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Augmented Reality in Mathematics Education: A Bibliometric Analysis Utilizing the Scopus Database

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A B S T R A C T

Augmented reality (AR) is a technology that combines real and virtual elements to create a hybrid experience. Research has shown that AR can improve spatial abilities, assist learning, and increase motivation in students. It has also been demonstrated to facilitate collaborative learning and the evolution of learning in mathematics. The purpose of this study is to analyze the status and trends of AR research in mathematics education over the past 20 years. AR has been studied extensively and has many potentials uses in education and learning, but it may be used more frequently in certain situations or for specific goals. The study used Scopus and PRISMA to conduct a systematic review of articles and Biblioshiny software for bibliometric analysis, including co-citation and co-author analysis. The research on augmented reality in mathematics education has grown steadily over the past 20 years and has had a significant impact, with an average of 13.74 citations per document. It has also been conducted and disseminated internationally and has seen a recent increase in publications. The most relevant source for this research is "Journal of Physics: Conference Series". Indonesia is the most productive country in this research, followed by Mexico and China. Keywords in the research include "mathematics education," "augmented reality," and "teaching and learning."

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A B S T R A K

Augmented reality (AR) adalah teknologi yang menggabungkan elemen-elemen nyata dan virtual untuk menciptakan pengalaman hibrida. Penelitian telah menunjukkan bahwa AR dapat meningkatkan kemampuan spasial, membantu pembelajaran, dan meningkatkan motivasi siswa. AR juga telah terbukti dapat memfasilitasi pembelajaran kolaboratif dan perkembangan pembelajaran matematika. Tujuan dari penelitian ini adalah untuk menganalisis status dan tren penelitian AR dalam pendidikan matematika selama 20 tahun terakhir. AR telah dipelajari secara ekstensif dan memiliki banyak potensi penggunaan dalam pendidikan dan pembelajaran, tetapi mungkin lebih sering digunakan dalam situasi tertentu atau untuk tujuan tertentu. Penelitian ini menggunakan Scopus dan PRISMA untuk melakukan tinjauan sistematis artikel dan perangkat lunak Biblioshiny untuk analisis bibliometrik, termasuk analisis kutipan dan penulis bersama. Penelitian tentang augmented reality dalam pendidikan matematika telah berkembang dengan mantap selama 20 tahun terakhir dan memiliki dampak yang signifikan, dengan rata-rata 13,74 kutipan per dokumen. Penelitian ini juga

Keywords:
Mathematic Anxiety, Systematic Literatire Review, Mathematic Learning.

telah dilakukan dan disebarluaskan secara internasional dan mengalami peningkatan dalam hal publikasi. Sumber yang paling relevan untuk pencarian ulang ini adalah "Journal of Physics: Seri Konferensi". Indonesia merupakan negara yang paling produktif dalam penelitian ini, diikuti oleh Meksiko dan Cina. Kata kunci dalam penelitian ini meliputi "pendidikan matematika," "augmented reality," dan "pengajaran dan pembelajaran."

1 Introduction

Milgram et al. [1] define augmented reality (AR) as a real-time picture of a physical environment that has been augmented with computer-generated virtual data. Similarly, Carmigniani & Furht [2] define AR as a real-time picture of a physical environment that has been augmented with computer-generated virtual data. These definitions emphasize the essential features of AR as a technology that blends real and virtual elements to create a hybrid experience. Milgram et al. [1] and Carmigniani & Furht [2] provide insights on the current state of AR and its future applications, such as its usage in education [3]. Furht [4] also provides an outline of AR and its present and future developments. These papers highlight the growing interest in and potential of AR as a technology with numerous applications.

Palancı & Turan, 2021 [5] explain that AR can help boost students' spatial abilities, assist learning, and motivation. Bujak et al. [6] also discovered that AR can facilitate the symbolic comprehension of abstract concepts by scaffolding the learning process. In addition, AR allows collaborative learning in non-traditional settings and creates opportunities for individually meaningful experiences [7]. Saidin et al. [7] also showed that the advantages of AR technologies outweigh those of conventional technologies (such as e-learning and courseware) and conventional teaching techniques (such as chalk and talk and traditional books). The research indicates that AR technology may have a favorable impact on education.

