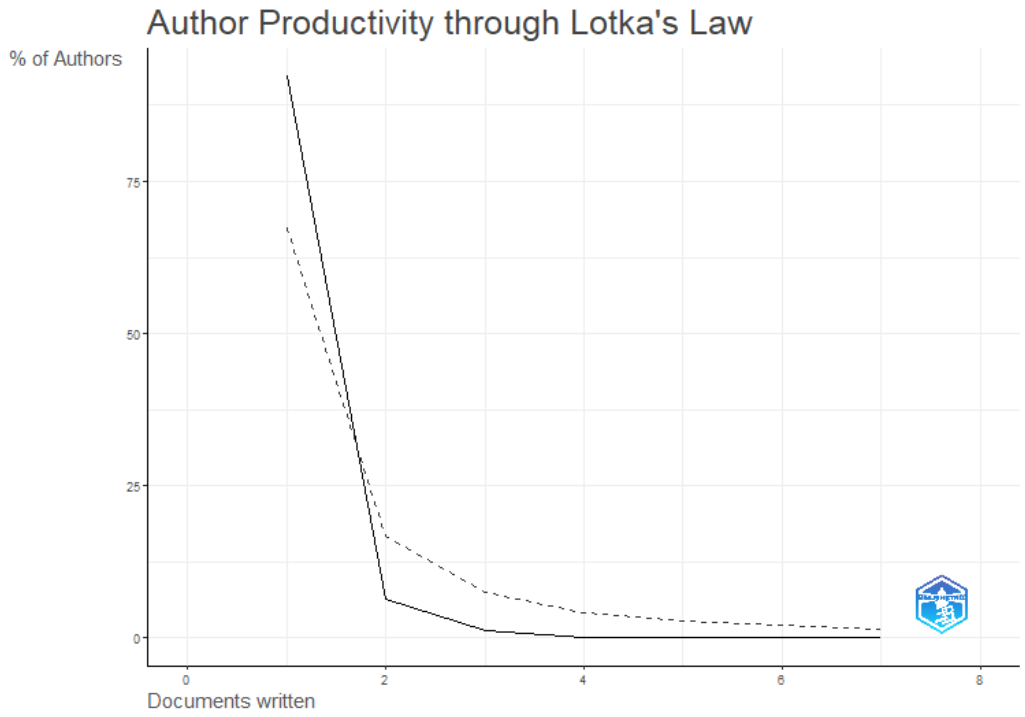

Figure 6. Author Productivity Through Lotka's Law

3.2.2. Main Sources

The most influential sources are shown in Table 3, which indicates that the *Education and Information Technologies* journal, published by Springer, ranks first with 21 articles on augmented reality, an h-index of 10, and the highest total citations of 550. This journal began publishing in 2000.

Table 3. Top Sources and Their Local Impact

Sources	N	Cite Score (2023)	h_index	g_index	m_index	TC	PY_start
Education And Information Technologies	21	10.0	10	21	0.4	550	2000
Education Sciences	19	4.8	8	14	1.6	222	2020
Sustainability (Switzerland)	16	6.8	8	16	1.3	378	2019
Interactive Learning Environments	14	12.1	9	14	1.5	217	2019
International Journal of Interactive Mobile Technologies	14	5.2	6	8	0.9	90	2018
Applied Sciences (Switzerland)	13	5.3	8	13	1.1	345	2018
International Journal Of Emerging Technologies In Learning	13	N/A	9	13	0.8	201	2013
Frontiers In Education	12	2.9	5	7	1	64	2020
Computer Applications In Engineering Education	9	7.2	6	9	0.7	126	2016
International Journal Of Learning, Teaching And Educational Research	8	2.1	2	3	0.4	12	2020

