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Trends of augmented reality studies in education: a bibliometric evaluation*

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Highlights:
- AR research shows 27.04% annual growth, gaining momentum since 2016.
- Collaboration is strong: 4.09 co-authors per document define the research culture.
- Asian author dominance suggests an apparent geographical centralization in AR research.
- AR research integrates technology, interdisciplinary foundations, and human-centered pedagogy.

Abstract

Augmented Reality (AR) is a technology that enhances user experiences by overlaying digital elements onto real-world objects or environments through technological devices, enabling interactive learning, especially in education. This study aims to analyze current trends, structural features, and interaction networks of 7,534 scientific studies published on AR technology in the education field, pulled from five databases: WoS, Scopus, Lens, PubMed, and OpenAlex. The results show that AR research in education has gained significant momentum, particularly since 2016, with an annual growth rate of 27.04%. The field demonstrates a strong culture of collaboration, with an average of 4.09 co-authors per study. The prominence of Asian authors such as Wang Y., Chen Y., and Chen C. among the most prolific researchers indicates a clear geographical concentration of research, while very limited international collaboration was observed between Southeast Asia and clusters in Europe and the Americas. The most cited studies focus on the 2009-2018 period. Additionally, "Education and Information Technologies" was the leading journal in terms of publications, while "Computers & Education" was the most influential. Keyword co-occurrence analysis highlights that AR research is centered around technology, interdisciplinary backgrounds (such as computer science, psychology, and artificial intelligence), and human-centered pedagogical outcomes. Trending topics reveal that the focus has shifted toward specific learning approaches like "psychology" and "young adult." Despite AR's transformative potential, accessibility challenges remain, including limited availability of mobile devices and insufficient teacher training.

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1. Introduction

Augmented Reality (AR) has transformative potential in education. As a technology, it enhances the user experience by overlaying digital elements (3D, 2D) onto real-world objects, thereby facilitating interactive learning (Azuma, 1997; Berryman, 2012). This potential is reflected in the notable increase in research on AR in education in recent years (Hincapie et al., 2021), driven by the rising popularity of the technology and its perceived benefits (Chang, 2022; Singh et al., 2025). A key advantage of AR is its ability to boost student engagement and motivation. By creating immersive learning experiences, it makes lessons more relatable and stimulating (Salmiyanti et al., 2023; Sandoval-Perez et al., 2022). For example, students can examine human anatomy in three dimensions or observe a virtual volcano eruption, making learning more concrete (Dunleavy & Dede, 2014). AR excels at concretizing complex and abstract concepts. Interactive 3D models and simulations help students better understand subjects that are otherwise difficult to visualize, such as molecular structures in chemistry or abstract geometric shapes in mathematics (Mirza et al., 2025; Saidin et al., 2015; Chang et al., 2022). At the same time, this interaction aligns directly with the principles of constructivist learning. Instead of passively receiving information, students actively engage with virtual objects to "construct" knowledge. This constructivist approach complements experiential learning because AR enables students to interact with virtual objects that simulate real-world scenarios. Therefore, it can help students develop practical skills and problem-solving abilities in safe, controlled environments (Chang et al., 2022; Wahyuanto et al., 2024). Moreover, this interactivity extends to simulating real-world scenarios, allowing students to develop practical skills and problem-solving abilities through interaction with virtual objects (Chang et al., 2022; Wahyuanto et al., 2024).

The research field continues to grow rapidly, especially since 2016 (Masalimova et al., 2023; Min & Yu, 2023). This expansion is due not only to AR's educational benefits but also to its greater access through mobile devices (Akçayır & Akcayır, 2017). As the field develops, its scope is broadening. Initially focused on university students, AR applications are now more widely used in primary and secondary education (Salmiyanti et al., 2023). At the same time, the future of technology is changing, particularly through the integration of artificial intelligence (AI). AI is expected to further boost AR's effectiveness by customizing learning experiences and making them more realistic (Mirza et al., 2025). Ultimately, AR helps create engaging classrooms that support 21st-century skills like experiential, collaborative, and game-based learning (Singh et al., 2025). Using AR can increase student motivation and help retain knowledge (Kaur et al., 2020). This motivation leads to heightened interest, which improves understanding and learning outcomes (Azı & Gündüz, 2020). One way this happens is through gamification; turning lessons into interactive experiences with AR can develop higher-order skills such as critical thinking, decision-making, and teamwork (Özyurt & Özyurt, 2025). Furthermore, research shows that AR instruction enhances specific cognitive skills, like spatial and visual thinking, and encourages positive attitudes toward learning (Fortuna et al., 2024; Singh et al., 2025). Additionally, AR applications can be tailored to meet diverse learner needs, allowing for personalized experiences based on individual pace and understanding (Belmonte et al., 2020). This flexibility benefits courses where students have different prior knowledge. Despite AR's promising potential, educators and researchers face several challenges. Poorly designed applications that do not align with pedagogical goals can cause cognitive overload, distracting students instead of supporting learning (Makransky & Petersen, 2021). Issues like technical glitches, usability problems, or poor content integration can also demotivate students and hinder learning (Radu, 2014). Practical barriers remain as well. Access is a major concern, since AR requires mobile devices (phones, tablets, etc.), incurring significant costs. Additionally, a lack of proper training for educators on how to effectively incorporate AR remains a considerable obstacle (Cai et al., 2017). Addressing these challenges is essential to fully unlock the technology's benefits.

The current literature includes various bibliometric analysis studies on AR in education (Belmonte et al., 2021; Hincapie et al., 2021; Masalimova et al., 2023; Min & Yu, 2023; Rullyana & Triandari, 2024; Talan, 2021). However, many of these analyses use data from before the 2022-2024 period, when the field experienced its most significant growth. This rapid advancement is also accompanied by a shift in research focus. New thematic trends have emerged, such as AI integration, a focus on psychology-based cognitive and emotional outcomes, and applications for specific demographics like 'young adults' (Lampropoulos, 2025). As a result, existing bibliometric maps probably do not capture these new conceptual structures. Additionally, few studies have attempted to compile a dataset of this size by combining five different databases (WoS, Scopus, Lens, PubMed, and OpenAlex). Therefore, a current and comprehensive bibliometric analysis is needed to reflect the field's present scale and to identify the interdisciplinary trends guiding future research. This study aims to give researchers an opportunity to assess the current state and

emerging trends in the field by addressing the following research questions. From this perspective, the following questions were developed to be answered:**

1) What is the distribution of articles published on Augmented Reality in Education according to years?

2) Which are the most cited articles published on Augmented Reality in Education?

3) Which journals publish the most articles on Augmented Reality in Education?

4) What are the most commonly used keywords in articles published on Augmented Reality in Education?