AR has been proven to assist students in learning mathematics. Cai et al. [8] and Palancı & Turan [5] showed that AR has a good influence on students' mathematical learning. Additionally, Estapa and Nadolny [9] demonstrated that incorporating AR into a mathematics class boosts student achievement and motivation. Bujak et al. [6] revealed that AR can facilitate collaborative learning in mathematics and facilitate the evolution of learning. Although there may be some disadvantages to adopting AR in mathematics education, such as technical issues and student

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aversion to new technology, the research suggests that AR can be a beneficial tool for assisting students in learning mathematics.

Bibliometric studies on how AR can be used have been written up in a number of articles. Several of them discuss the development of AR in a variety of fields. Santosa et al. [10] found numerous studies of AR and its application as a learning medium. Karakus et al. [11] discovered that AR is frequently investigated in the context of virtual reality, mobile learning, interactive learning environments, and e-learning. Cadavieco et al. [12] noted that AR is a great source of data for knowledge development. However, [13] observed that AR is primarily used in therapy settings as opposed to teaching scenarios. Based on these results, it seems that AR is a technology that has been studied a lot and has many possible uses in education and learning. However, it may be used more often in certain situations or for certain goals.

Even though the importance of AR has been recognized, there has been no attempt to collect data on the scientific production of AR research in mathematics education. Bibliometric analysis has been used to study the advancement of knowledge. It can provide an accurate and possibly objective measurement of the value of a paper or author. Various bibliometric indicators have been used to analyze trends and performance, including annual production, country of publication, affiliation, journal, and author keywords. The purpose of the study is to analyze the status and trends of AR research in mathematics education in the last 20 years.

2 Method

Scopus was used in this study. "Selected Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) was used to conduct a systematic review of the articles in the analysis, and the bibliometric analysis method was used to generate knowledge maps utilizing Biblioshiny software for co-citation and co-author analysis.The four steps of bibliometric analysis research are collecting data, pre-processing the data, calculating statistics, and analyzing how the data is used.

Keywords are used to start bibliometric analysis. For this, more than 100 research articles will be highlighted that were recently published and had a decent amount of citations collected from the Scopus Database to list important author keywords that are regarded as the central theme of "Augmented Reality in Mathematics Education." With this query string TITLE-ABS-KEY ("augmented reality" AND "mathematics education" OR "mathematics learning" OR "mathematics classroom"), it generates 107 documents on January 6, 2023, on the website www.scopus.com.

At this level, 107 documents were obtained that met the criteria for the first stage. No language is screened during the second phase of the procedure. Investigations are limited to documents published in Scopus-indexed journals. The initial data is still used in this stage, but no data is excluded from the data generated in the first stage. In the third stage, the researcher evaluates

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the feasibility of the article by examining the article title and abstract to determine whether it meets the researcher's criteria, such as discussing the use of AR in learning mathematics or not. In the final stage, the researcher still used 107 documents from the previous data collection procedure. In the final stage, data stored in *.ris, *.csv, and *.bib formats was analyzed using the Biblioshiny program, which is a library from Bibliometrix in the R programming language [14]–[18].

