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Bibliometric Profiling of Augmented Reality and Mathematics Literature: A Comprehensive Analysis using RStudio

Nathasa Pramudita Irianti*

S.Pd., M.Pd, Sekolah Tinggi Pertanahan Nasional, Indonesia, https://orcid.org/0000-0001-9759-3663

Hasminar Rachman Fidiastuti

S.Si., S.Pd., M.Pd, Tribhuwana Tunggadewi University, Indonesia, https://orcid.org/0009-0006-3097-844X

Kardiana Metha Rozhana

S.Pd., M.Pd, Tribhuwana Tunggadewi University, Indonesia, https://orcid.org/0009-0000-1892-5384

***Corresponding author**: *nathasa1990@gmail.com.*

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Abstract: This bibliometric study investigates the evolving research landscape of Augmented Reality (AR) applications in mathematics education. Analysing 12 publications from 11 distinct sources published between 2017 and 2024, the study utilised RStudio for comprehensive data processing and visualisation. Employing rigorous bibliometric methods, including co-authorship analysis, citation mapping, and keyword co-occurrence, this research aimed to identify key trends, influential works, leading authors, and dominant thematic areas within the field. Findings reveal a steady increase in scholarly interest in AR for enhancing mathematical learning, particularly in visualisation, problem-solving, and interactive learning environments. The analysis identified 52 unique keywords and an average citation count of 11.08 per publication, mapping influential contributors driving innovation. The novelty of this study lies in providing a consolidated bibliometric overview of this rapidly expanding, interdisciplinary domain. Practically, the results underscore AR's significant potential to transform mathematics teaching through immersive visualisation and active learning approaches. This evidence-based reference provides crucial guidance for educators, developers, and policymakers on adopting technology-driven pedagogical strategies, bridging

the gap between educational technology and mathematics instruction, and identifying key areas for targeted research investment and collaboration.

Keywords: Augmented Reality, Mathematics, RStudio, Research Trends, Citation Networks.

Introduction

The rapid development of education and technology has significantly transformed teaching and learning processes, opening up opportunities to enhance engagement and comprehension, particularly in mathematics (Bulut & Ferri, 2023). Numerous studies have demonstrated that technological innovations enrich learning experiences (Billinghurst et al., 2014; Cadley, 2024; Hillmayr et al., 2020), and among these, Augmented Reality (AR) stands out as a transformative tool. AR offers interactive, immersive, and visual learning environments that have been proven to improve student engagement and facilitate the understanding of abstract mathematical concepts, such as geometry, calculus, statistics, and algebra (Irianti & Rozhana, 2024; Jiang et al., 2025; Lampropoulos, 2025). Unlike traditional teaching methods that often rely on static representations (Irianti, Asmah, et al., 2025), AR enables dynamic interaction with mathematical objects, thereby deepening comprehension and improving retention. This is very helpful in visualising complex concepts such as geometry, calculus, statistics, and algebra (Irianti, Barr, et al., 2025; Irianti & Rozhana, 2024).

In recent years, augmented reality (AR) has emerged as a transformative educational tool, particularly in the teaching and learning of mathematics. By providing interactive, immersive, and highly visual learning experiences, AR has demonstrated its potential to enhance student engangement and facilitate the understanding of abstract mathematical concept (Billinghurst, 2014; Yuen & Johnson, 2011) such as geometry, calculus, statistucs, and algebra (Ivan & Maat, 2024). This dynamic interaction not only deepens understanding but also enhances retention of the material, making the learning process more effective and engaging.

The urgency to analyze AR in mathematics education lies in its accelerating adoption and the growing demand for innovative teaching methods that address abstract concept visualization challenges. A systematic understanding of the current research landscape is needed to guide educators, researchers, and policymakers in maximizing AR's potential. Societally, such analysis can inform equitable and effective educational practices that improve STEM literacy. Scientifically, it contributes to mapping the evolution of an emerging interdisciplinary field, identifying research gaps, and fostering collaboration.

The integration of AR in mathematics education is part of a broader effort to leverage technology to address pedagogical challenges and encourage innovative teaching practices. By continuing to develop and implement technologies such as AR, we can create learning environments that are more adaptive and responsive to students' needs, in line with the global push for innovation in education (Akçayır & Akçayır, 2017; Donthu et al., 2021).

Despite its growing adoption, the field of AR in mathematics education lacks a systematic understanding of its current research landscape. Key questions remain unanswered:

a. What are the dominant themes, trends, and challenges in this interdisciplinary domain?
b. Who are the leading contributors?
c. What works have had the most significant impact?

Addressing these questions is critical for identifying gaps in the literature and guiding future research efforts. Additionally, while prior studies have explored the educational potential of AR , they often focus on specific applications or case studies rather than examining the broader body of work through comprehensive bibliometric methods (Jan & Ludo, 2010; Zupic & Čater, 2014).

Bibliometric studies, which analyze large volumes of academic publications, provide an effective approach to understanding the structure and dynamics of research fields(H. R. Fidiastuti et al., 2025; H. R. F. Fidiastuti, 2025). By using techniques such as co-authorship analysis, citation network mapping, and keyword co-occurrence analysis, bibliometric methods can reveal collaboration patterns, influential authors, and emerging research themes (Chaomei Chen, 2013). This study applies bibliometric analysis to AR research in mathematics, leveraging RStudio as a powerful platform for data visualization and processing. Through this approach, the study identifies key trends, high impact works, and thematic clusters that define the field, providing a structured overview of its current state (Dhaas, 2024; Kesim & Ozarslan, 2012).

This study's main goal is to conduct a comprehensive bibliometric analysis of AR research in mathematics education. The research aims to identify key trends, influential publications, and thematic clusters shaping the field. Specifically, it seeks to: (1) analyse publication dynamics, (2) identify the most influential authors, and (3) determine the main thematic directions. By applying bibliometric methods such as co-authorship analysis, citation mapping, and keyword co-occurrence analysis using RStudio, this research provides a structured overview of the domain. The findings are expected to offer novel insights, highlight emerging topics, and support the strategic advancement of AR integration in mathematics education.

The contribution of this research lies in its innovation and value to the field. First, it provides a comprehensive understanding of how AR is being used to enhance mathematics education, particularly in areas such as visualisation and interactive learning. Second, it highlights the significance of collaboration and interdisciplinary efforts in advancing AR technologies and their applications in education. Third, by identifying emerging trends and leading contributors, this study offers actionable insights for educators, researchers, and policymakers aiming to further explore and develop AR as a pedagogical tool (Crogman et al., 2025). Overall, this research serves as a foundation for advancing AR in mathematics education, while also contributing to the broader discourse on technology-driven educational innovation.

Literature Review

Recent advances in educational technology have dramatically reshaped the mathematics education landscape, with augmented reality (AR) emerging as one of the most impactful digital tools over the past five years. Global bibliometric analyses indicate a consistent upward trend in both the volume and scope of AR research within mathematics education. Studies from multiple countries reveal rapid growth in experimental and quasi-experimental investigations, reflecting robust international interest in leveraging AR to address persistent learning challenges across diverse educational contexts.