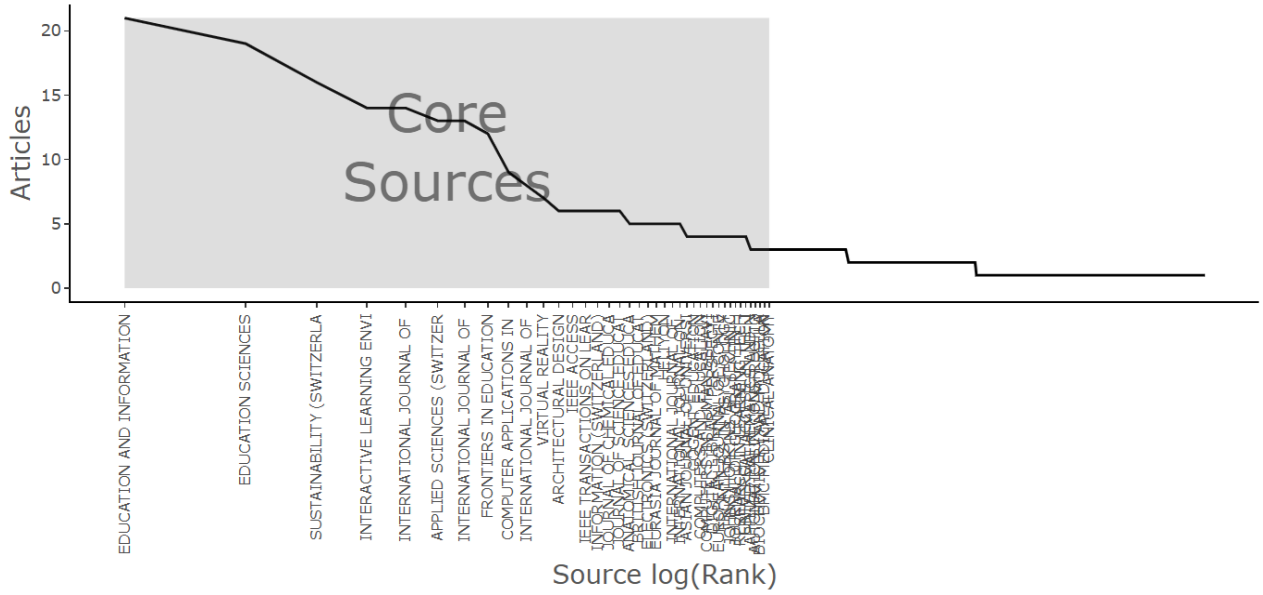

Figure 7. Bradfords Law

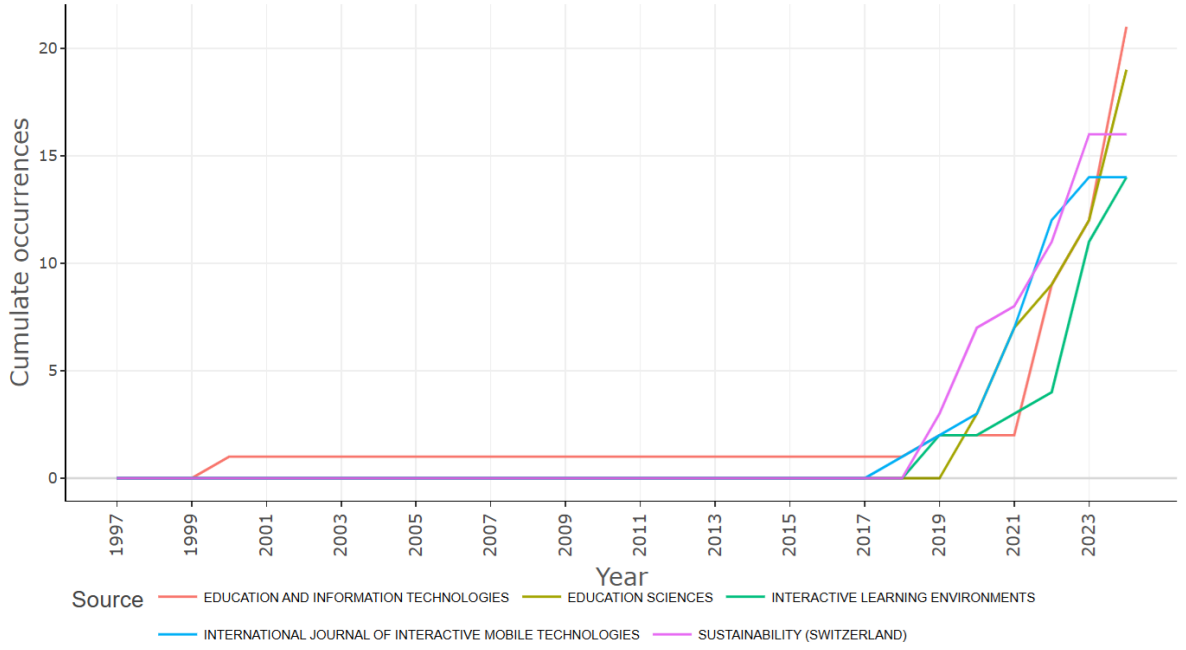

Figure 8. Top Sources Publication Growth

Figure 7 illustrates the shaded area as the first zone according to Bradford's Law, which encompasses the most significant and influential studies on the topic. This zone represents the primary sources for writing and publishing articles related to augmented reality (Delcea et al., 2024). The top five journals with the highest publication numbers are Education and Information Technologies (published by Springer in Germany), Education Sciences and Sustainability (published by MDPI in Switzerland), Interactive Learning Environments (published by Taylor & Francis in the UK), and International Journal of Interactive Mobile Technologies (published by IFEES in the USA). These journals are crucial in disseminating important research and new developments in augmented reality.

Figure 8 highlights the cumulative number of publications across different journals from 1997 to 2024. The five journals featured in the figure are Education and Information Technologies, International Journal of Interactive Mobile Technologies, Education Sciences, Interactive Learning Environments, and Sustainability (Switzerland). Among them, Sustainability (Switzerland) and Education Sciences have

consistently published fewer articles compared to the other journals shown in the graph. Meanwhile, Interactive Learning Environments has seen a significant rise in publications in recent years. International Journal of Interactive Mobile Technologies also experienced an uptick in publications starting in 2020, and Education and Information Technologies has shown a steady increase since 2021.

3.3. Most Influential Literature

Table 4 presents a list of the most cited articles in augmented reality research. The article by Akçayir M, published by Elsevier in the *Educational Research Review* journal in 2017, has the highest total citations, with 1309 citations. The article, discusses the application of augmented reality (AR) in education is examined by exploring various factors such as learner types, the technologies employed, and the associated benefits and challenges. AR has been shown to enhance learning outcomes, but the primary obstacles include difficulties in its implementation and technical limitations (Akçayır Akçayır, 2017).

Additionally, the article by Potkonjak et al., (2016) holds the second-highest total citations with 604. This article, published by Elsevier in the *Computers and Education* journal, the article addresses the growing popularity of distance learning, while noting that fields like science, technology, and engineering continue to face challenges due to the need for hands-on laboratory exercises. Emerging technologies such as virtual reality and augmented reality provide solutions by enabling virtual laboratories. However, there is also an article with a lower total citation count of 220 by (Papanastasiou et al., (2019). This article, published by Springer in the *Virtual Reality* journal, discusses how virtual reality (VR) and augmented reality (AR) technologies can help enhance student learning and develop 21st-century skills. VR/AR has proven capable of complementing traditional curricula by providing more immersive, interactive learning experiences that engage multiple senses.

Table 4. Most Highly Cited Augmented Reality Paper from 1997 to 2024

Rank	TC	TC per Year	Author(s)	Year	DOI	Source
1	1309	163.63	Akçayir M	2017	10.1016/j.edurev.2016.11.002	Educ Res Rev
2	604	67.11	Potkonjak V	2016	10.1016/j.compedu.2016.02.002	Comput Educ
3	550	68.75	Moro C	2017	10.1002/ase.1696	Anat Sci Educ
4	391	43.44	Akçayir M	2016	10.1016/j.chb.2015.12.054	Comput Hum Behav
5	303	30.30	Martín-Gutiérrez J	2015	10.1016/j.chb.2014.11.093	Comput Hum Behav
6	274	9.79	Feiner S	1997	10.1007/BF01682023	Pers Ubiquitous Comp
7	260	17.33	Martín-Gutiérrez J	2010	10.1016/j.cag.2009.11.003	Comput Graphics (Pergamon)
8	255	42.50	Khan T	2019	10.1155/2019/7208494	Adv Hum Comput Interact
9	243	9.72	Kaufmann H	2000	10.1023/A:1012049406877	Educ Inf Technol
10	220	36.67	Papanastasiou G	2019	10.1007/s10055-018-0363-2	Virtual Reality

3.4. Top Countries and Affiliations

The number of citations used in an article reflects its quality (Aksnes et al., 2019; Bauer et al., 2016). The greater the number of citations, the more the article is favored and referenced in other research (Aulianto, 2012). The countries with the highest number of citations also correspond to those with the highest number of scientific publications. The top ten countries listed in Table 5 exhibit the most publications and citations, spanning across four continents. Europe (n=608) with a total citation (TC) of 3544 includes Spain, the UK, Germany, and Italy. This is followed by Asia (n=678) with a TC of 2056, including China, Malaysia, Indonesia, and Japan. Next is North America (n=399) with a TC of 1708, represented by the USA, and Australia (n=99) with a TC of 1131, represented by Australia.