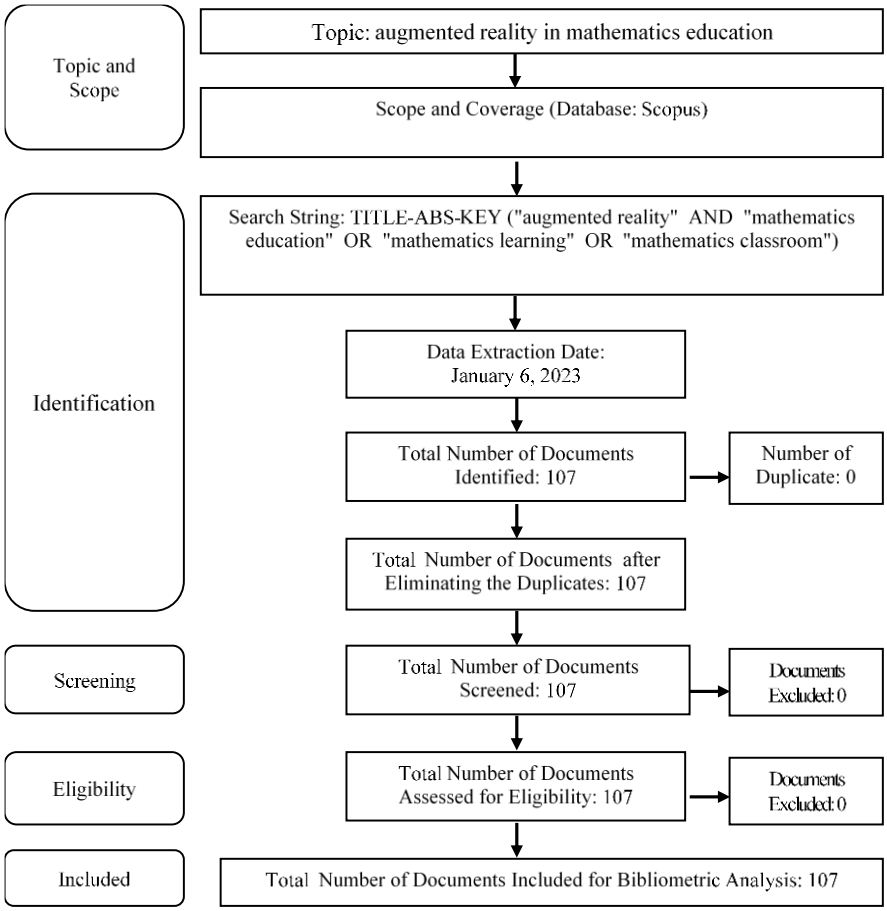

Fig. 1. Flowchart of the PRISMA Methodology and Bibliometric Analysis

3 Result and Discussion

3.1 Main Information of AR in Mathematics Education

The 20-year research on AR in mathematics education includes data from many sources (2002-2022). 65 journals, books, and other sources were used to analyze 107 documents. The data shows a 9.67% annual growth rate, indicating that the number of documents published on this topic has been rising steadily. The average document age is 4.36 years, so the data is current. The average number of citations per document is 13.74, indicating that these publications' research has had a major impact on the field. 3128 references show a comprehensive literature review. 445 keywords plus (ID) and 214 author's keywords are in the documents (DE). These keywords categorize and

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index documents, making them easier to search and find. There are 261 authors and 6 single-authored documents. On average, each document has 2.93 co-authors, and 7.477% of the documents have international co-authorships, indicating collaboration and international exchange in this topic's research. Articles (34), book chapters (4), conference papers (56), and conference reviews (34) were analyzed (13). This variety of document types reflects the diverse ways research on AR in mathematics education is conducted and disseminated.

Table 1. Main Information of Publication from Scopus Database

Description	Results
Timespan	2002:2022
Sources (Journals, Books, etc)	65
Documents	107
Annual Growth Rate %	9.67
Document Average Age	4.36
Average citations per doc	13.74
References	3128
Keywords Plus (ID)	445
Author's Keywords (DE)	214
Authors	261
Authors of single-authored docs	6
Single-authored docs	19
Co-Authors per Doc	2.93
International co-authorships %	7.477
article	34
book chapter	4
conference paper	56
conference review	13

3.2 Annual Publication of AR in Mathematics Education

Research publications on AR **in mathematics education show the number of articles published on this issue each year from 2002 through 2022 illustrated in Fig. 2. The Fig. 2 shows that 2019–2022 had the most papers published. Articles were published 15, 21, 19, and 19 times in these years. These data imply that research in this area has increased significantly in recent years, with a particular spike in publications in the past four years. In 2004, 2005, 2006, 2007, 2008, and 2011, no articles were published. These years may indicate times of**

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relative quiet in the subject, or they may simply reflect the fact that the data utilized in research publications only includes articles from particular sources.