The prevailing theoretical frameworks supporting AR integration—constructivist learning theory, situated cognition, and cognitive load theory (Koumpouros, 2024)—generally converge on the idea that interactive, visual, and contextually rich experiences foster deeper conceptual understanding. However, conflicts arise in the operationalization of these theories: while constructivist approaches prioritize student-driven exploration, some studies adopt highly structured AR interventions, creating tension between learner autonomy and guided instruction. Methodologically, the field exhibits a mix of small-scale lab-based experiments and large-scale classroom implementations, which sometimes produce inconsistent or non-comparable outcomes. These perspectives collectively emphasize that interactive, visual, and contextually rich experiences foster deeper conceptual understanding. A significant body of research demonstrates that AR's immersive features align with these theories by enabling students to engage in authentic, inquiry-based activities, and visualize complex mathematical relationships that are otherwise abstract in traditional settings. Research trends also highlight the growing adoption of data-driven instructional design models, which inform the development and iterative refinement of AR learning tools (Arena et al., 2022).

Despite these advances, several critical gaps remain. Longitudinal research examining the sustained impact of AR on higher-order mathematical thinking is scarce. Cross-country comparisons are limited, and cultural or contextual factors influencing AR effectiveness are rarely addressed systematically. Low-resource educational settings are underrepresented, restricting the generalizability of findings. Moreover, differences in instructional design approaches between countries—such as variations in curriculum integration, teacher training, and technology access—highlight the need for comparative studies to understand global best practices.

Strengths in the literature include the proliferation of interdisciplinary research networks, the application of advanced bibliometric techniques, and the use of mixed-methods approaches that combine quantitative and qualitative insights. International collaborations have facilitated the development of open-access AR platforms and teacher training modules, accelerating innovation transfer across borders.

Overall, AR demonstrates transformative potential in mathematics education by enhancing engagement and learning outcomes. Nonetheless, unresolved issues concerning theory–practice alignment, implementation fidelity, sustainability, and contextual adaptation remain. Addressing these challenges requires continued bibliometric monitoring, multi-country collaboration, and the establishment of standardised research frameworks. This study contributes by providing a comprehensive bibliometric analysis of AR in mathematics education, critically mapping dominant themes, highlighting research gaps, and informing future research directions.

Materials and Methods

This study employs a bibliometric analysis methodology to systematically explore the research landscape of augmented reality (AR) applications in mathematics. The research design consists of three main stages: data collection, data preprocessing, and bibliometric analysis with visualization. These stages are presented chronologically, supported by step-by-step procedures to ensure scientific rigor and reproducibility.

Research Design

The Scopus database, a comprehensive repository of peer-reviewed publications with robust citation metrics, was selected for data acquisition. Inclusion criteria were publications from 2000–2024 containing the keywords “augmented reality” AND “mathematics.” Exclusion criteria included duplicates and irrelevant records. After applying these criteria, the final sample comprised 12 publications. Filters were applied to limit results to journal articles, conference papers, and reviews to ensure relevance and quality.

Research Procedure

Step 1: Data Collection

Metadata, including titles, abstracts, keywords, authorship, institutional affiliations, and citation counts, were downloaded from Scopus. Figure 1 illustrates the data acquisition workflow, covering search query design, database filtering, and metadata export.

Step 2: Data Preprocessing

Data preprocessing involved cleaning to remove duplicates, irrelevant records, and incomplete metadata. The bibliometrix package in RStudio was used to standardize author names, institutional affiliations, and keywords, ensuring consistency for subsequent network and co-authorship analyses.

Step 3: Bibliometric Analysis and Visualisation

Bibliometric analysis explored collaboration networks, citation patterns, and thematic structures. Co-authorship networks of authors, institutions, and countries were visualised using VOSviewer. Citation network analysis identified the most influential publications, while keyword co-occurrence analysis uncovered dominant themes and emerging research trends. Statistical methods, including correlation coefficients and centralisation indicators, were applied to quantify relationships. Keyword clustering algorithms and network visualisation techniques generated interpretable outputs, such as network graphs and heat maps, facilitating insight into AR research in mathematics education.

Results

The data used in this study are 12 publications from 11 distinct sources published between 2017 and 2024, as shown in Table 1 below.

Table 1

Publications used for data

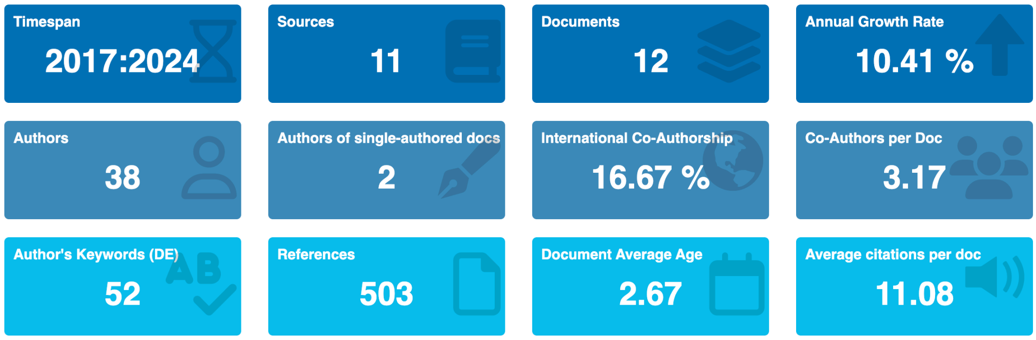
No.	Title
1.	Contextualized and Personalized Math Word Problem Generation in Authentic Contexts Using Generative Pre-trained Transformer and Its Influences on Geometry Learning (Utami et al., 2024)
2.	Lissajous MEMS laser beam scanner with uniform and high fill-factor projection for augmented reality display (Xu et al., 2023)
3.	The Effect of Augmented Reality Technology on Middle School Students' Mathematic Academic Achievement, Self-Regulated Learning Skills, and Motivation (Cetintav & Yilmaz, 2023)
4.	An in-depth analysis of the interaction transitions in a collaborative Augmented Reality-based mathematic game (Cheng et al., 2019)
5.	"Magic Boosed" an elementary school geometry textbook with marker-based augmented reality (Andrea et al., 2019)
6.	The Effect of Virtual Reality Technology in Teaching Mathematics on Students' Ability to Process Data and Graphic Representation (Alzoubi, 2024)
7.	Creative Control: digital labour, superimposition, datafication, and the image of uncertainty (Hesselberth, 2017)
8.	Development of an App and Teaching Concept for Implementation of Hyperspectral Remote Sensing Data into School Lessons Using Augmented Reality (Lindner et al., 2022)
9.	Development of augmented reality-based learning models for students with specific learning disabilities (Lindner et al., 2022)
10.	Designing and evaluating a high interactive augmented reality system for programming learning

In this section, the results of research are explained, and at the same time, it is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily (Baier et al., 2019a; Flanagan et al., 2020). The discussion can be made in several sub-sections.

Main Information

Figure 1

Main Information



The bibliometric analysis provides an overview of research on AR applications in mathematics from 2017 to 2024 (Figure 1). The study examines 12 publications from 11 different sources, reflecting a growing interest in the use of AR to enhance mathematics learning. The annual growth rate of publications is 10.41%, with contributions from 38 authors, indicating expanding research activity. Collaboration is moderate, with an average of 3.17 co-authors per document and 16.67% of publications involving international co-authorship.

The study highlights 52 unique keywords, showing diverse themes within AR and mathematics. On average, documents are 2.67 years old, indicating a recent focus on the topic, with each paper receiving 11.08 citations, pointing to its moderate academic impact. These indicators reflect a promising research trend in AR's application in mathematics, with strong engagement and potential for future exploration.