Table 5. Countries with the Highest Number of Documents and Citations

Country	Frequency	Total Citations	Average Article Citations
USA	399	1708	25,1
China	361	1656	16,9
Spain	257	2465	44,0
Italy	133	382	18.2
Malaysia	124	211	7.0
Indonesia	115	108	6.0
UK	115	372	12.8
Germany	103	325	19,1
Australia	99	1131	51.4
Japan	78	81	7.4

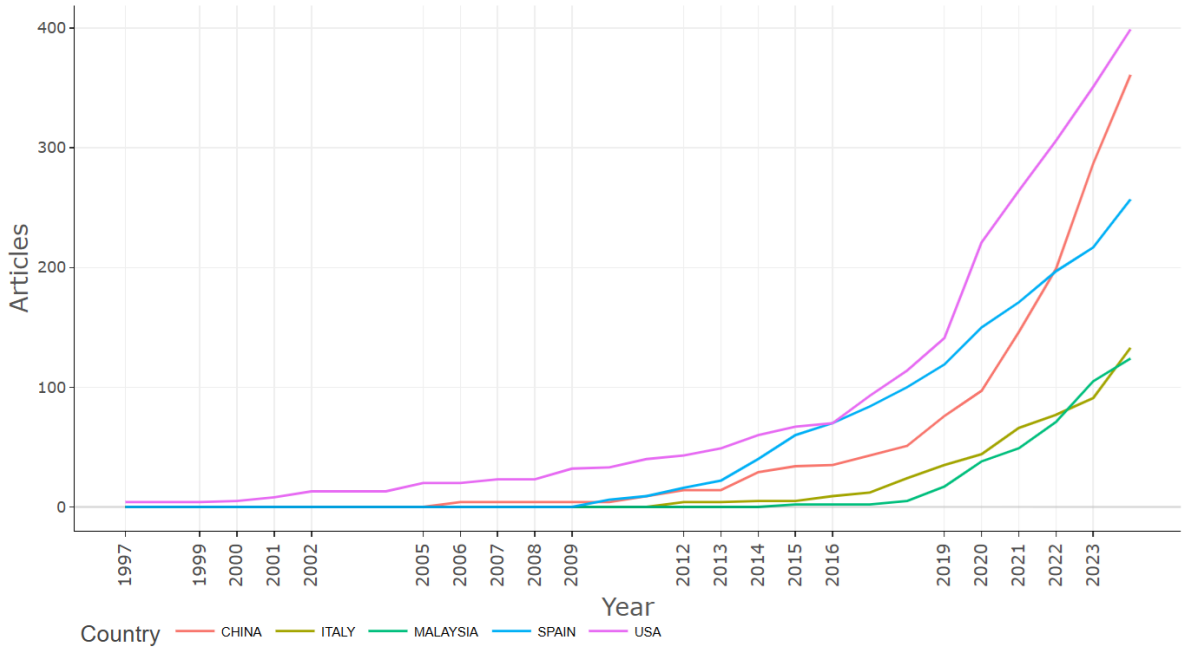

Figure 9. Document Growth of Augmented Reality by Country

Figure 9 shows the development of the number of articles on augmented reality in several leading countries from 1997 to 2024. The first article on AR appeared in 1997 (n=4) from the USA. One of these articles, by Feiner et al. (1997), discusses a prototype system that combines 3D AR technology with wireless mobile devices using internet connections.

Between 1997 and 2008, the number of articles published by the top five countries steadily grew, with the USA, China, Italy, Malaysia, and Spain leading the way. In contrast, the number of articles from other countries remained relatively stable, with fewer than 20 publications. The United States maintained a dominant position, publishing significantly more articles than any other country. China then emerged as the second leader from 2018, followed by Spain and the USA. The number of articles published in China sharply increased starting in 2019. Italy continued to show slow growth, while Malaysia exhibited gradual increases. Of all the countries shown, Spain experienced the fastest increase in articles published during 2013 and 2014.

The "Top Affiliations" (Figure 10) highlights the top 10 universities most closely associated with the field of augmented reality. These affiliations not only contribute a significant number of articles but also exhibit a high level of productivity in augmented reality research (Delcea et al., 2024). The five universities with the most publications are led by the University of Bologna in Italy (N=32), leading with the most publications, followed by Al Ain University from the United Arab Emirates (N=24) and Nanyang Technological University from Singapore (N=23). Next, Universitas Negeri Padang from Indonesia and the University of Seville from Spain each have 19 articles.

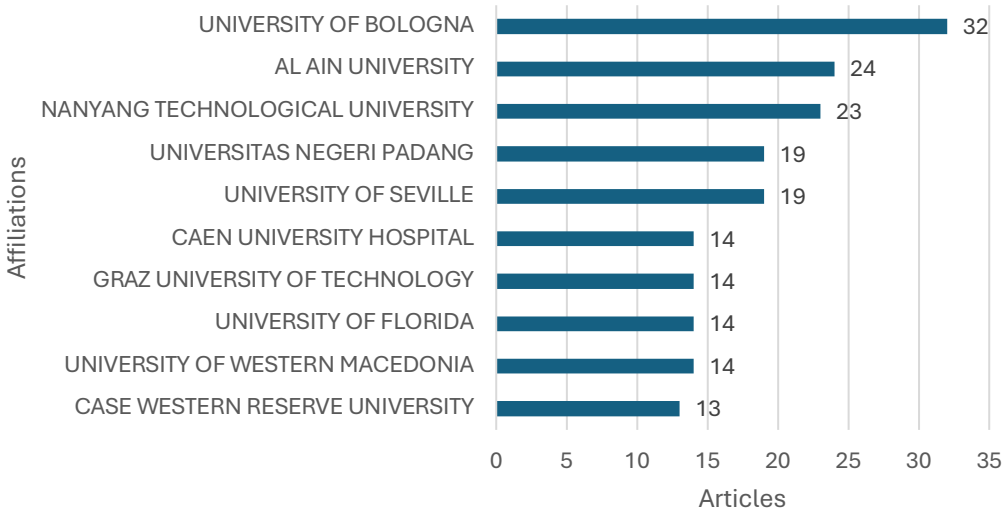

Figure 10. Top Affiliations

The first university to affiliate and publish an article is Nanyang Technological University (NTU) in 2006, which discusses the use of augmented reality (AR) in human-robot interaction to help reduce errors in task execution. Furthermore, AR provides real-time feedback that can help address time-delay issues, making robot operations more efficient and responsive (Xiong et al., 2006). This article, published by Cambridge University Press in 2006, is associated with Huazhong University of Science and Technology, which is based in Wuhan, China.