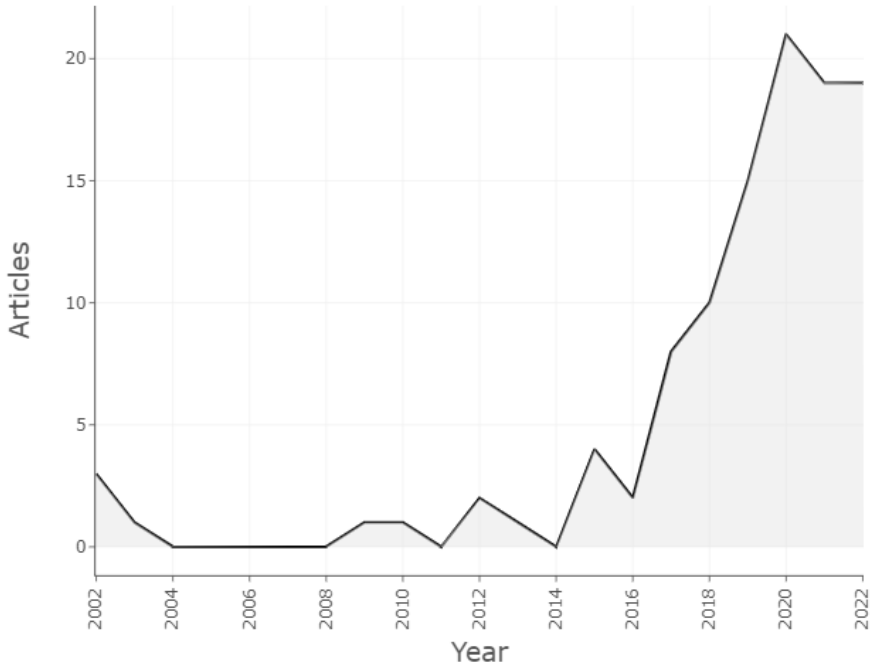

Fig. 2 Annual Publication and cumulative from Scopus Database

3.3 Most Relevant Source of AR in Mathematics Education

The most relevant sources listed in Table 2. Research publications on AR in mathematics education shows the sources with the most articles on this topic. The Table 2 shows the source's name and the number of articles it has published, making it easy to discover the most important sources for this topic's study. "Journal of Physics: Conference Series" has published 19 articles on this topic, according to the Table 2. This shows that this magazine is a particularly important source of knowledge about AR in mathematics education. "AIP Conference Proceedings," "ACM International Conference Proceeding Series," and "Procedia Computer Science" have also published many publications on this topic (4 articles). Researchers and instructors looking for the latest and most relevant papers may also consider these sources. The most relevant sources shows the most important sources for AR in mathematics education research. Researchers and educators can use it to find the most essential sources of information on this topic and focus their search accordingly. The Table 2 provides comparison information about sources' contributions to the topic's study.

Table 2. Top 10 Most Relevant Sources

Sources	Articles

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Journal of Physics: Conference Series	19
AIP Conference Proceedings	5
ACM International Conference Proceeding Ser	4
Procedia Computer Science	4
Augmented Reality in Educational Settings	3
Education and Information Technologies	3
Education Sciences	3
Lecture Notes in Computer Science (Includi Subseries Lecture Notes in Artificial Intelligence a Lecture Notes in Bioinformatics)	3
17th Conference on Applied Mathemati APLIMAT 2018 – Proceedings	2
Advances in Intelligent Systems and Computin	2

3.4 Most Relevant Countries of AR in Mathematics Education

The Table 3 listed top 10 most relevant countries by corresponding author in research publications on AR in mathematics education show the countries with the most articles on this topic. The Table 3 lists the country and the number of articles, single-authored papers (SCP), and multi-authored papers (MCP) by authors from that country. With 11 articles, Indonesia has the most on this topic, according to the Table 3. There were ten single-authored articles and one multi-authored article included. This shows that Indonesia is a leader in mathematics education and AR. Mexico is the second-most productive country with seven single-authored publications. China has published five publications, three of which were single-authored and two multi-authored. The most relevant countries by corresponding author shows how research on AR in mathematics education is distributed across countries. Researchers and educators can use it to find the most active and productive countries in this field and prospective collaborators or sources of knowledge in these countries. The Table 2 shows which countries have made the most contributions to this topic's research and their respective relevance.

Table 3. Top 10 Most Relevant Country

Country	Articles	SCP	MCP
Indonesia	11	10	1
Mexico	7	7	0
China	5	3	2

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Austria	4	4	0
Turkey	4	4	0
Germany	2	2	0
Malaysia	2	2	0
Spain	2	2	0
USA	2	2	0
Costa Rica	1	1	0

3.5 Most Relevant Affiliation of AR in Mathematics Education

The research publications on AR in mathematics education show the most productive affiliations (universities, research institutions, etc.). The table 4 lists the affiliation and the number of publications published by its members. With 6 articles, Beijing Normal University has the most on this topic. Universitas Pendidikan Indonesia (5 papers), Eindhoven University of Technology (4 articles), and Notreported (2 articles) are other associations with several articles on this topic (4 articles). Table 4 might help to comprehend AR research in mathematics education by affiliation. It can also help researchers and educators find the most active and productive affiliations in this field and identify possible collaborators or information sources linked to these organizations. The Table 4 shows which affiliations have contributed most to research on this topic and their proportional importance to the field.