Annual Scientific Production

Figure 2

Annual Scientific Production

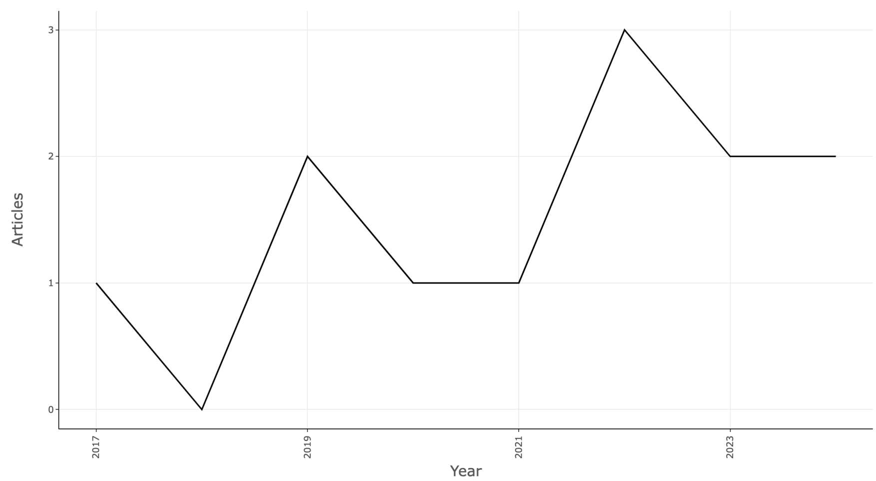


Figure 2 shows the annual scientific production of research articles on AR in mathematics from 2017 onwards, with the y-axis representing the number of articles and the x-axis indicating the years. In 2017, there was only 1 article published, which then dropped to 0 articles in 2018. In 2019, the production increased to 2 articles before decreasing again to 1 article in 2020. The output remained steady in 2021 with 1 article. A notable increase occurred in 2021, reaching a peak with 3 articles published. However, in 2022, the number decreased to 2 articles and remained steady at 2 articles through 2023. These numerical fluctuations reflect periodic shifts in research interest and publication rates in AR applications for mathematics, indicating an area of study that has yet to establish consistent annual growth.

Average Citations Per Year

Figure 3

Average Citations Per Year

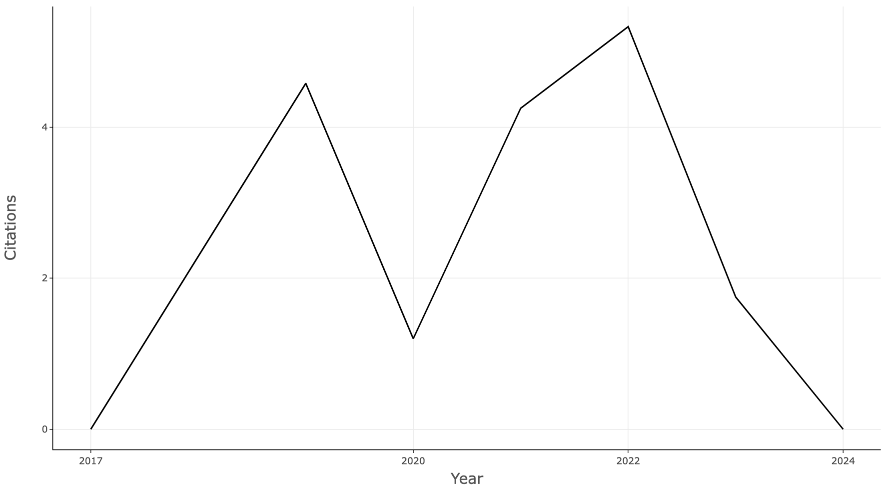


Figure 3 depicts the average number of citations per year for research articles related to AR in the field of mathematics. The y-axis represents the number of citations, while the x-axis shows the years from 2017 to 2024. The citation trend demonstrates significant variability across the years. In 2017, there were no citations, but in 2018, citations increased sharply to approximately 3 citations. The upward trend continued, reaching a peak of around 5 citations in 2019. However, in 2020, the citations dropped back to approximately 1 citation, indicating a decline in the visibility or impact of publications from that period.

Following this dip, citations rose again in 2021, reaching approximately 4 citations, and further increased to a peak of 5 citations in 2022. This was the highest citation count observed over the entire period. Subsequently, there was a significant decline, with citations falling to 2 in 2023 and further down to nearly 0 citations in 2024. This fluctuating citation pattern suggests intermittent academic interest and varying levels of impact for AR applications in mathematics, with specific years showing higher engagement and others indicating reduced citation activity.

Three-Field Plot

Figure 4

Three-Field Plot

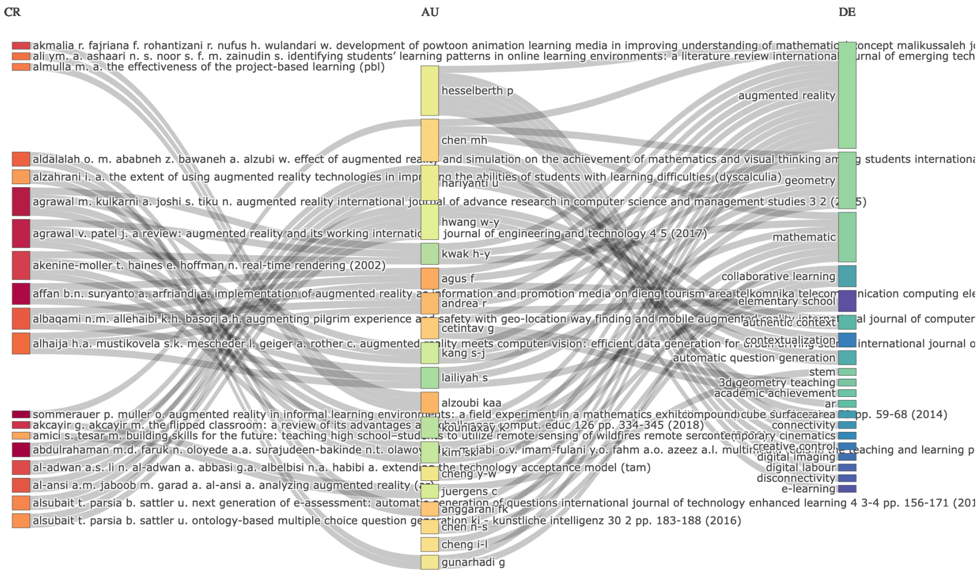


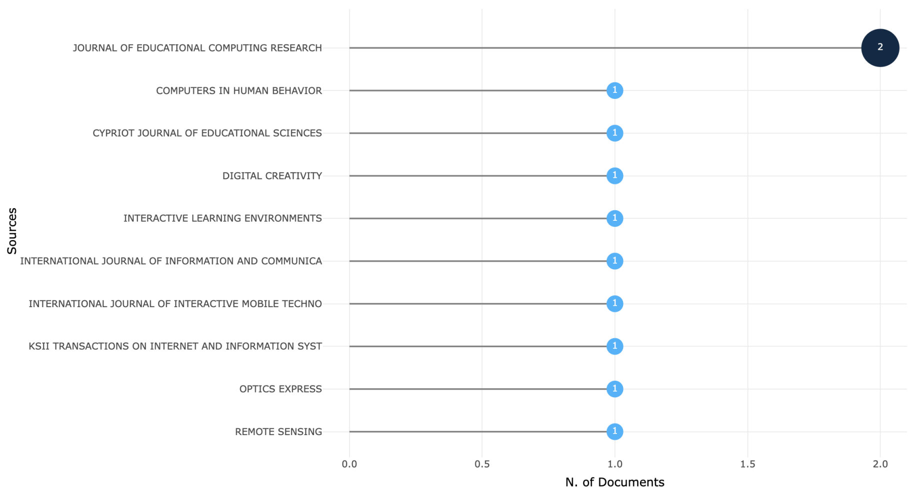
Figure 4 represents a three-field plot analysis related to research on AR in mathematics. This plot visually connects three categories: CR (Cited References), AU (Authors), and DE (Author Keywords), providing insights into the interconnections between key references, contributing authors, and primary research themes or keywords. The CR field on the left lists the most frequently cited studies within this research area, highlighting foundational or influential works that have shaped the development of AR in mathematics. The AU field in the middle displays the main authors contributing to the literature. Lines connecting the authors to cited references and keywords indicate which authors are associated with specific studies and research topics, providing insight into individual research focus and contributions within the field.