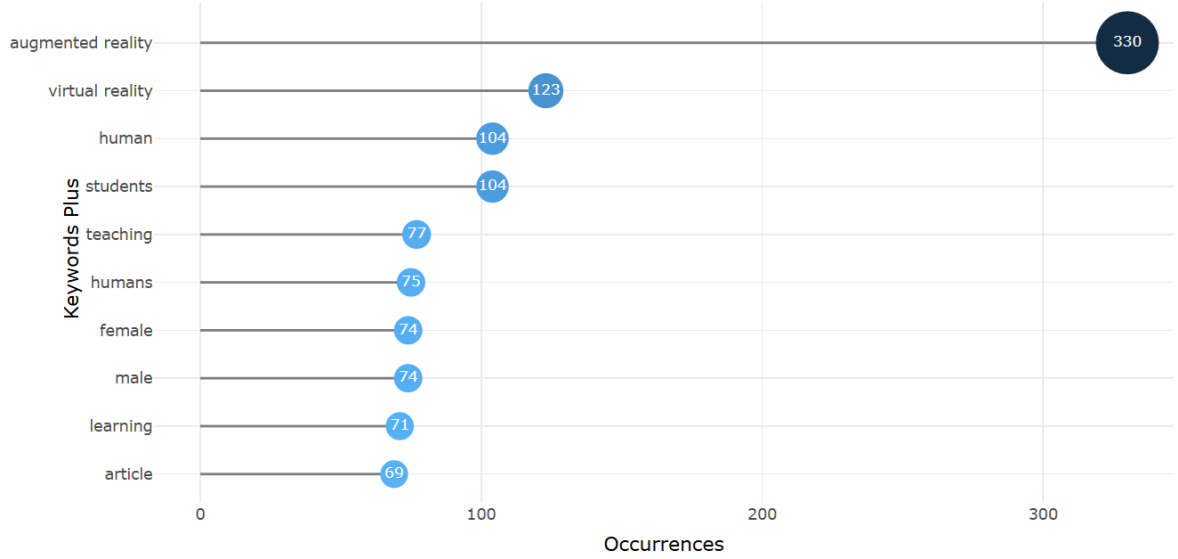

Figure 11. Most Frequent Words

Figure 11 shows the frequency of keywords related to augmented reality research. The top five most frequently used keywords are: first, "augmented reality" with 330 occurrences, followed by "virtual reality" with 123 occurrences. Other regularly used keywords include "human" and "students," each with 104 occurrences. Meanwhile, the keyword "teaching" appears 75 times. This diagram can be used to understand the topic of augmented reality and the most relevant associated keywords.

Figure 12 shows the usage of terms in AR research from 1997 to 2023. The increase in keywords displayed in the figure indicates that "augmented reality" has experienced significant growth since 2008. This is followed by a second increase with the term "virtual reality." This indicates a growing interest and research in the field.

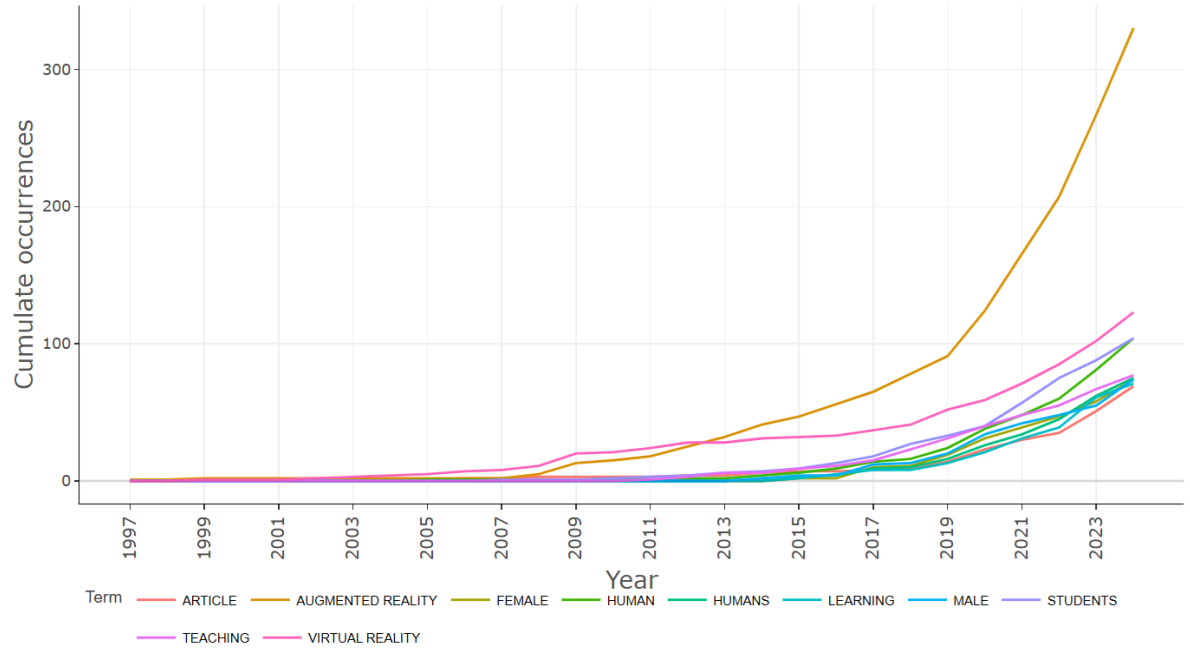

Figure 12. Words' Frequency Over Time

3.5. Knowledge Structure Analysis

3.5.1. Conceptual Structure

Figure 13 presents a visualization of the relationships between keywords across various publications. This network consists of three major groups, with each group representing a set of interconnected terms, indicating the dominant themes and directions of research (Ananda et al., 2024). The first group, in red, represents concepts related to augmented reality such as 'anatomy', 'simulation training', 'procedures', 'humans', 'medical education', 'surgery', 'computer simulation', etc. The second group, in green, represents more in-depth concepts related to augmented reality such as 'technology', 'teaching', 'virtual reality', 'augmented reality', and 'students'. Finally, the third group, in blue, represents concepts linked to the applications and implications of augmented reality, such as 'educational technology', 'higher education', 'e-learning', 'visualization', 'surveys', 'curricula', 'augmented reality technology', 'augmented reality application', 'mixed reality', etc."

