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THE AUGMENTED REALITY FOR MATHEMATICS LEARNING IN SCOPUS DATABASE : A BIBLIOMETRIC ANALYSIS

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Abstract: In the 21st century, the role of technology in education has grown rapidly, and one technology that stands out is Augmented Reality (AR). By combining elements of the virtual world with the real action, AR technology allows students to visualize mathematical concepts that are often difficult to understand in a more concrete way. This study is intended to analyze research trends through bibliometric analysis using VOSviewer software on *The Augmented Reality for Mathematics Learning*. Data collection was carried out using Publish or Perish to find out the citation matrix, the management reference application is Scopus. The research results found that from 2002 to 2023, research trends on *The Augmented Reality for Mathematics Learning* fluctuated. The number of citations for the articles used in this research was 4795 over a period of 21 years. The number of citations per year is 228.33 and the number of citations per paper is 23.98. These results can be concluded that studies about *The Augmented Reality for Mathematics Learning* are still rare. This means that this research has a great opportunity to be carried out in the future because learning is increasingly developing with the application of technology in mathematics learning.

Keywords: The Augmented Reality for Mathematics Learning; Scopus; VOSviewer

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INTRODUCTION

Mathematics learning in the 21st century has experienced significant developments due to the use of information technology. The integration of technology in mathematics learning has changed the way students and teachers interact with subject matter. (Wijaya et al., 2022) explained that online learning platforms, mathematics applications and special software have enabled students to learn mathematics in a more interactive and personalized way. In addition, this technology also enables the use of complicated visualization tools, such as interactive graphics, adaptive learning tools, and mathematical simulations that help students understand complex concepts (Ghanbari & Atangana, 2020; Santagata et al., 2021; Scaradozzi et al., 2019). With technology, mathematics learning has not only become more accessible, but also more interesting and relevant to the ever-evolving digital world (Bakker et al., 2021; Liu et al., 2019). Mathematics learning reform has experienced a significant shift, from an approach based on memorization, formulas and theory towards the implementation of technology that allows learning that is more interactive and relevant to the needs of the 21st century. The use of technology will be able to help deliver mathematics material in a variety of techniques so that learning will be interactive and multidimensional. In this way, 21st century learning will be created by utilizing technology in its implementation.

Mathematics learning has undergone a tremendous transformation in recent decades. In the past, an approach dominated by memorization, formulas, and theory was the main paradigm in the mathematics education process. However, with the rapid development of technology, especially in the digital world, mathematics learning has undergone profound reforms (Belmonte et al., 2019; Engelbrecht et al., 2020). The implementation of technology has changed the way for revolutionary changes in the way students learn and teachers teach mathematics (Perienen, 2020). Through educational software, mathematical applications, and online platforms, mathematical approaches that were once rigid and monotonous have now become more dynamic, interactive, and relevant to the demands of the modern world (Love et al., 2014; Mendoza et al., 2019). In this section, we will explore how these changes have opened up new opportunities in mathematics learning, replacing old rote-based patterns with more engaging and powerful methods.

The use of Augmented Reality in the world of education has brought interesting innovations and changed the learning landscape substantially. Augmented Reality combines the physical world with digital elements, creating an immersive and interactive learning experience (Pape et al., 2022). In recent years, the use of Augmented Reality in learning has grown rapidly, allowing students to explore knowledge in a more visual and practical way. With Augmented Reality technology, textbooks can come to life with moving images, three-dimensional models, and additional information that can enrich students' understanding (Alibraheim et al., 2023; Del Cerro Velázquez & Méndez, 2021). Additionally, Augmented Reality also opens up opportunities for more project-based learning, where students can actively participate in creating their own learning experiences. The use of Augmented Reality has changed the way we view learning, opening the door to endless opportunities in education.

The use of Augmented Reality technology in the context of mathematics learning is a revolutionary breakthrough that has changed the way we approach this discipline. Mathematics is often considered a difficult subject, with a number of students feeling awkward or unmotivated (Paulo et al., 2021). However, with AR, the approach to learning mathematics becomes more interesting and real. With Augmented Reality technology, students not only understand theory and formulas, but they can also see how mathematics interacts in the real world (Özçakır & Aydın, 2019). This creates a more visual and concrete learning experience, allowing students to tap into their creativity while deepening mathematical understanding. In this section, we will explore how Augmented Reality has opened the door to more engaging and effective learning methods in the context of mathematics.