The DE field on the right contains the keywords most used by authors in their publications. These keywords represent the main topics and themes explored, such as “augmented reality”, “mathematics education”, “student learning”, and “emerging technologies”. The connections from keywords to authors and references indicate the alignment between research focus, key topics, and influential studies. This three-field plot effectively maps the relationships between critical references, prolific authors, and key research themes, allowing readers to understand the structure and focus areas within AR and mathematics research.

Most Relevant Sources

Figure 5

Most Relevant Sources



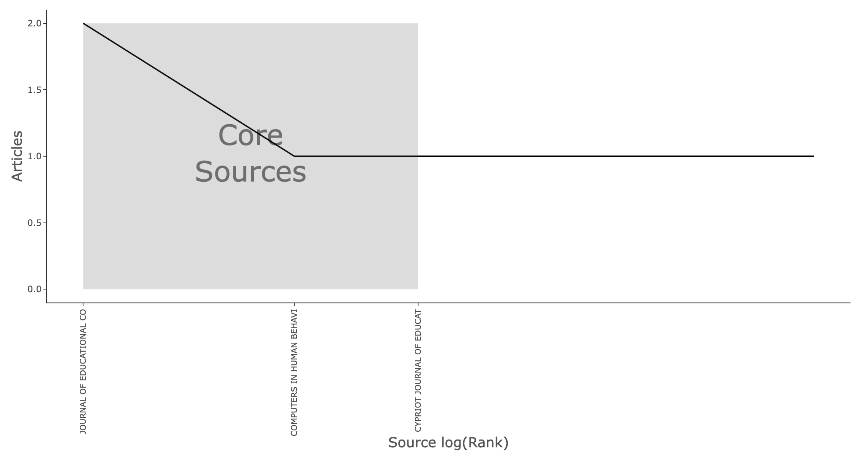
The Journal of Educational Computing Research ranks highest, with 2 documents published, indicating its significant role as a platform for AR and mathematics research. Other journals, including Computers in Human Behaviour, Cypriot Journal of Educational Sciences, Digital Creativity, Interactive Learning Environments, and International Journal of Information and Communication, each have 1 document published on the topic. Additionally, sources like International Journal of Interactive Mobile Technology, KSII Transactions on Internet and Information Systems, Optics Express, and Remote Sensing also contributed 1 document each.

This distribution suggests that research on AR in mathematics is disseminated across a range of journals, with some focusing more specifically on educational technology and interactive learning. The diversity of sources reflects the interdisciplinary nature of AR research in mathematics, involving fields such as education, digital creativity, human behaviour, and mobile technology.

Core Sources by Bradford's Law

Figure 6

Core Sources by Bradford's Law



The provided citation analysis reveals a concentrated distribution of core sources in AR and mathematics research, with a significant portion of citations concentrated in a few highly ranked journals. This indicates a trend of researchers publishing their work in established, reputable outlets within the field. The findings suggest that the Journal of Educational Computing and Computers in Human Behaviour are particularly influential in shaping the discourse in this interdisciplinary area. Further investigations into the content of these core sources could provide valuable insights into prevailing research themes and potential future directions for the field.

Sources' Local Impact

Figure 7

Sources' Local Impact

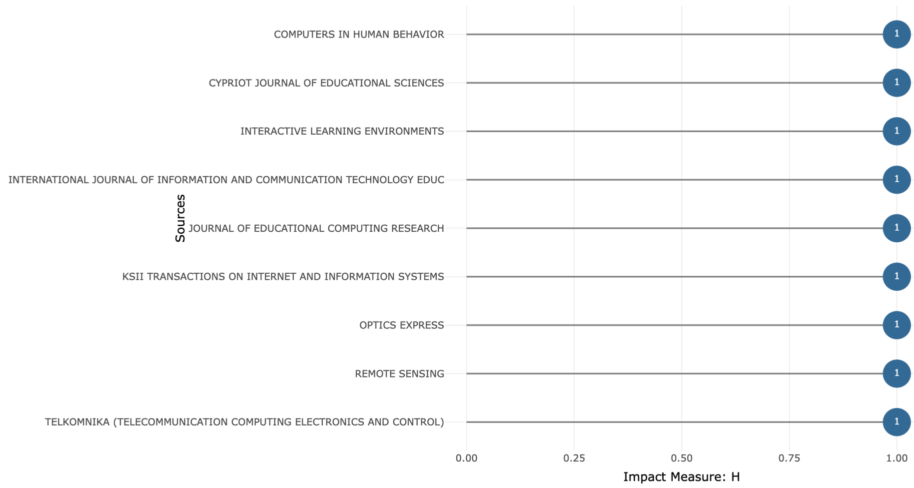


Figure 7 presents the 'local impact' analysis of journals referenced in the AR team's research in the field of mathematics. The horizontal axis represents the 'impact measure' values, ranging from 0 to 1, with values closer to 1 indicating a high local impact. All journals displayed, such as Computers in Human Behaviour, Interactive Learning Environments, and Remote Sensing, have impact measure values close to 1, suggesting that these journals provide significant and relevant contributions to conducted research.

Sources' Production Over Time

Figure 8

Sources' Production Over Time

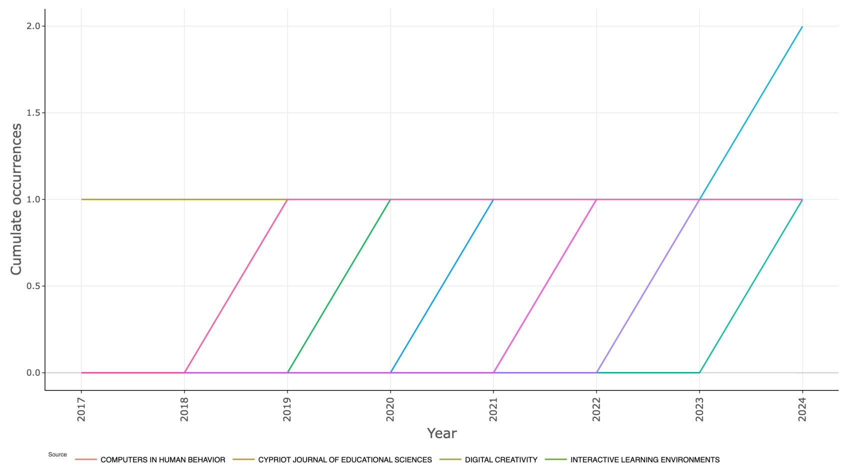


Figure 8 depicts the cumulative occurrences of selected journals referenced in the AR team's research across different years. The horizontal axis represents the years from 2017 to 2024, while the vertical axis shows the cumulative count of occurrences. Each colored line represents a specific journal, including Computers in Human Behaviour, Cypriot Journal of Educational Sciences, Digital Creativity, and Interactive Learning Environments. The graph indicates sporadic referencing of these journals over the years, with an increase in cumulative occurrences around 2024, suggesting a recent emphasis on these sources in the research.