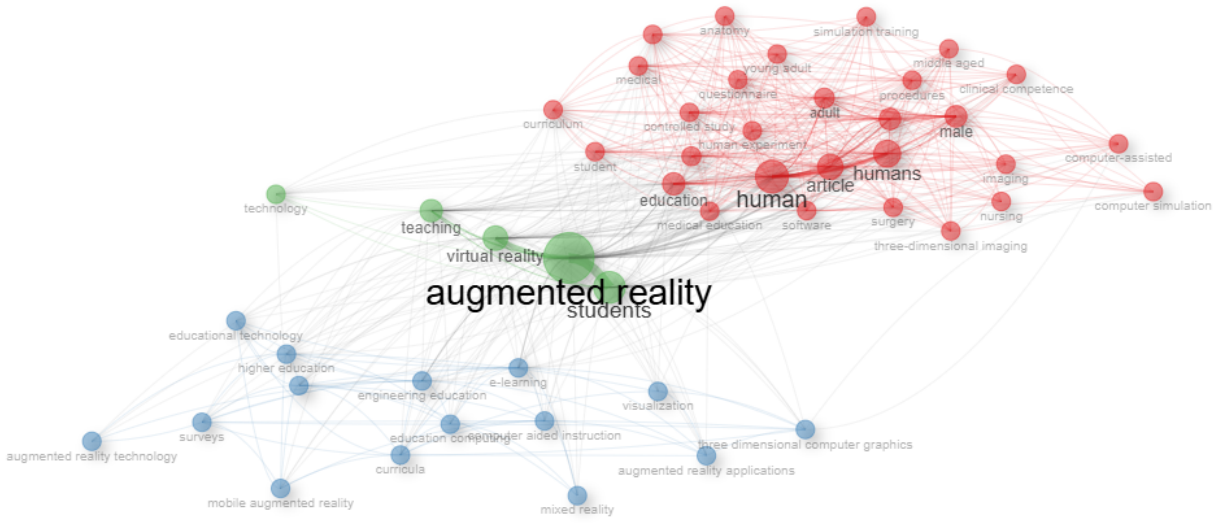

Figure 13. Co-Occurrence Network

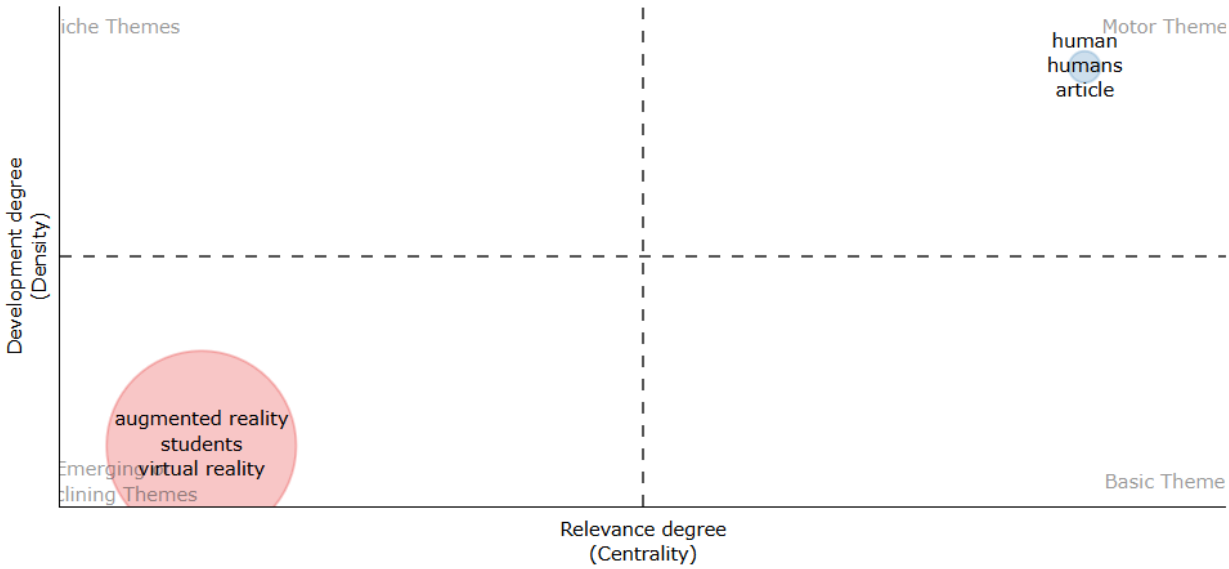

Figure 14. Thematic Map

The thematic map (Figure 14) in the bibliometric analysis, created using Biblioshiny, provides a visualization that organizes and displays the frequency and interest of keyword occurrences across all the reviewed literature (Necula et al., 2024). This map is divided into four quadrants based on two key indicators: relevance degree and development degree (Shen et al., 2024). Each group in the map is formed by how frequently keywords appear together in the literature, signifying a thematic connection or shared research focus.

According to Shen et al., (2024), The bibliometric analysis highlights themes in the first and third quadrants. The themes in the first quadrant, referred to as "mainstream" or "dynamic" due to their high research activity and well-established frameworks, include "human," "humans," and "articles." These themes represent key areas in current research with the potential to influence future developments. Themes in the third quadrant, such as "augmented reality," "students," and "virtual reality," are still in the early stages of exploration, indicating they may either evolve into new fields or require further study.

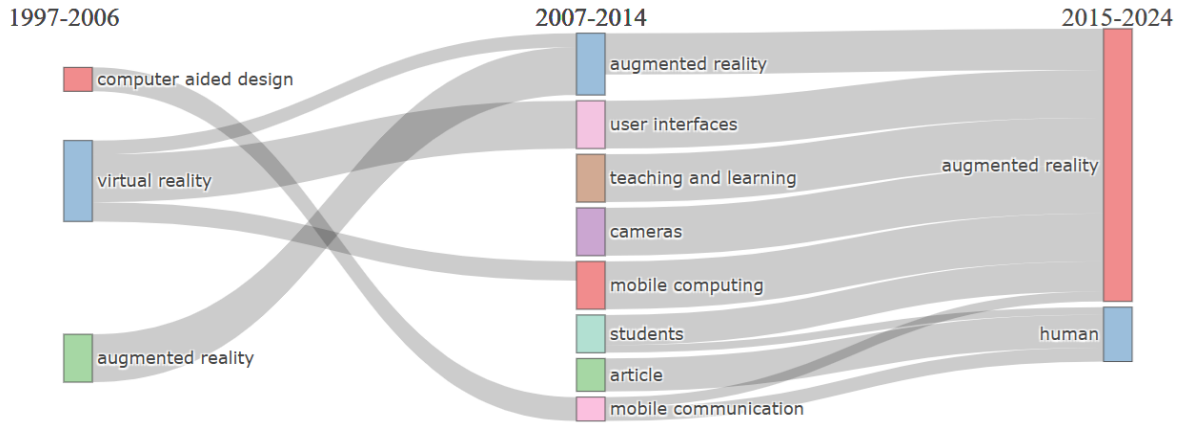

Figure 15. Thematic Evolution

Figure 15 shows the thematic evolution of the augmented reality topic from 1997 to 2024. According to Necula et al., (2024), the image helps visualize how the main themes have developed and the increasing breadth of this interdisciplinary field. Each color represents a different group of topics or research themes. The size of these colored groups indicates the amount of publication and research activity that has occurred in the topic over a specific period (Necula et al., 2024). Overall, these changes show that research in the development of augmented reality continues to evolve. The research topics have evolved from 1997 to 2024. From 1997 to 2006, research focused on 'computer-aided design,' 'virtual reality,' and 'augmented

reality.' Then, from 2007 to 2014, the research focus expanded to include 'user interface,' 'teaching and learning,' 'cameras,' 'mobile computing,' 'students,' 'articles,' and 'mobile communication.' Finally, from 2015 to September 2024, the research focus shifted toward 'augmented reality' and 'human.' This development in the topic shows that research continues to grow and adapt to new technologies in line with societal needs.