Table 4. Top 10 Most Relevant Affiliations

Affiliation	**Articles**
Beijing Normal University	6
Universitas Pendidikan Indonesia	5
Eindhoven University of Technology	4
Notreported	4
Vienna University of Technology	4
Alanya Alaaddin Keykubat University	3
Johannes Kepler University	3
Universitas PGRI Semarang	3
Universiti Teknologi Malaysia	3
Yogyakarta State University	3

3.6 Most Global Cited Document of AR in Mathematics Education

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Two of the top four AR articles in mathematics education were written by Kaufman H. With 16.43 annual citations, the 2003 publication has the most. This means this publication has had a substantial impact on the subject and has been mentioned by researchers over time. With 25.55 citations per year, Bujakkr's 2013 article is second in citations. This is a high number of citations each year, suggesting that this work had a major impact on the field after its release. Some of the articles on the list do not have a Digital Object Identifier (DOI), which may make them harder to find and access. It's also important to note that the list simply includes cited papers and does not necessarily indicate research quality or impact. There may be noteworthy papers on AR in mathematics education that have been under-cited.

Table 5. Top 10 Most Global Cited Document

Author	DOI	TC	TC/Year
[19]	10.1016/S0097-8493(03)00028-1	345	16.43
[6]	10.1016/j.compedu.2013.02.017	281	25.55
[20]	10.1145/1242073.1242086	104	4.73
[21]	10.12973/eurasia.2017.00621a	55	7.86
[22]	10.1111/bjet.12718	53	10.60
[23]	NA	52	2.36
[24]	10.1007/s10639-019-09973-5	47	11.75
[25]	NA	42	10.50
[26]	10.15390/EB.2017.7140	39	5.57
[27]	10.1016/j.procs.2015.12.251	38	4.22

3.7 Most Frequent Word of AR in Mathematics Education

The significant number of occurrences of "augmented reality" in the author's keyword suggests that the usage of AR in mathematics teaching is well-studied. AR may improve student engagement and learning. AR in mathematics education may help students to explore and manipulate mathematical topics more interactively and immersive. The high number of "mathematics education" keyword occurrences shows that research on AR in mathematics education generally focuses on its effects on the educational process and outcomes. This may involve studies on how AR improves student performance, motivation, and engagement, as well as how to best implement technology into mathematics instruction. The keyword "mathematics learning" suggests that research on AR in mathematics education may also examine how AR affects the learning process, such as how pupils learn and retain mathematical concepts. "Virtual reality," "education," and "geometry education" may also be applicable to research on AR in mathematics education. The most frequent words by author only covers author keywords, not the

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research articles' overall content or subject. Researchers may use different language or terminology; therefore, certain key themes or subjects may not be on the Table 6.

Table 6. Top 10 Most Frequent Word

Words	Occurrences
augmented reality	58
mathematics education	24
mathematics learning	14
Mathematics	5
spatial ability	5
virtual reality	5
Education	4
geometry education	4
spatial intelligence	4
mobile augmented reality	3

4 Conclusion

Research on augmented reality in mathematics education has grown steadily over the past 20 years, with a 9.67% annual growth rate. This research has had a significant impact, with an average of 13.74 citations per document. The data used in the research comes from a variety of sources and documents, including articles, book chapters, conference papers, and conference reviews. The research has also been conducted and disseminated internationally, with 7.47 percent of the documents having international co-authorship. The research has seen a recent increase in publications, with 2019–2022 having the most papers published. The most relevant sources for this research are "Journal of Physics: Conference Series," "AIP Conference Proceedings," "ACM International Conference Proceeding Series," and "Procedia Computer Science." Indonesia is the most productive country in this research, followed by Mexico and China. The research has focused on a variety of keywords, including "mathematics education," "augmented reality," and "teaching and learning."

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