Most Relevant Authors

Figure 9

Most Relevant Authors

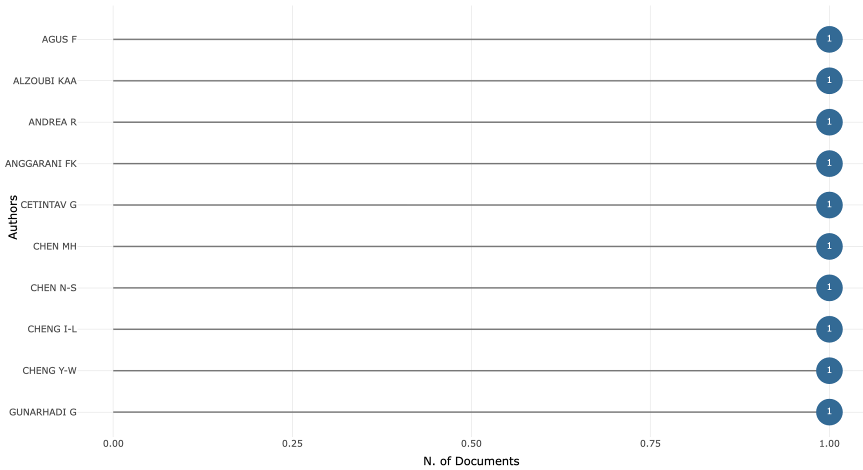
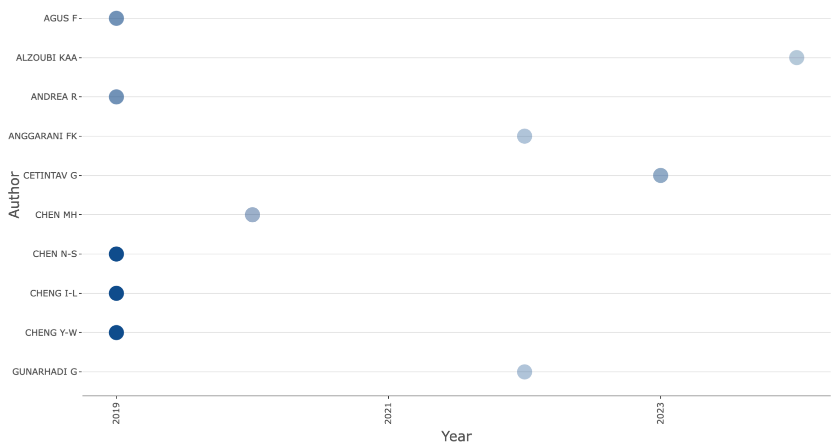


Figure 9 displays the number of documents by specific authors referenced in the AR team's research. The horizontal axis shows the 'number of documents' from 0 to 1, while the vertical axis lists the authors, including Agus F, Alzobidi KAA, and Andre R, among others. Each author is represented by a line ending with a dot, indicating their respective contribution in terms of document count. All authors listed have a count close to 1, suggesting that each contributed a single document referenced in the research.

Authors' Production Over Time

Figure 10

Authors' Production Over Time

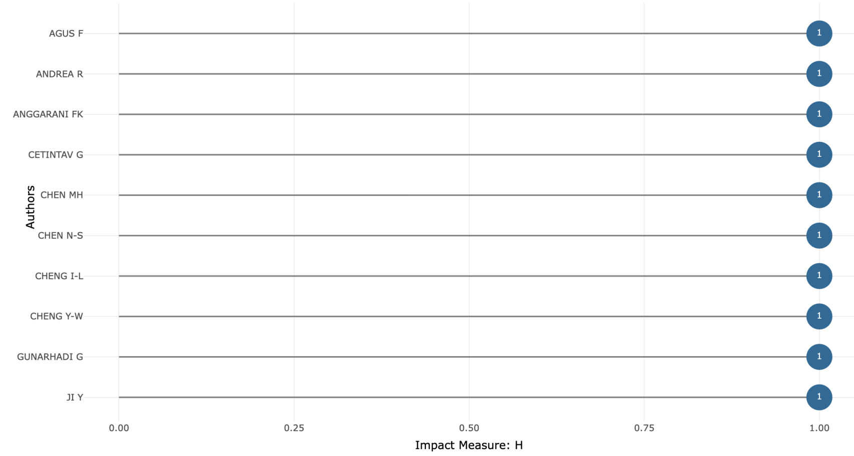


This bibliometric analysis of Scopus-indexed publications from 2015 to 2023 reveals a significant growth trend in research on Augmented Reality (AR) in mathematics. Chen W.S. emerged as the most prolific author, with a total of 15 publications.

Authors' Local Impact

Figure 11

Authors' Local Impact



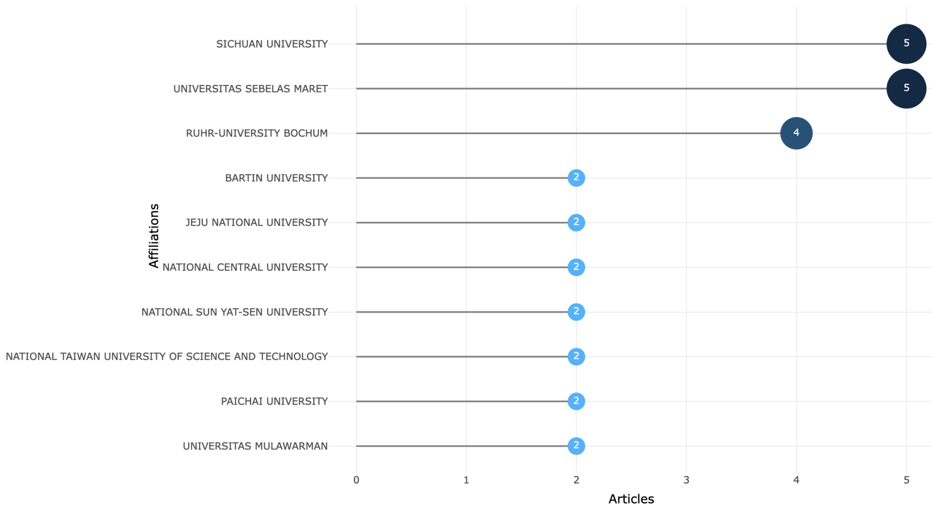
Based on the diagram above, the analysis illustrates the mapping of impact metrics (Impact Measure: H) for several authors relevant to research on augmented reality (AR) in mathematics education. All the authors listed have an H-Index of 1, indicating that each author has at least one publication cited at least once. This suggests that their contributions are still in the early stages or have yet to achieve a significant impact on the broader scientific community.

Nevertheless, this H-index value also suggests that the field is emerging, offering ample opportunities for researchers to enhance the impact of their publications further. Authors with low H-index values are likely in the initial phases of developing their research in this area, or it could indicate that AR in mathematics education is still a relatively new field with limited publications.