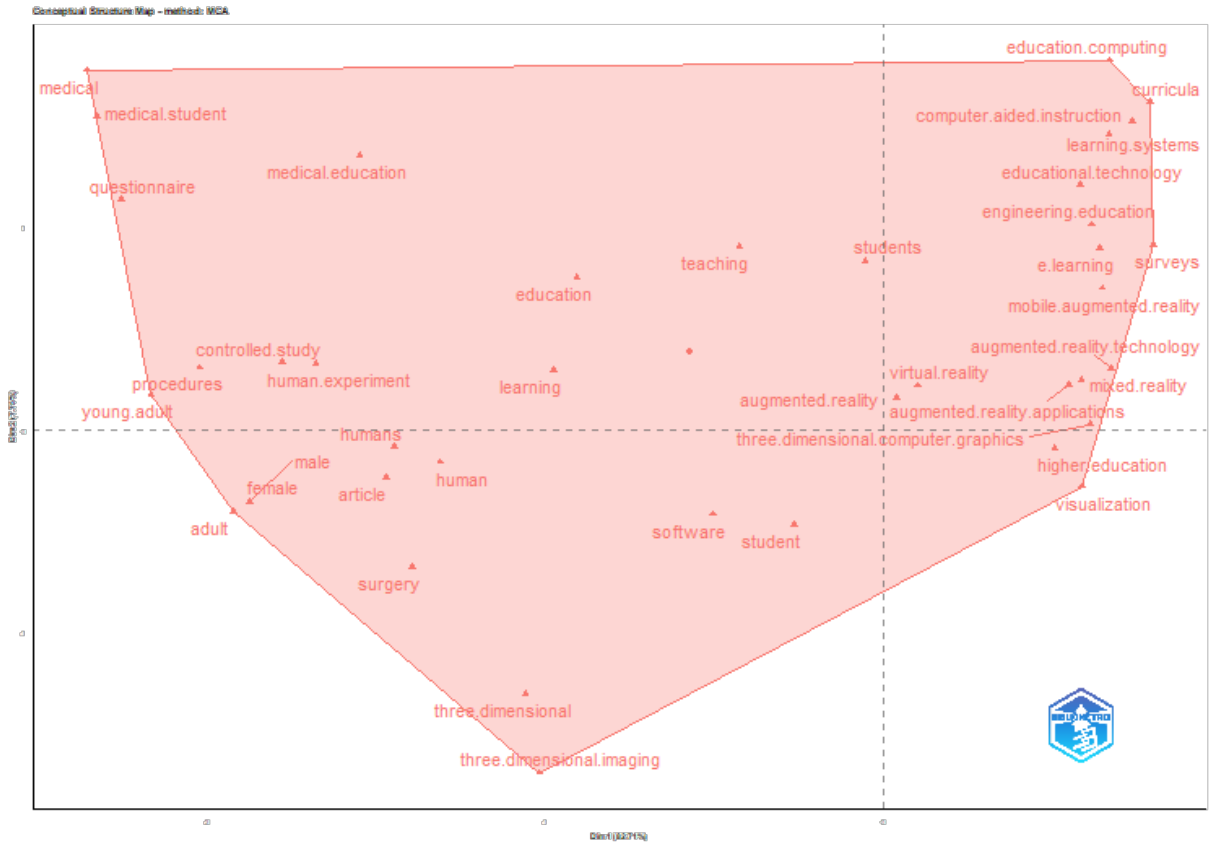

Figure 16. Factor Analysis Using MCA

Multiple Correspondence Analysis (MCA) is a method used to analyze categorical data and aims to simplify the numerous variables into a few smaller components, making the important information from the data easier to understand and analyze (Dwipurwani, 2020; Khangar & Kamalja, 2017; Roux & Rouanet, 2011). Figure 16 shows a concept map illustrating the relationships between various terms related to education, computers, and technology. This concept map uses a visualization technique based on a set of points to show how different concepts are interconnected and how they form a complex knowledge network (Hjellbrekke, 2018).

The concept map on the left shows that the concept "medical" is related to various elements, such as medical student, medical education, questionnaire, controlled study, procedures, human experiment, young adult, gender (including male and female), article, adult, and surgery. Meanwhile, the concept map on the right shows that the concept "education.computing" is related to various elements such as curricula, computer-aided instruction, learning systems, educational technology, engineering education, students, teaching, education, e-learning, surveys, mobile augmented reality, augmented reality technology, virtual reality, mixed reality, augmented reality applications, three-dimensional computer graphics, higher education, visualization, human, software, and student.

This concept map can be useful for enhancing the understanding of the relationships between various concepts and stimulating critical and creative thinking about topics related to education, computers, and technology.

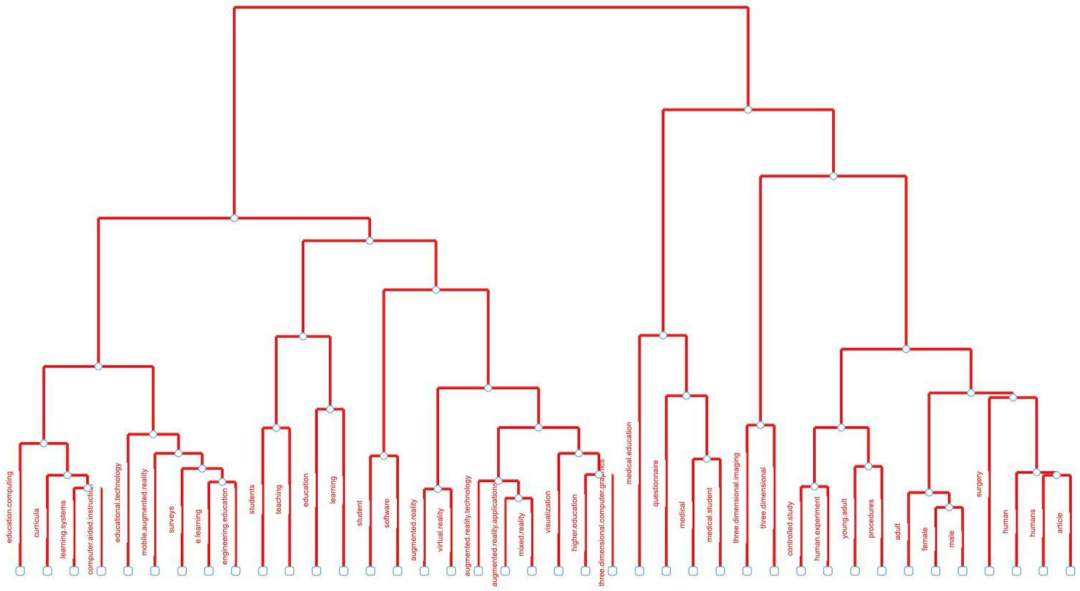

Figure 17. Thematic Dendogram

Thematic dendrogram, as presented in Figure 17, is a diagram that effectively organizes and visualizes data (Qaissi, 2024). This diagram shows the relationships between various terms in the fields of technology, education, and healthcare. For example, "education" is divided into "e-learning," "engineering education," "students," and "teaching." "E-learning" is further divided into "learning system," "computer-aided instruction," and "educational technology." The presence of this thematic dendrogram helps to gain a deeper understanding of a field and discover relationships that were not previously visible or recognized.