5) Who are the main authors of studies on Augmented Reality in Education?

6) How is the collaboration of authors and institutions in articles published on Augmented Reality in Education?

7) What are the trends and emerging themes in articles published on Augmented Reality in Education?

2. Method

The bibliometric analysis method was used to examine the scientific articles published within the scope of the research. Bibliometric analysis is a type of examination that systematically utilizes data from databases to provide detailed insights into the development of a field (Aria & Cuccurullo, 2017; Leung et al., 2017). In this context, the study data were analyzed from articles on AR in the field of education from the WoS, Scopus, Lens, PubMed, and OpenAIRE databases.

2.1. Data Collection Process

The data of the study were obtained by using the keywords ("augmented reality" OR "AR technology" OR "mobile augmented reality" OR "marker-based AR" OR "markerless AR") AND ("education" OR "teaching" OR "learning" OR "instruction") in the relevant databases. The inclusion and exclusion criteria for how relevant data were obtained from the databases are discussed below:

Table 1. Databases Included in The Study and Descriptions

Database	Description
WoS (All fields)	1. Using the keywords identified for the research (mentioned under the data collection process section), a search was conducted with "Author Keywords" selected and 4245 studies were found. 2. Among these studies, early access ones were excluded and only "articles" were included. As a result of the relevant filtering, 2052 studies were found. 3. Only "English" as the language and "Education and educational research" were included, resulting in 785 studies. The data obtained were saved to the computer in "BibTeX" format as two separate files of 500 data each, which is the highest download limit allowed by the system.
SCOPUS (Title, abstract and keyword):	1. A search was made using the keywords determined for the research and 20719 data were accessed. 2. Of these studies, only "articles" were included. 3. Only those in "English" were included as the language and as a result, 2505 data were accessed. "Citation information", "bibliographic information", "abstracts and keywords" and "including references" were selected from the export information of the data obtained and saved to the computer in "BibTeX" format.
Lens (Title, Abstract and Keyword):	1. The field of scientific research was selected and searched through the relevant keywords and 39169 studies were reached. 2. Only "Education" was included in the filtering and the number of data obtained decreased to 2674. 3. Only 2625 studies were reached by including only "articles". The data obtained were saved to the computer in ".cvs" format.
PubMed *(All fields)*	1. 2403 studies were reached as a result of the search using the keywords determined for the research. 2. Only those with "English" as the language were included. As a result of filtering, 2258 studies were reached. The data obtained were saved to the computer in ".txt" format.
OpenAlex *(Title and Abstract)*	1. As a result of the search using the keywords determined for the research, 23110 studies were reached. 2. 18220 studies were obtained by including only "articles". 3. Only "English" studies were included as language. 4. Only AR studies in the context of "Education" were included. As a result, a total of 1541 studies were obtained and saved to the computer in ".txt" format.

Data merging and extraction process: A total of 9714 data points obtained from the databases specified above for inclusion and exclusion criteria were merged using a code written in R Studio. Mainly, data from the Wos and SCOPUS databases downloaded in "BibTeX" format were used. After merging, 649 duplicate data points were identified and removed with a custom code. Next, data from the Lens databases saved in ".csv" format were imported into R Studio and combined with the previous merged file using relevant code strings, resulting in a single file from three databases. Subsequently, 1122 duplicate data points were identified and removed using code. Then, data from PubMed were integrated into R Studio with custom code, extracting 222 duplicates. Later, data from the "OpenAlex" database were also combined via R Studio, with 173 duplicate data points identified and removed. Finally, a total of 7548 data points from five databases (WoS, Scopus, Lens, PubMed, OpenAlex) were downloaded in ".xlsx" format.

This dataset was sorted alphabetically for review. During this process, 14 records with identical DOI numbers were identified and deleted. As a result, 7534 studies were prepared for analysis.

In this study, a multi-database approach was used to create a comprehensive map of the field. WoS and Scopus were chosen as primary indexes covering the most cited, high-impact journals; Lens and OpenAlex were included to reduce publication bias by adding open access publications and a wider range of sources; PubMed was selected specifically to focus on studies in medical and health sciences education, a key area of AR in education. However, "The filtering criteria were determined based on the focus of the study. Only 'articles' were included, thus focusing on peer-reviewed and completed research. Other publication types, such as reviews, book chapters, and conference proceedings, were excluded. English was selected as the language filter because English is the dominant language of international scientific communication, and these filters are necessary to enable consistent terminological analysis and the smooth operation of the biblioshiny package.

2.2. Data Analysis

The R Studio program, which is compatible with the R statistical program, was used in the analysis of the data obtained. The program is preferred because it is open source, receives continuous updates and has a wide range of operations. The program allows various analyses to be performed by downloading various packages. In this study, the "Bibliometrix" package (developed by Massimo Aria and Corrado Cuccurullo of the University of Naples Federico II) was used for the analysis. In addition, data visualizations were performed with the "Biblioshiny" web plugin included in the package. To comprehensively map the field, several bibliometric techniques were employed:

Descriptive and Citation Analysis: To identify the annual scientific production (Araştırma Sorusu 1), determine the most impactful articles based on total citations (RQ 2), and identify the most prolific journals (RQ 3).

Co-authorship Analysis: To visualize the social structure of the field, this analysis mapped collaboration networks among prominent authors (RQ 5), institutions, and countries (RQ 6).

Keyword Co-occurrence Analysis: To map the conceptual structure of the field, a co-word analysis was conducted using keywords plus (RS Q). This technique helps identify the main themes and the relationships between them.

Thematic Evolution Analysis: To understand how the field has changed over time, a trend topics analysis was conducted to identify emerging or declining research themes (RQ 7).

Table 2. Basic Information About The Studies

Description	Values
Time range	1997-2025
Documents	7534
Authors	22274
Single Author Documents	809
Average citation per document	13.12
Number of co-authors per document	4.09
Annual growth rate %	27.04

Descriptive statistics of the basic bibliometric indicators of the literature on AR in education analyzed within the scope of the research are presented in Table 2. The analysis covers a 28 year period between 1997 and 2025. A total of 7,534 original documents were accessed in this time period. The literature accessed was created by 22,274 authors. The average number of citations per document, one of the main indicators reflecting the impact level of the field, was calculated as 13,12. This shows that the studies produced in the field have considerable visibility and impact. One of the most striking findings of the research is the level of collaboration in the field. The fact that the number of co-authors per document is 4.09 and that 809 documents, representing only 10.8% of total publications, have only one author reveals that collective and collaborative research production is a dominant trend in this field. Finally, the annual growth rate of 27.04% shows that the field has a highly dynamic structure and that academic interest in this field is increasing, and that it is a research topic that is growing and developing at a significant pace. This basic information reveals that the field exhibits a well-established, interactive, collaborative and dynamic structure. Figure 1 shows the scientific study production graph of studies on AR in education by years.