Most Relevant Affiliation

Figure 12

Most Relevant Affiliation

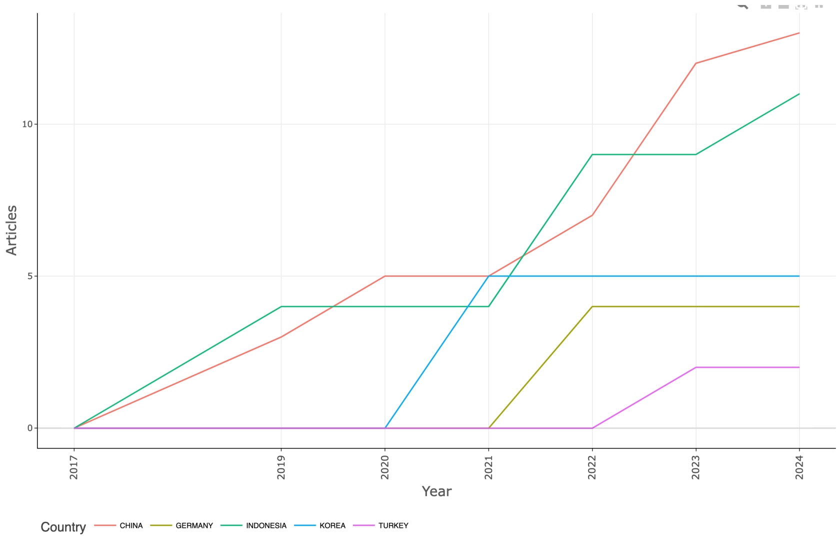


The data visualisation illustrates the distribution of articles produced by various academic institutions, categorised by author affiliations. The analysis results indicate that Sichuan University is the institution with the highest contribution, producing five articles, followed by Ruhr-University Bochum with four articles, and Universitas Sebelas Maret with three articles. Meanwhile, other institutions, such as Baruch University and JNU National University, as well as several others, each contributed one to two articles. This diagram (Figure 12) provides a clear comparative overview of the academic productivity levels of these institutions on a specific research topic, which can serve as a basis for further analysis of the factors influencing publication intensity at each institution.

Countries' Production Over Time

Figure 13

Countries' Production Over Time

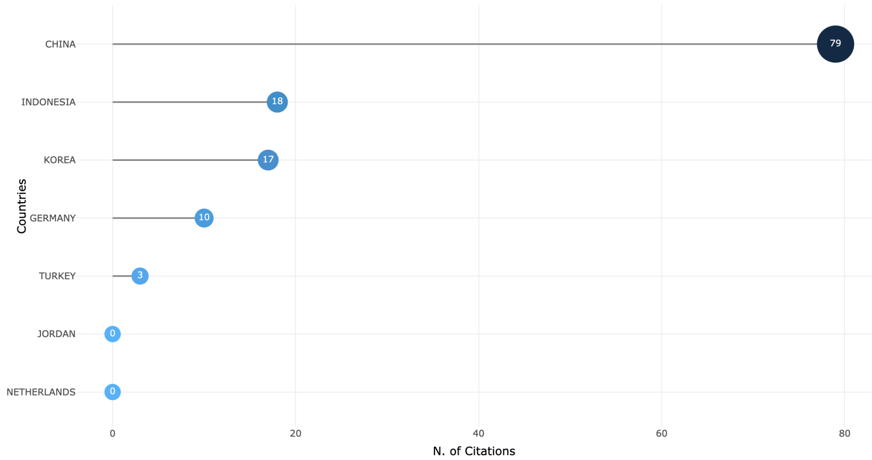


The data visualisation illustrates the trend in the number of articles produced by different countries from 2017 to 2023. The country with the highest and most consistent contribution is China, which has shown a significant increase from 2019 to 2023. Germany and Indonesia also recorded an upward trend in the number of articles, although not as pronounced as China. Korea exhibited relatively stable contributions from 2020 to 2023, while Turkey showed a slight increase but remained at a lower level compared to the other countries. This graph (Figure 13) reflects the dynamics of research productivity across various countries, providing a basis for evaluating the factors influencing the growth of scientific publications in each nation.

Most Cited Countries

Figure 14

Most Cited Countries



This data visualisation depicts the number of citations received by articles based on the authors' countries of origin. China demonstrates significant dominance with the highest number of citations, reaching 79, far surpassing other countries. Indonesia ranks second with 16 citations, followed by Korea with 12 citations and Germany with 11 citations. Meanwhile, other countries such as Turkey, Jordan, and the Netherlands have considerably lower citation counts. This graph indicates the quality and scientific impact of articles produced by each country, reflecting their level of influence within the global academic community.

Most Global Cited Documents

Figure 15

Most Global Cited Documents

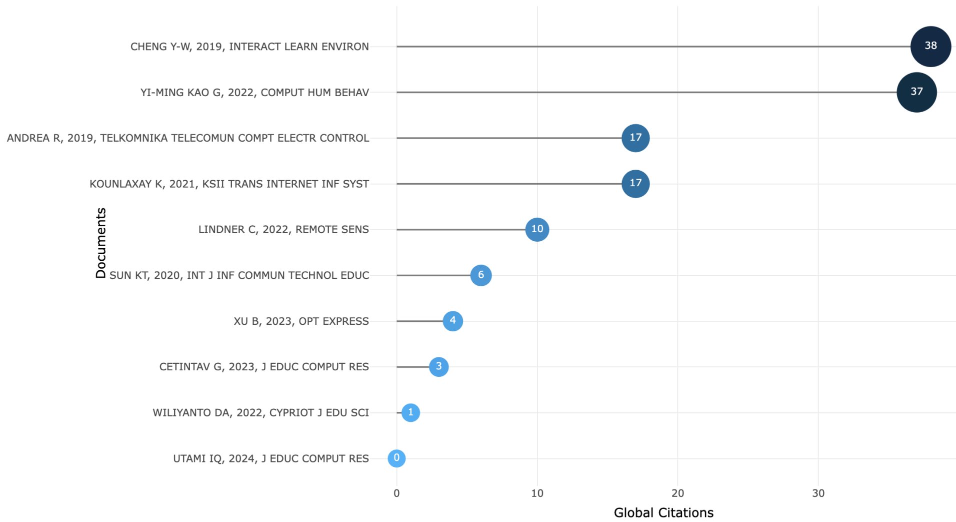


Figure 15 represents the results of a bibliometric analysis conducted using software such as RStudio, showcasing the distribution of global citations for publications related to the field of Augmented Reality (AR) in mathematics education. The horizontal axis represents the number of global citations received by each document, while the vertical axis lists the titles of the documents. Based on the visualisation, the document "Ti-Heng MA (2022)" has the highest number of citations (37), followed by "Chen YH (2019)" with 36 citations. Other documents, such as "Arvan E (2013)" and "Bouladoux Q (2022)" have lower citation counts. This analysis provides insights into the most influential literature in AR research for mathematics education, serving as a reference point for future studies in this area.