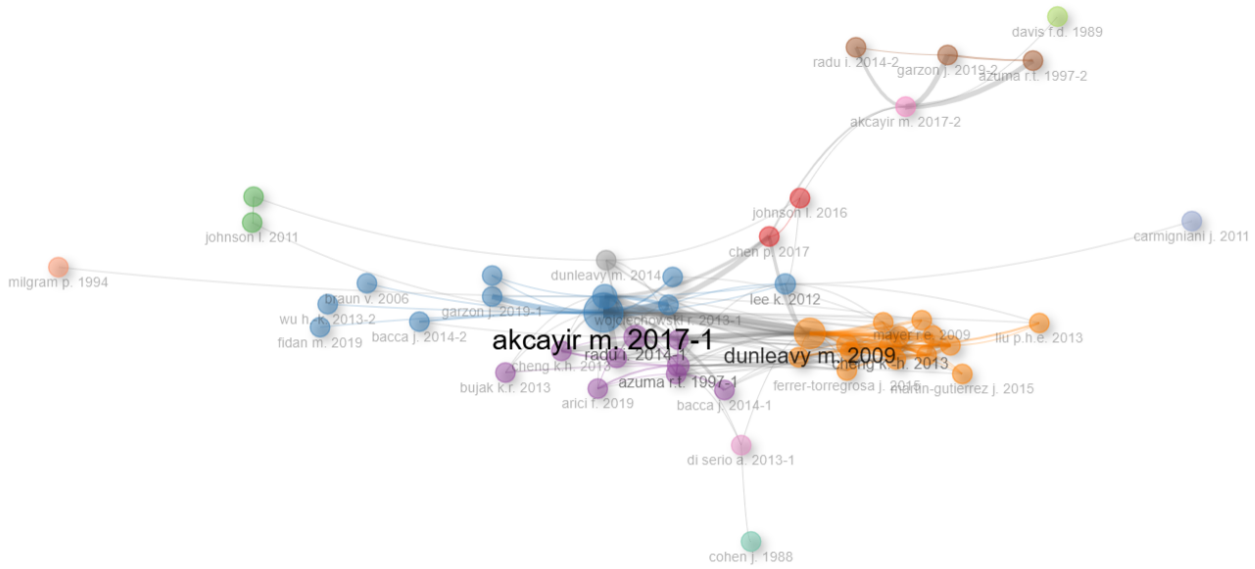

Figure 18. Co-Citation Network

Figure 18 illustrates the connections between authors based on the articles they have written. A co-citation network is formed when two documents are cited together (Small, 1973). Different colors represent various clusters of frequently co-cited works (Öberg, 2023). The dots in the figure represent the authors, with the size of the dots reflecting the total number of articles each author has published—the larger the dot, the more articles the author has produced. Lines connecting the dots indicate that two authors have co-authored articles (Wisnawa, 2024). Each author is linked to the year of their published works. The figure highlights Akçayır M as the most productive author in this dataset, evidenced by their many connections and a larger dot compared to others, linking them to numerous co-authors. One of their notable

publications, discusses the positive impact of AR technology on learning outcomes in educational contexts (Akçayır & Akçayır, 2017).

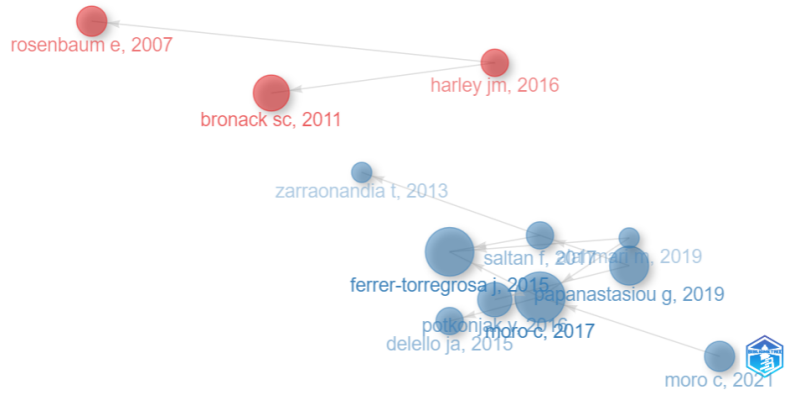

Figure 19. Historiography Map

Figure 19 illustrates the evolution of studies and key authors across different time periods. This map features members of the scientific community from diverse academic fields who are exploring the broader scope of AR research, including individuals with various perspectives on the subject (Tröhler, 2020).

This map offers a glimpse into the evolution of research directions and prominent figures throughout time. In particular, the period between 2007 and 2021 is clearly visible as a successful mapping, showing dynamic developments in the theme of augmented reality. This growth indicates that the subject remains relevant and continues to be explored in research. For example, the article written by Rosenbaum et al., (2007), discusses the development of AR accessible via smartphones and network connections. This article combines realistic AR role-playing games with participatory simulation models. Then, the article by Moro et al., (2021), explains how augmented reality technology can help deepen understanding of physiology and anatomy, especially because students need to comprehend the human organ system and body structures in three dimensions.

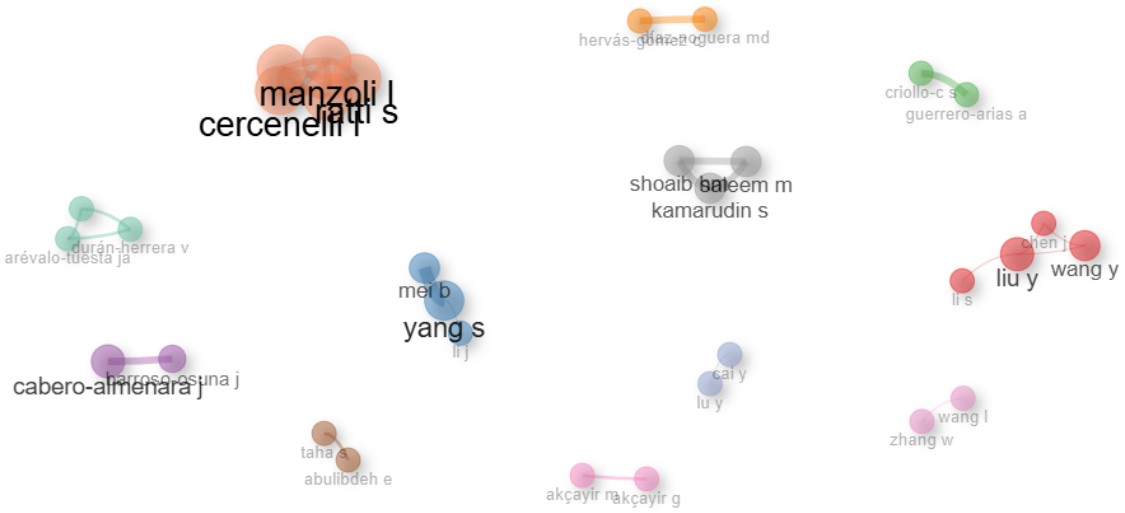

Figure 20. Collaboration Network

3.5.2. Social Structure

The social structure analysis was carried out through the mapping of co-author networks and country collaboration maps. The author collaboration network (Figure 20) reflects the results of the analysis of their

colleagues' networks (Donthu et al., 2021). This analysis identifies relationships between authors in the field of augmented reality and reveals the existence of 12 distinct groups. Highly prominent author collaborations are reflected in the size of the displayed groups.