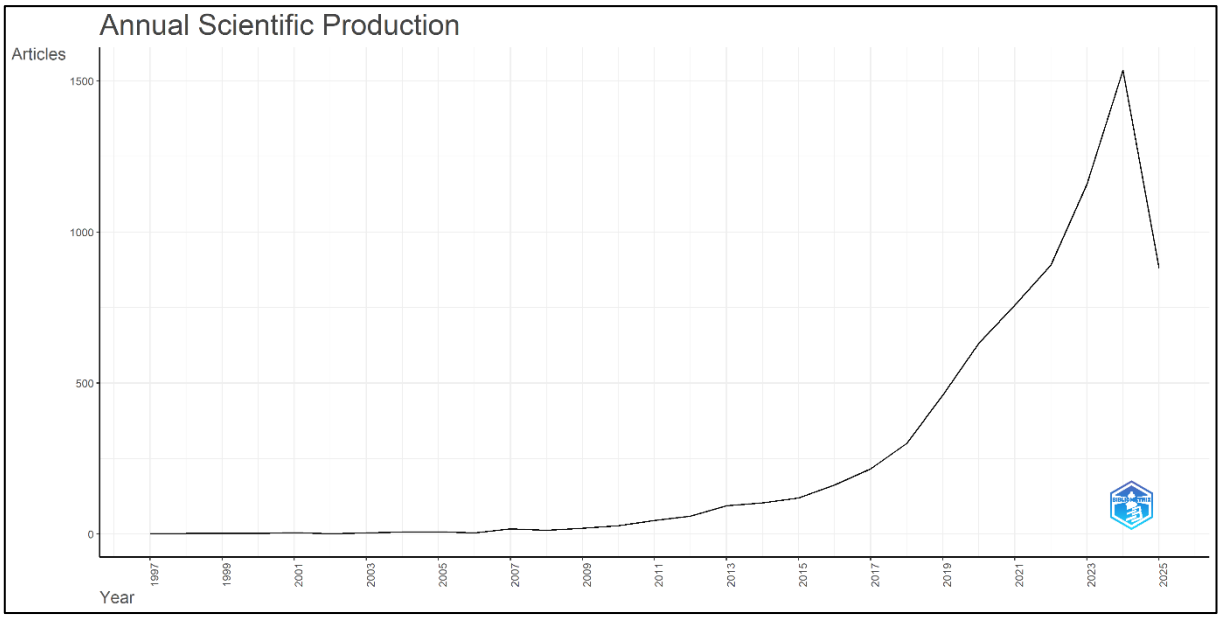

Figure 1. Annual Scientific Study Production Graph in The Related Field

The distribution of academic studies on AR in education by time is presented in Figure 1. When the graph is analyzed, it can be said that the research topic went through three distinct phases. The first period, which lasted from 1997 to the mid-2000s, can also be characterized as incubation. Because the number of publications per year is quite limited in this period. Since 2008, there has been a marked increase in interest in the field and a significant growth in the number of academic publications, especially after 2016. This development phase shows that AR in education is rapidly growing in popularity in academic circles and has become a research focus. From 2022 onwards, the rate of increase in publications increased further and reached its peak in 2024. The sudden drop seen in the graph for 2025 can be interpreted not as a decline in interest in the field, but as a methodological result of the time delay in the indexing process of articles by databases. This is because it may take time to reflect all the data for 2025 in the system due to incomplete data for the current year and delays in the indexing process. When the graph is evaluated overall, it clearly shows how academic studies on AR in education have become a dynamic, rapidly growing trend in the field, especially in the last decade or so, after a long period of steady progress. Figure 2 shows the top 10 researchers interested in the field of AR in education and the number of studies they produced.

3. Findings

The Findings section should introduce the results of the research in the form of texts, tables, and figures, and the interpretation of these results. The last section of the main text should draw conclusions from the previous section, discuss them with the relevant literature, and propose suggestions for policy, practice, and future research. The Findings section must not include any subheadings.

Figure 2 displays the authors with the highest number of publications in the field of AR in education, along with their total number of academic studies. According to the analysis results, "Wang Y." can be identified as the most prolific author in the field with 52 academic works. He is followed by "Chen Y." with 43 papers and "Chen C." with 39 papers. The fact that all of the top 10 authors have produced 30 or more academic studies suggests a stable, productive group of researchers contributing to the development of the field. The most notable aspect of this finding is that most of the names on the list of the most prolific authors are of Asian origin. This indicates a significant geographical concentration in research production on AR in education. This view is also supported by the inter-institutional collaboration graph on AR in education in Figure 5.

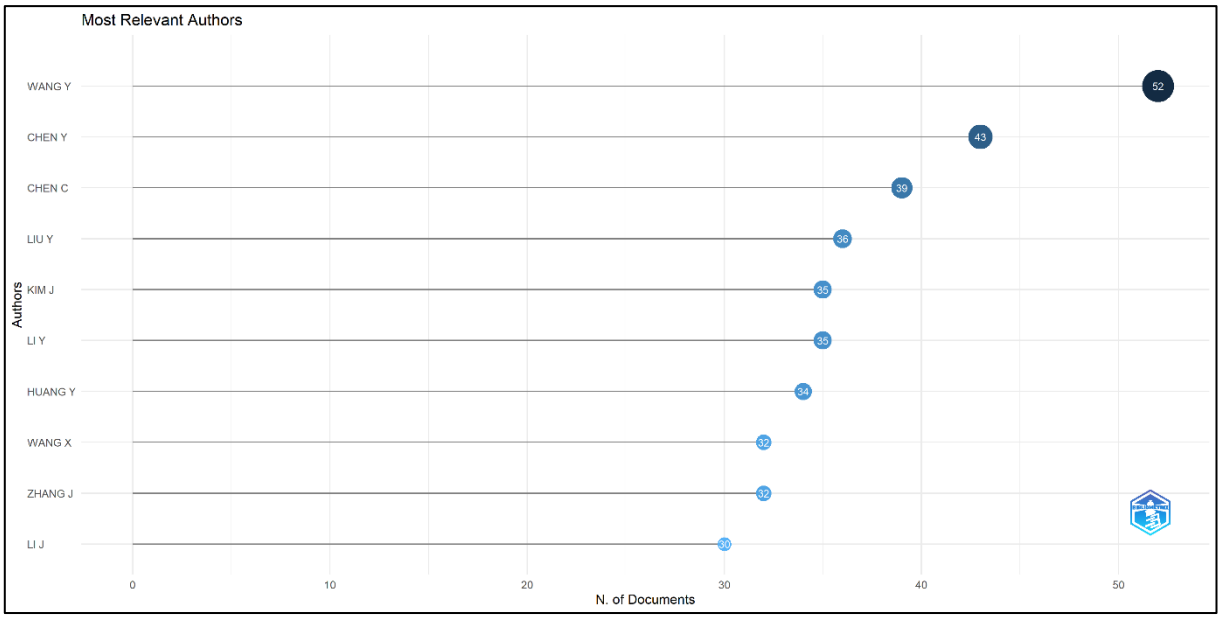

Figure 2. Most Relevant Authors

In Figure 3, the years in which the authors with the highest number of publications in the relevant field realized their first publications within the scope of the subject, and the density of citations to their publications are shown with the size and density of the dots.