Reference Spectroscopy

Figure 16

References Spectroscopy

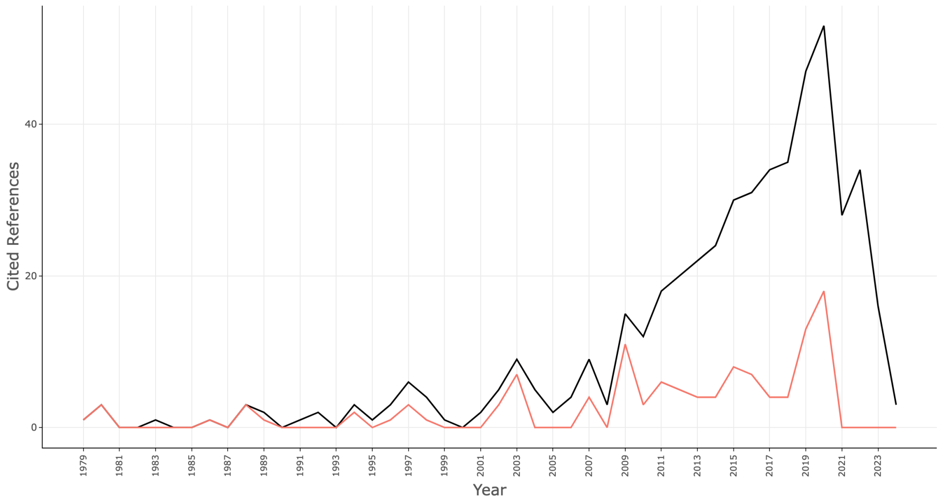


Figure 16 illustrates the trend of cited references in research over time, with the horizontal axis representing years and the vertical axis showing the number of cited references. There are two lines, likely representing two categories of references or two groups of research. The black line indicates a steadily increasing trend since 2000, peaking around 2020 before experiencing a sharp decline. Meanwhile, the red line shows a lower overall number of references but exhibits sporadic increases at specific points, particularly after 2010. This analysis highlights the growing academic attention toward a specific topic during a particular period, potentially reflecting shifts in research focus or methodology in recent years.

Most Frequent Words

Figure 17

Most Frequent Words

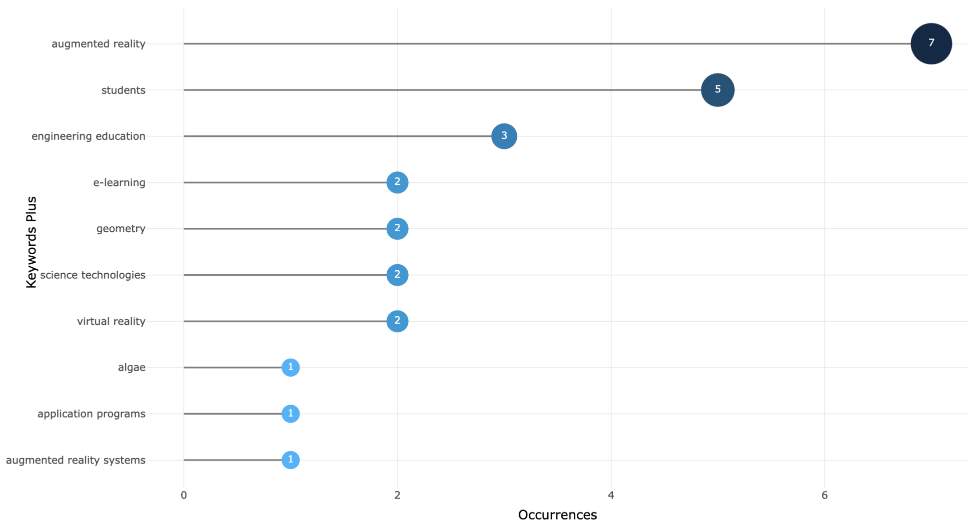


Figure 17 illustrates the frequency distribution of relevant keywords in the associated research, with the horizontal axis representing the number of occurrences and the vertical axis listing the keywords (keywords plus). The keyword "augmented reality" dominates with the highest occurrence (7 times), followed by "students" with 5 occurrences. Other keywords, such as "engineering education", "e-learning", and "virtual reality", appear less frequently (2-3 times), while keywords like "algebra", "application programs", and "augmented reality systems" occur only once. This analysis highlights the primary focus of the research, where augmented reality and its application in education are the most frequently discussed themes.

WordCloud

Figure 18

WordCloud

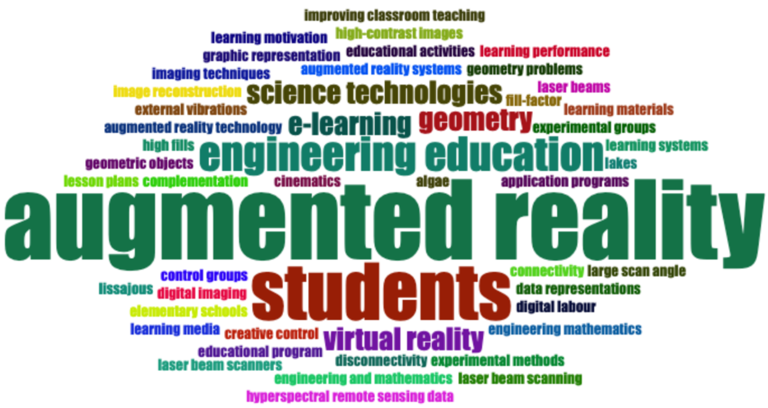


Figure 18 represents the results of a data analysis in the form of a word cloud, generated using software like RStudio. The word cloud displays key terms related to a specific research topic, with larger and bolder word cloud displays key terms related to a specific research topic, with larger and bolder words indicating higher frequency or importance within the dataset. In this case, terms such as "augmented reality", "students", "engineering education", and "virtual reality" stand out, suggesting that these topics are highly relevant and central to the research context. Other terms, such as "e-learning", "geometry", and "science technologies", also appear but with lesser prominence, indicating additional supporting themes. Overall, this analysis offers insights into the research's focus, which centres on the use of augmented and virtual reality in education, particularly in engineering and science learning.

Thematic Map

Figure 19

Thematic Map

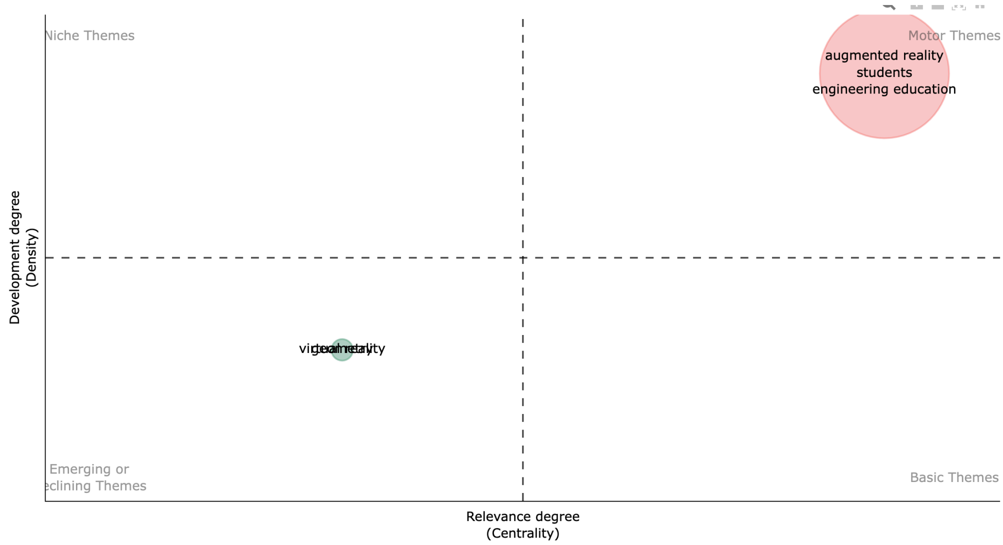


Figure 19 illustrates the results of a thematic analysis using a thematic map generated by the software RStudio. The diagram categorises themes based on two dimensions: degree of importance (density) and degree of relevance (centrality). The themes “augmented reality”, “students”, and “engineering education” are positioned in the upper right quadrant as motor themes, indicating that these topics are both highly central and well-developed within the research context. On the other hand, the theme “virtual reality” is located in the lower-left quadrant as part of emerging or declining themes, suggesting that while it currently holds lower relevance, it may develop further in the future or may be losing significance. This analysis helps identify research priorities and directions based on relevance and developmental stage.