The primary group (highlighted in orange) consists of highly active and productive authors who have worked together over time. This group features authors like Ratti S., Manzoli L., Cercenelli L., Marcelli L., and Ruggeri A. Their collaboration is reflected in the published article that explores how AR supports the visualization of anatomy (Battaglia et al., 2020). The following two groups also show active collaboration. Both groups are of equal size (depicted in red), with authors Liu Y., Wang Y., Chen J., and Li S. forming one cluster. The collaborative article within this group examines the educational advantages and impact of integrating mixed reality (MR) with 3D models of aortic disease for surgical residency training. (Li et al., 2023).

In a different cluster (shown in blue), Yang S., Mei B., and Ii J. are included. Their joint article examines the perspectives of future chemistry teachers on chemistry education enhanced by mobile augmented reality (MAR) (Yang et al., 2018). The next group (depicted in purple) consists of Cabero-Almenara J. and Baroso Ossuna J. Their joint article explores students' acceptance of AR technology when engaging with AR objects, assessing their performance, and examining whether gender affects their understanding. (Cabero-Almenara et al., 2019). The remaining eight groups also had a significant impact during the analysis period.

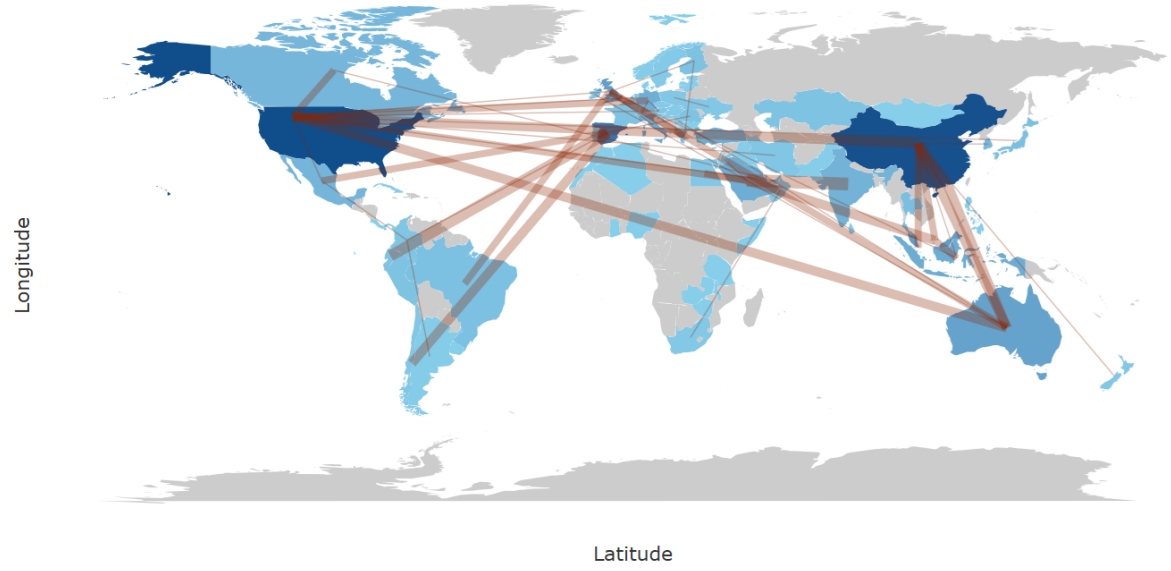

Figure 21. Country Collaboration Map

Regarding international collaboration, Figure 21 shows a map illustrating the international cooperation in the publication of literature on augmented reality, represented by red lines. Looking at the colors on this collaboration map, there are varying shades of blue, from light to dark. This means that countries with darker blue shades have higher collaboration levels compared to those with lighter blue shades. The darker the blue color of a country, the higher the collaboration network. This is reflected in the frequency of collaboration from each country. Additionally, it highlights significant collaboration levels, such as between the United States and Australia, Spain, China, and the UK. Other collaborations are also seen between Australia and the UK, China, and between China and Spain. The six countries with the highest collaboration frequencies are the USA (n=42), China (n=32), Spain (n=24), the UK (n=19), Australia (n=15), and Saudi Arabia (n=14).

4. CONCLUSION

The study's results, as shown in Table 6, reveal a significant increase in augmented reality (AR) research. This bibliometric analysis offers valuable insights into AR research trends from 1997 to September 2024, highlighting a rapid growth rate of 20.3% with expectations of continued expansion. Notably, the

United States and China have emerged as the leading contributors to AR research. This study is significant as AR technology can serve as an effective learning tool, enhancing students' problem-solving skills. Furthermore, AR technology's accessibility anytime and anywhere enables students to visualize abstract concepts as clear object models.

Table 6. Summary of the Findings

Parameter	Information
Number of Documents	832
Annual growth rate (%)	20.3
Number of authors	2973
Top author	Kumar, A (n=7)
Number of sources	484
The most productive source	Education And Information Technologies (n=21)
Top-cited article (DOI)	10.1016/j.edurev.2016.11.002
The country with the most publications	USA (n=399)
University with the highest number of doc	University of Bologna (n=32)
The most favourite keywords	Augmented reality, virtual reality, human, students, teaching, humans, female, male, learning, article

A key limitation of this study is its reliance on data from the Scopus database. Therefore, the researchers suggest that future studies incorporate broader and more comprehensive databases, such as Web of Science (WoS) or Google Scholar, to improve data quality and support comparative analysis. Despite this, the study offers various avenues for further exploration. Educators can apply augmented reality technology in teaching to help students grasp complex concepts, enhance visualization skills, and encourage collaboration, making the learning experience more memorable. Ultimately, this research lays a strong foundation for future investigations into augmented reality and related fields, aligned with the key themes discussed in this article.

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Research Ethics. Not Applicable.

Data Availability Statement. All data can be obtained from the corresponding author.

Conflicts of Interest. The author declares no conflicts of interest.

Funding. Not Applicable.

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