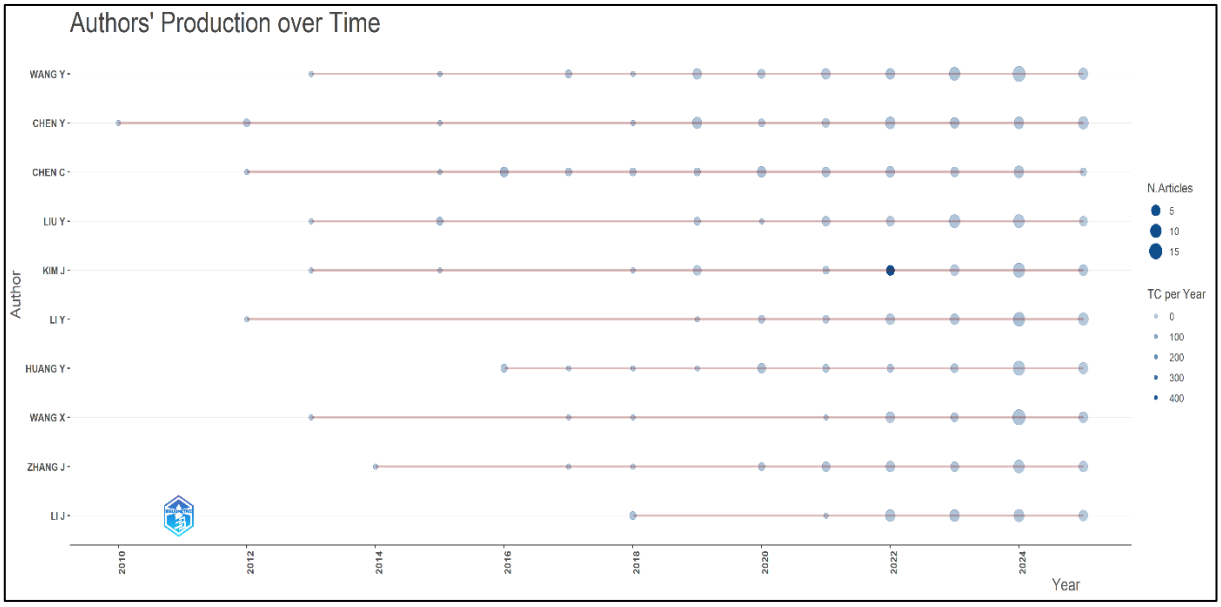

Figure 3. Production and Citation Densities of The 10 Most Influential Authors Over Time

Figure 3 offers a comprehensive view of the scientific productivity of the most influential authors over time and the citation impact of their publications. Each circle represents an author's publication performance in a given year. The size of the circle correlates directly with the number of articles published that year, while the shade indicates the total number of citations received by publications in that year. Therefore, the figure provides valuable insights into the authors' level of work and influence in the research area. For instance, authors like Wang, Y., Chen Y., and Chen, C. have a consistent publication history over a long period. Notably, after 2022, the circles grow larger, indicating an increase in their academic output in the field of AR in education. Regarding scientific impact, the situation differs. Despite having fewer publications, Kim, J.'s studies from 2022, marked by the dark circles, received more citations than those of all other authors. This demonstrates that Kim, J. has achieved a high impact in the field with relatively few studies, which are widely recognized as important reference sources. When analyzing the overall trend in the graph, it shows that most listed authors have increased their publication activities since 2018, and there has been notable growth in the field in both the number of publications and citation impact, especially from

2020 onward. Figure 4 shows the collaboration between authors who produced academic studies on AR in education in databases.

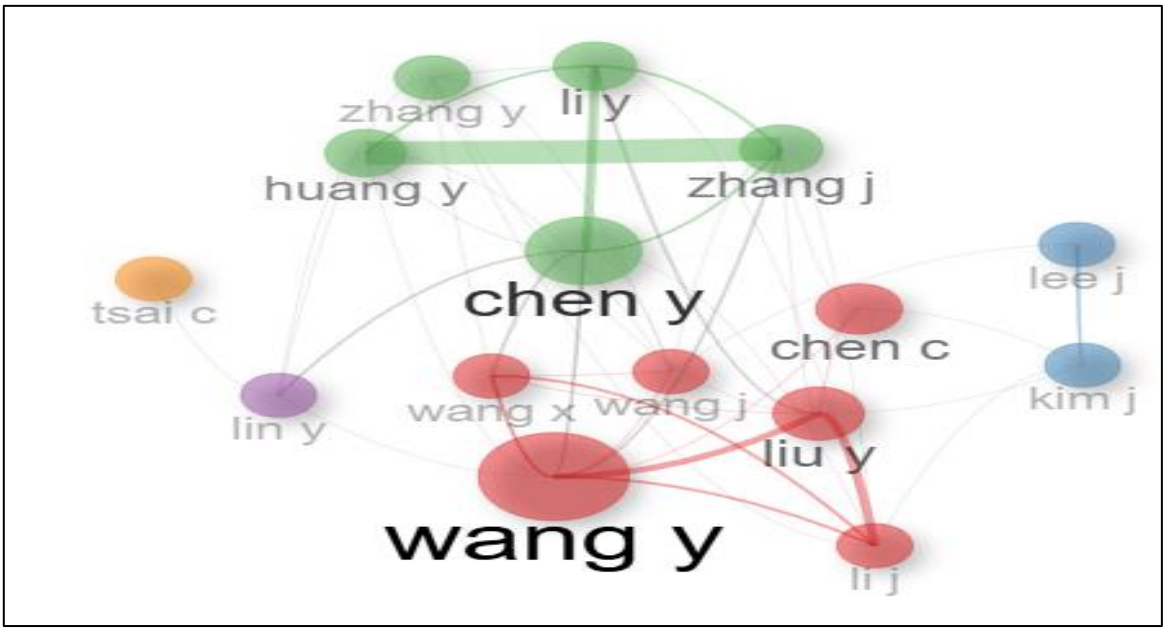

Figure 4. Collaboration Network Between Prominent Authors in The Studies on The Related Subject Area