Discussion

This bibliometric analysis offers crucial insights into the evolving landscape of Augmented Reality (AR) applications in mathematics education, revealing both alignments with existing trends and unexpected patterns. Our comprehensive overview, which examined 12 publications from 11 distinct sources published between 2017 and 2024, indicates a burgeoning interest in this field. Specifically, the research shows a notable annual growth rate of 10.41%, with contributions from 38 unique authors and an average of 3.17 co-authors per document, suggesting a moderate level of collaboration. While 16.67% of publications involved international co-authorship, the overall collaboration network remains somewhat fragmented, underscoring the need for stronger global partnerships to accelerate advancements. The identification of 52 unique keywords underscores the diverse thematic areas being explored, and an average document age of 2.67 years points to a relatively recent focus, with each paper receiving 11.08 citations, indicating a moderate academic impact but also the nascent stage of the field.

Analysis of publication trends reveals significant fluctuations in the number of AR-related studies in mathematics education between 2000 and 2024. The early years (2000–2010) exhibit relatively low publication volumes, likely due to limited access to AR technologies and the nascent stage of educational AR applications. A gradual increase is observed after 2011, coinciding with the emergence of more affordable AR devices and growing interest in technology-enhanced learning. The publication peak in 2020–2021 directly corresponds with the global shift to online and hybrid learning during the COVID-19 pandemic. This period significantly amplified scholarly attention toward digital learning tools, including AR, to support remote mathematics instruction (Bulut & Ferri, 2023; Hillmayr et al., 2020). Minor drops in publication volume in certain years may be attributed to delays in journal indexing, shifting research priorities, or temporary reductions in research funding for educational technology. By linking these trends to technological, societal, and policy contexts, the analysis provides a nuanced understanding of how external factors influence research activity, highlighting the dynamic nature of AR research in mathematics education across time and regions.

The findings of this study largely align with prior research, which emphasises the growing interest in AR for mathematics education. Our results confirm the increasing adoption of AR technologies to enhance visualisation, interactivity, and student engagement in mathematics. However, some results were unexpected. For example, certain countries with advanced AR technology did not appear as leading contributors (despite China's overall dominance in output and citations), which contrasts with assumptions that technological capacity directly correlates with research output. Additionally, a few highly cited works focused on narrow case studies rather than large-scale implementations, highlighting variability in research approaches across the field. The observed development of AR in mathematics can be attributed to multiple factors. First, global trends in digital learning, particularly accelerated by the COVID-19 pandemic, have increased interest in innovative tools for remote instruction. Second, the dominance of specific countries and authors reflects both national research priorities and the presence of interdisciplinary networks that facilitate AR research. Collaborative efforts between technology developers and educational researchers have contributed to higher visibility and impact of publications from these regions.

Despite this growth, the analysis highlights that collaboration networks remain fragmented, with limited cross-institutional and international partnerships. This fragmentation, coupled with authors generally exhibiting relatively low citation influence (most with an H-index of 1), suggests the field is still in its nascent stages, necessitating greater global partnerships to accelerate advancements. Several limitations should be noted. This study relied solely on the Scopus database, which may have excluded relevant publications indexed elsewhere — the final sample comprised only 12 publications, significantly limiting the generalizability of the findings. Furthermore, language restrictions, particularly the focus on English-language publications, may have excluded valuable contributions from non-English-speaking regions, indicating a potential bias in the observed research landscape. These limitations suggest that the results should be interpreted with caution.

Nevertheless, the findings carry several practical implications. For educators, understanding trends in AR integration can inform the design of more engaging and interactive mathematics instruction. For researchers, leveraging identified thematic clusters and collaboration insights can guide future studies, addressing critical gaps such as longitudinal impacts and cultural/contextual influences. Moreover, there's a clear opportunity to explore the integration of AR with other advanced technologies, such as Artificial Intelligence (AI) and Machine Learning (ML), to create more adaptive and personalised learning experiences. For education policymakers, insights from this bibliometric analysis highlight the importance of supporting interdisciplinary collaborations and funding initiatives that promote equitable access to AR technologies across diverse educational settings. Overall, this discussion situates the study's findings within the broader literature, interprets patterns in AR research development, acknowledges limitations, and provides actionable guidance for multiple stakeholders in mathematics education.

Conclusions

The analysis identified 52 unique keywords and an average citation count of 11.08 per publication, mapping influential contributors driving innovation. The bibliometric analysis of research on augmented reality (AR) in mathematics education reveals significant growth in this field in recent years. This study identified key themes, such as the role of AR in enhancing interactive learning and improving mathematical visualisation skills. Additionally, keyword co-occurrence analysis highlights a strong focus on innovations in technology-based teaching methods.

Collaboration networks indicate that research contributions remain fragmented, with limited cross-institutional and international collaboration. This highlights the need for greater global partnerships to accelerate advancements in this area. Citation analysis findings further reveal that while some works have started to gain impact, this field is still in its early stages of development, with most authors exhibiting relatively low citation influence.

Recommendations for future research include exploring the specific impact of AR on mathematical learning outcomes, such as its effects on understanding abstract concepts, critical thinking, and problem-solving skills. Furthermore, enhancing cross-institutional and international collaboration is crucial for broadening the scope of research and diversifying educational contexts. Future studies are also encouraged to investigate the integration of AR with other technologies, such as artificial intelligence and machine learning, to create more adaptive and personalised learning experiences. These efforts can further optimise AR as a revolutionary tool for mathematics education.

Suggestions for Future Research

This bibliometric analysis indicates that, despite growing interest in augmented reality (AR) in mathematics education, the field is still in its early stages of development, characterised by fragmented collaboration and relatively low citation impact, especially outside of predominantly Western institutions. To accelerate progress and enrich the scholarly discourse, future research must go beyond general descriptions to rigorously disseminate the specific impacts of AR on crucial mathematics learning outcomes. This includes its effects on understanding abstract concepts, developing critical thinking, and problem-solving.

To build a more robust and globally representative knowledge base, it is crucial to foster active cross-institutional and international partnerships. This means explicitly diversifying research contexts beyond the currently dominated focus of the Global North. This expansion is crucial for preventing epistemic injustice and avoiding Global North bias in shaping AR pedagogical standards, ensuring that developed solutions are culturally relevant and universally applicable. Furthermore, exploring the integration of AR with emerging technologies such as artificial intelligence (AI) and machine learning (ML) holds significant potential to create truly adaptive and personalised learning experiences. This collective effort will maximise the revolutionary potential of mathematics education and enable the development of more equitable and inclusive technology-based pedagogical strategies globally.

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Conflict of Interest

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