Figure 4 illustrates the co-authorship relationships in the research area. The size of each circle indicates the number of publications by the authors, the thickness of the links shows collaboration density, and the colors represent different collaboration clusters. The largest collaboration network, the red cluster, is centered around Wang, Y., the most prolific author. Notably, the thickness of the connection between Wang, Y., Liu, Y., and Li, J. suggests that these researchers have a very close and productive collaboration. The second major research group, the green cluster, is anchored by Chen, Y. In this cluster, there is strong interaction among authors such as Li, Y., Zhang, Y., and Huang, Y. Overall, the network structure indicates that connections within clusters are much stronger than those between different clusters. This implies that the leading research groups working in the field of "AR in Education" are primarily collaborating within their groups due to shared expertise, geographic proximity, institutional ties, or social relationships. Figure 5 shows the collaboration between the institutions to which the authors who produced the studies on AR in education in the databases are affiliated.

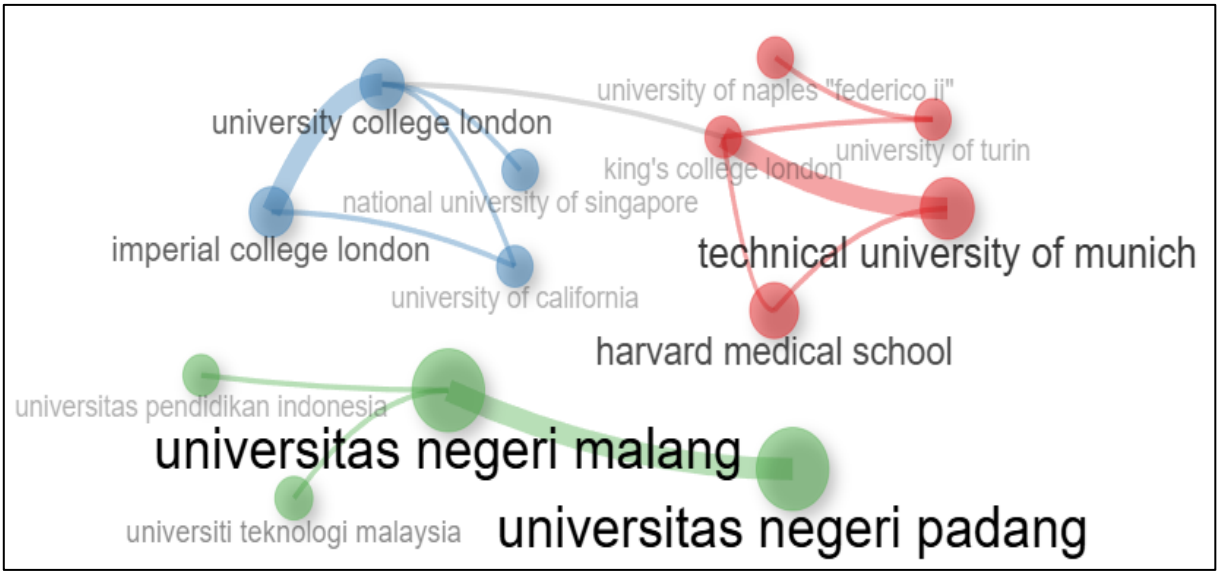

Figure 5. Inter-Organizational Collaboration Network Prominent in AR Studies in Education

The network of inter-institutional cooperation shown in Figure 5 reveals clusters that are geographically based and clearly different from each other. The most noticeable cluster is the Southeast

Asian network, led by universities in Indonesia and Malaysia, forming the green cluster. At the center of this network is "Universitas Negeri Malang," which has the largest circle and a particularly strong collaborative relationship with "Universitas Negeri Padang." Conversely, there are two large, interconnected clusters—red and blue—comprising European and American institutions that are prominent in the field. The blue cluster includes UK-based institutions like "University College London" and "Imperial College London," while the red cluster features organizations such as "Technical University of Munich," "University of Turin," and "Harvard Medical School," representing a Europe-US cooperation network. "King's College London" serves as a link between these two clusters, interacting with both. Interestingly, there is no connection between the Southeast Asian green cluster and the red and blue Euro-American clusters. This may be due to geographical separation, language barriers, or lack of shared interests. Table 3 shows the most cited studies among the academic studies on AR in education in international literature.

Table 3. The 10 Most Cited Studies and Total Number of Citations in The Related Literature

Author Name	Years	Journal Name	Total Citation Number
Wu, H.	2013	Compedu	1722
Dwıvedı Y	2022	Int J Inf Manage	1675
Akçayır M,.	2017	Educ Res Rev	1511
Dunleavy M,.	2014	J Sci Educ Technol	1007
Bacca J,	2014	Educational Technology and Society	918
Lee, K.	2012	Techtrends	739
Potkonjak, V.	2016	Compedu	713
Ibanez, M.	2018	Compedu	657
Cheng, K.	2012	Journal of Science Edu and Tech	645
Radu, I.	2014	Pers Ubiquitous Comp	627

Table 3 shows the top 10 most cited studies and the journals where these studies were published. Based on the analysis, Wu, H. (2013) study published in Computers & Education is the most influential in the field, with 1722 citations. This is followed by publications by Dunleavy, M. (2014) and Akçayır, M. (2017), which also received very high citation counts. The fact that three of the top 10 cited studies are from Computers & Education suggests that this journal is a leading publication for high-impact research in the field. The concentration of study publication dates mainly between 2009 and 2018 indicates that this period is crucial for shaping the theoretical and conceptual frameworks of AR studies in education, during which many descriptive and pioneering studies were conducted. These studies are valuable resources for researchers working in the field of AR in education or new researchers entering this field.

Table 4 shows the journals in which the academic studies on AR in education were published the most.

Table 4. The Journals in Which The Articles Written in The Context of The Research Topic Were Published The Most

Journal Name	Number of Article
Education and Information Technologies	506
Bmc Medical Education	144
Interactive Learning Environments	114
Sensors (Basel, Swıtzerland)	110
Techtrends	84
Journal Of Science Education and Technology	79
Sustainability (Switzerland)	75
Education Sciences	68
Educational Technology Research and Development	68

Table 4 shows the academic journals in which the scientific articles produced within the scope of the research topic are most frequently published and the number of scientific publications in these journals. The findings reveal that studies in the field are concentrated in certain journals. With 506 articles, the journal "Education and Information Technologies" stands out as the journal with the highest number of publications on this topic. This is followed by "BMC Medical Education" with 144 articles and "Interactive Learning Environments" with 114 articles. The fact that a medical journal ranks second in the list shows that AR technologies are one of the important and productive application areas in medical and health sciences education.

Figure 6 shows the most frequently used keywords in academic studies on the use of AR technologies in the context of education.

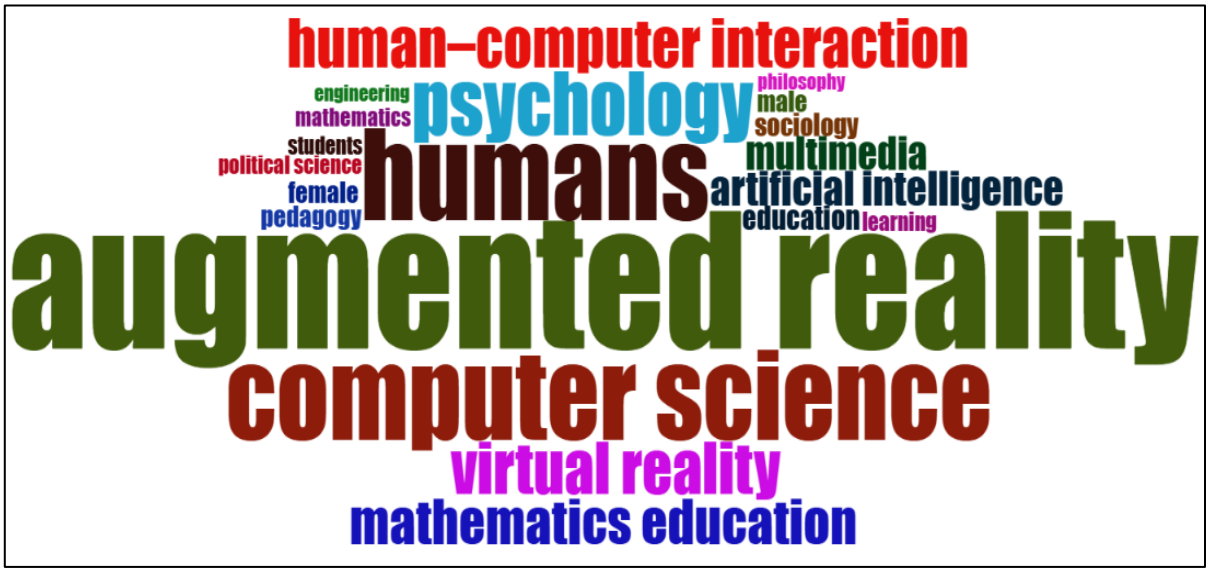

Figure 6. Word Cloud Consisting of Keywords Related to The Study Area

The keywords (keywords plus) given in Figure 6 include information compiled from the title and reference records regarding the words and/or phrases in the content of the scientific studies included in the research. Keywords summarize the content of the studies and make them more visible. This corresponds to frequently mentioned topics and concepts in the relevant literature. On the other hand, the word cloud generated using keywords plus reveals the general trend related to the topic (Tripathi et al., 2018). Figure 6 shows the keywords frequently mentioned in the studies included in this research. The font size of the words is directly proportional to their frequency of appearance in the studies.

The word cloud showing the most frequently used keywords, along with a co-occurrence network analysis indicating which words are used together more frequently, is presented in Figure 7.

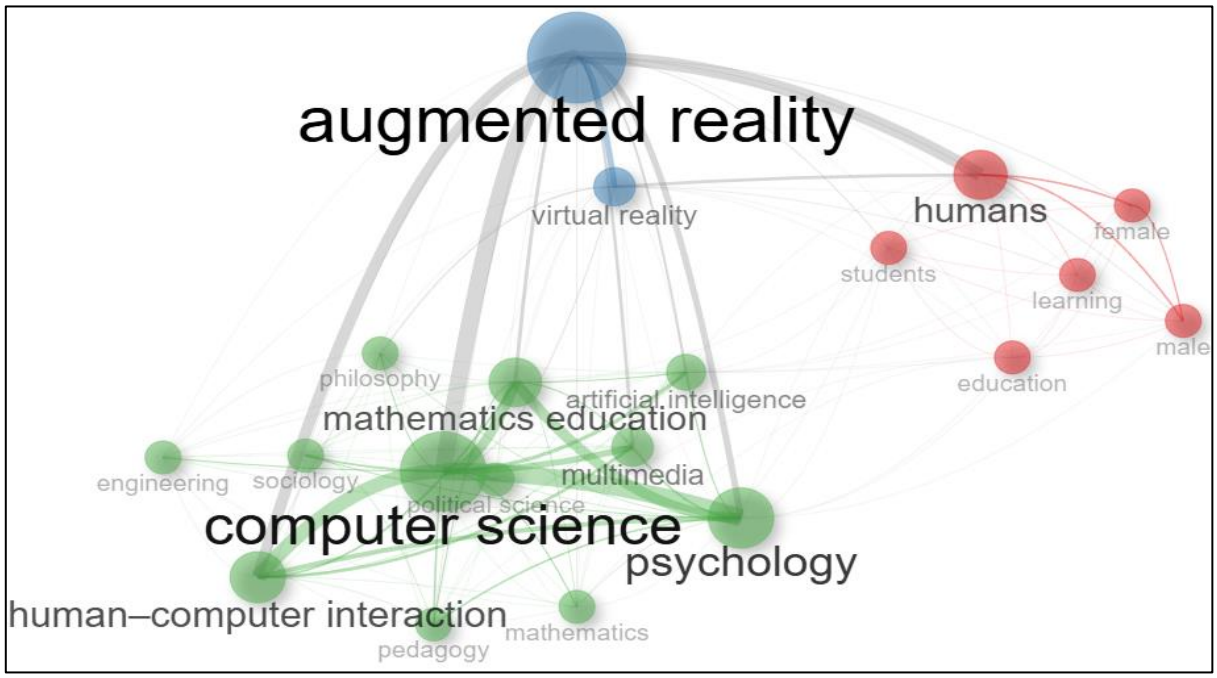

Figure 7. Visual Representation of The Co-Occurrence Network Analysis Showing The Frequency of Keywords Used Together in Related Studies

Figure 7 illustrates the network of relationships between the keywords analyzed in the literature. It also reveals three main thematic clusters that define the research area. The cluster centered around AR, shown in blue and forming the largest circle, represents the technological core of the field. It plays a central

role by establishing strong links with all other conceptual structures. Conversely, the green cluster reflects the foundation of AR studies in education in terms of discipline and methodology. This cluster, which revolves around computer science, includes various fields such as psychology, human-computer interaction, mathematics education, and AI, which has gained significant popularity in recent years. It is important to note that AR research in education heavily relies on computer science during development and application phases, while social sciences like psychology and pedagogy are crucial in evaluating user experience and learning outcomes. The red cluster highlights the pedagogical aspect of the research, with concepts such as people, students, learning, education, and gender. It also defines the focal point of AR studies in education. This cluster emphasizes that the primary goal of AR in research is to enhance learning processes in humans, especially students. Overall, the co-creation network shows that AR research in education is inherently interdisciplinary, situated at the intersection of technology (blue cluster), conceptual infrastructure (green cluster), and human-centered educational outcomes (red cluster).

According to the databases examined in Figure 8, there are trending topics in scientific studies related to the research topic.

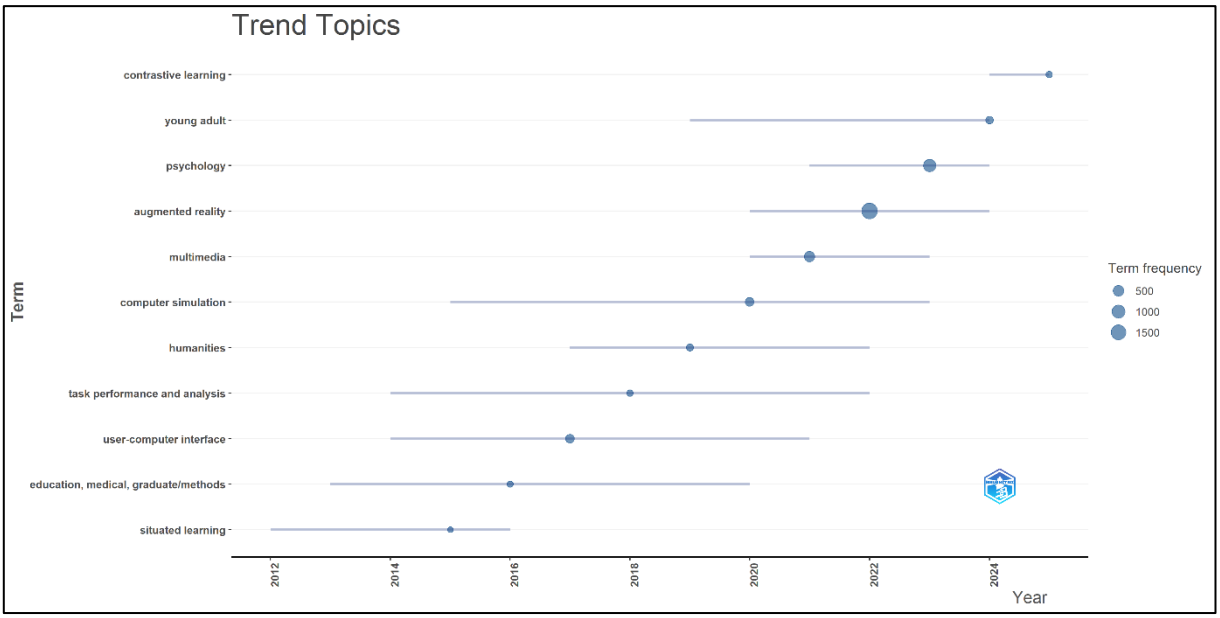

Figure 8. Trend Topics Obtained by Analyzing Scientific Studies Related to The Field of Work.

Figure 8 illustrates the trend and publication frequency of key terms in the literature over time. The findings show that the focus of research has changed significantly. Between 2015 and 2018, topics such as "situational learning," "user-computer interface," and "task performance and analysis" were prominent. Since 2020, with the increasing popularity of terms like "computer simulation" and "multimedia," it is clear that AR research applications in education have advanced. Notably, the term "augmented reality" reached its peak around 2022, indicating that this area was at its height as a research field and became a central topic. The rise of the term "psychology" during the same period suggests that more attention is being given to studying AR's effects on affective and cognitive learning outcomes. Additionally, new topics like "young adults" and "contrastive learning" emerging as trends by 2024 suggest that the field is increasingly focusing on specific demographic groups and adopting more targeted learning approaches. Figure 9 shows the intensity of countries that have co-authored scientific studies on the use of AR in education.

Figure 9 visualizes the international cooperation network based on scientific studies in the field under review. The density and thickness of the connection lines represent the number of joint publications between countries and, consequently, the extent of cooperation. The analysis shows that the US, China, and Spain are at the center of the global cooperation network. These three countries have the most intense and strongest cooperation ties both among themselves and with other countries. Based on the relevant publication links, the UK, Germany, other Western European countries, and Australia follow this cooperation.

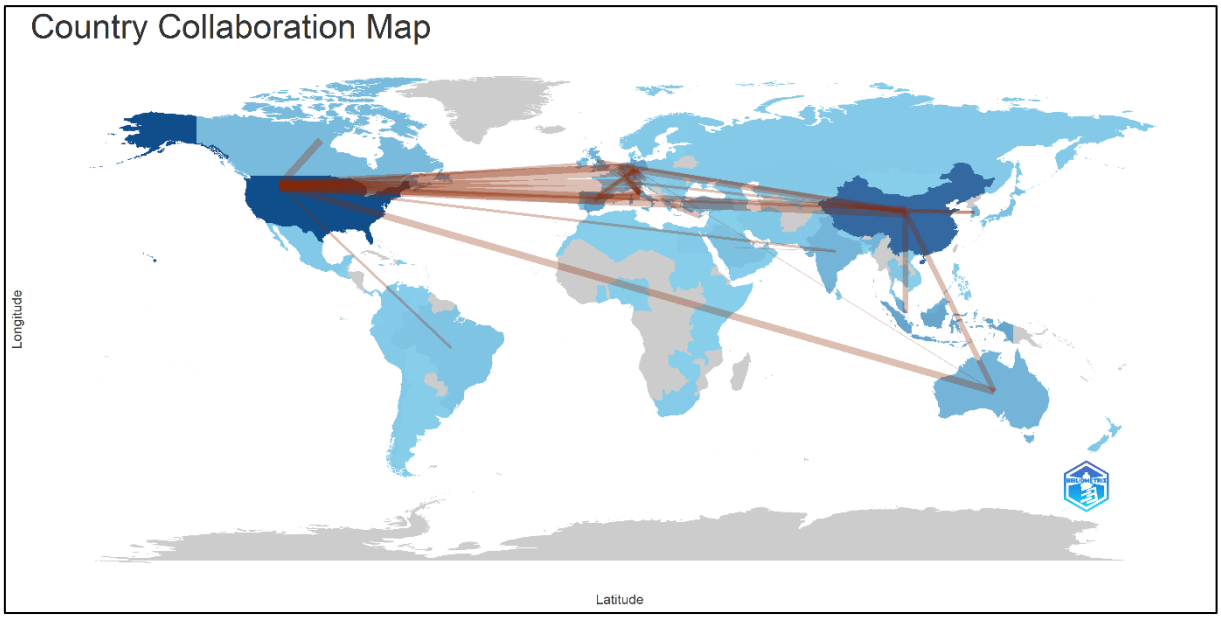

Figure 9. Map of Global Cooperation in The Field of Work.

4. Discussion and Conclusion

This study, which conducts a bibliometric evaluation of scientific publications in the field of AR in education, clearly shows that academic interest has grown significantly in recent years and that the field is experiencing a period of dynamic growth. In particular, the notable increase in the number of publications since 2016 and the annual growth rate of 27.04% highlight the level of scholarly interest in this area. This finding aligns with the rising trend in AR research in education, as noted in previous bibliometric studies such as Hincapie et al. (2021), Masalimova et al. (2023), and Min & Yu (2023). Research indicates that studies in the field of AR in education have embraced a collaborative research culture. The average number of co-authors per study is 4.09, and single-author studies make up only 10.8% of total publications, showing that collaboration is a dominant trend. Additionally, the author's collaboration network analysis reveals the presence of strong collaboration clusters, with these groups showing intense internal interactions. This collaboration trend supports the collective work structure observed in AR research across STEM and vocational education, as demonstrated in other bibliometric analyses such as Talan (2021) and Fortuna et al. (2024). Examining the most prolific authors, such as Wang Y., Chen Y., and Chen C., shows they have a long-standing, consistent, and productive publication record. This suggests that a core group of researchers has contributed significantly to the ongoing development of the field. The dominance of Asian authors among the most influential researchers highlights a clear geographical concentration in AR educational research. This is further supported by an analysis of inter-institutional collaboration, particularly the large cluster dominated by universities in Southeast Asia (Indonesia and Malaysia). Conversely, the limited links between clusters formed by European and American institutions and those in Southeast Asia suggest that factors like geographic distance and language barriers may hinder international cooperation. The concentration of the most cited studies between 2009 and 2018 indicates that this period was foundational, establishing the theoretical and conceptual frameworks for AR research in education. These works serve as key references for new researchers. Analyses show that the journal "Education and Information Technologies" publishes the most articles on this topic, while "Computers & Education" boasts the highest impact factor for AR in education research. Interestingly, a medical journal like "BMC Medical Education" ranks as the second most cited, demonstrating that AR technologies have also played a significant role in medical and health sciences education.

Research findings emphasize that AR is inherently an interdisciplinary field in education. The keyword co-occurrence network analysis shapes this field around three main thematic clusters: technological element (AR), conceptual infrastructure (computer science, psychology, human-computer interaction, artificial intelligence, mathematics education), and human-centered pedagogical outputs (students, learning, education, gender). This situation demonstrates that AR research draws on the accumulated knowledge of different scientific disciplines to understand its impact on both technology development and learning processes. This interdisciplinary interaction has also been highlighted in other studies, such as those by Belmonte et al. (2021) and Rullyana & Triandari (2024). The analysis of trending topics has revealed

that the focus of research has evolved over time. While topics such as "Situational learning" and "User-computer interface" were prominent between 2015 and 2018, the rise in popularity of terms such as "Computer simulation" and "Multimedia" since 2020 indicates that the application dimension of AR research has strengthened. The peak usage of the term "augmented reality" in studies around 2022 shows that the field became the center of attention during this period and became a focus for researchers. The emergence of the term "psychology" as a trend during the same period highlights the fact that AR's effects on affective and cognitive learning outcomes began to be studied more closely. Finally, the emergence of topics such as "young adults" and "contrastive learning" as rising trends toward 2024 can be interpreted as an indication that the field is now focusing on specific demographic groups and moving toward more detailed learning approaches. This indicates that AR research is moving toward more specific pedagogical applications, as indicated by studies such as Özyurt & Özyurt (2025). In conclusion, this study demonstrates that despite its long-standing history in education, the field of AR has rapidly grown over the past decade to become a collaborative and interdisciplinary area of research. The potential benefits of AR, such as increasing student participation, concretizing complex concepts, developing practical skills, and supporting 21st-century skills, form the basis for this rapid growth and academic interest. Although accessibility challenges such as the lack of mobile devices and teacher training in related areas persist, innovations such as AI integration and personalized learning experiences are expected to further strengthen the role of AR in education. On the other hand, it highlights the need for studies that integrate technological developments with pedagogical principles and address practical challenges in order to fully utilize the potential of AR for future research. There are some limitations to the study, including the exclusion of Turkish studies, which is a significant limitation. Future studies may consider including Turkish publications. Additionally, studies included from the WoS, Scopus, PubMed, Lens, and OpenAlex databases have been used; however, studies from other databases not compatible with analysis in R Studio represent another limitation. Future research could aim to reflect broader trends by incorporating a wider range of databases.

4.1. Directions for future research

In the current study, articles obtained from five separate databases were examined. In future studies, studies covering different types of publications can be conducted.

It has been determined that cooperation and connection between Asia-based institutions and Europe-based studies are quite limited. Programs and funds that will increase cooperation can be created for future research. Joint research projects and exchange programs can reduce this limited connection.

Findings have revealed that AR has broad application potential in various disciplines such as medical and health sciences education. It is recommended that such cross-sector applications be further investigated and AR solutions specific to different fields be developed.

Statement of Researchers

Researchers' contribution rate statement:
ND: Conceptualization, Methodology, Investigation, Writing – original draft, Project administration, Supervision. **TÇ:** Data curation, Resources, Writing – review & editing. **Yİ:** Software, Formal analysis, Validation, Visualization, Writing – review & editing.
Conflict statement:
The researchers have no personal or financial conflicts of interest with other individuals or institutions related to the research.
Data Availability Statement:
The data used to support the findings of this study are available from the corresponding author upon request.
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Ethical Considerations:
Ethics committee approval was not obtained, as it was a review article.
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Yusuf İnel completed a PhD at the Gazi University Institute of Educational Sciences in 2014 and was appointed associate professor in 2020. Specializing in educational sciences and social studies education, the author focuses on topics such as educational technologies, geography education, human rights-based teaching approaches, responsible citizenship, and sustainable development. Contributing to projects supported by the Council of Europe and TUBITAK, the author has worked on integrating democratic values into educational processes. Research includes innovative methods such as EEG-based learning analytics and augmented reality applications to enhance learning efficiency. The author has contributed to social studies education by addressing topics such as sustainable development and environmental awareness, and has worked to develop materials and integrate technology to improve student achievement. Academic publications emphasize critical thinking, empathy, environmental awareness, and the teaching of democratic values.

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