It cannot be denied that the use of Augmented Reality in mathematics learning has provided a number of significant benefits. This technology allows students to explore mathematical concepts in a real-world context, with three-dimensional models, interactive visualizations, and simulations that help explain difficult concepts (Cahyono et al., 2020). In an Augmented Reality-powered learning environment, students can design their own math experiments, measure real objects, and see results instantly. In addition, the use of Augmented Reality also opens up wider collaboration opportunities, because students can work together in the virtual world to solve complex mathematical problems (Elsayed & Al-Najrani, 2021). Augmented Reality-based technology enriches the mathematics learning experience and provides a stronger foundation for understanding and appreciation of this discipline.

Augmented Reality in mathematics learning refers to the use of technology that combines real world elements with virtual elements, creating a more immersive and interactive learning experience. In this context, Augmented Reality utilizes devices such as smartphones, tablets, or other devices based on Augmented Reality to display objects, graphics, or mathematical information in the student's physical environment (Awang et al., 2019). This allows students to see, interact, and even manipulate mathematical objects directly in the real world, which in turn helps them understand mathematical concepts in a more concrete way. The definition of Augmented Reality in mathematics learning focuses on the use of this technology as a tool to visualize and teach mathematical concepts in a more realistic and interesting way (Awang et al., 2019). In an educational context, Augmented Reality in mathematics learning also includes applications and software specifically designed to provide a more creative and interactive learning experience. Students can use Augmented Reality devices to play math games, complete math challenges set in the real world, or even receive interactive guidance in understanding difficult math formulas and concepts. With this approach, Augmented Reality provides an innovative way to improve students' understanding of mathematics, encourage active involvement in the learning process, and create a more interesting learning environment.

There are several studies on bibliometric analysis related to education, for example (Ersozlu & Karakus, 2019; Gökçe & Güner, 2021a; B. Li et al., 2020a; Lozada et al., 2021; Zhou et al., 2023a). These studies discuss trend analysis of concepts in mathematics learning. However, bibliometric analysis of the Augmented Reality for mathematics learning in Scopus uses the VOSviewers application. Therefore, this research aims to analyze research trends through bibliometric analysis using VOSviewer software regarding the Augmented Reality for mathematics learning. The novelty in this research is *analyzing research trends on the Augmented Reality for mathematics learning through bibliometric analysis, investigating the relationship between students' conceptual understanding of mathematics and the Augmented Reality for mathematics learning*, and *finding further research to come*.

METHOD

Bibliometric analysis is the method used in this research, because it can analyze publication trends regarding the keyword Augmented Reality for mathematics learning. Bibliometric analysis is an approach used to measure, analyze and understand the impact and development patterns of scientific literature in a particular research field (W. Li et al., 2019). This method utilizes bibliographic data, such as reference lists in journal

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articles, to identify trends, research collaborations, and the impact of scientific work. In bibliometric analysis, several parameters that are often used include the number of citations, journal impact factor, frequency of writing by certain researchers, and collaboration networks between researchers (Duan & Guo, 2021). This analysis provides valuable insight into the development of science, the role of researchers, and patterns of knowledge dissemination within a discipline or field of study.

Downloading research data from Scopus is an important step in conducting bibliometric analysis and scientific research. Scopus is one of the well-known databases that provides access to thousands of scientific journals, conferences, and other indexed literature (Cabeza et al., 2020). To download research data from Scopus, researchers can use various methods provided by this platform, such as downloading reference lists, citations, or even statistical data related to research trends. Data obtained from Scopus can be used for various purposes, such as identifying current research in a discipline, measuring the impact of a scientific work through citations, or tracking researcher collaborations (Warren et al., 2019). With access to data from Scopus, researchers can perform in-depth bibliometric analysis, develop better insight into research developments, and take more precise steps in their research process (Karakus et al., 2019; Yang et al., 2023). The aim of using the Harzing's Publish or Perish application is to see the analysis of the flow of citations that have been carried out and read the mapping. Meanwhile, to carry out mapping using the VOSviewers application. Data is extracted in (*.ris) format into the VOSviewers application to see a visual representation.

RESULT AND DISCUSSION

The collected data was analyzed using Harzing's Publish or Perish application using the keywords "augmented reality" AND "mathematics" to avoid bias. Metadata activities were carried out to synthesize information related to keywords related to "augmented reality" AND "mathematics" which were discussed only for articles of the type based on data obtained from Scopus. The data collected related to "Augmented Reality" AND "Mathematics" was found to be 175. Metadata activities were carried out to find out how long the research was conducted, the number of articles, the number of citations, and the number of citations. To help with the metadata process, Harzing's Publish or Perish application is used using the keywords "augmented reality" AND "mathematics". Table 1 below shows the results of the data obtained and analyzed from the Harzing's Publish or Perish application to view the metadata obtained.

Table 1. Metadata Citation Metrik

Publication year	1996-2023
Citation Year	27 (1996-2023)
Papers	175
Citations	3758
Cite/year	139.19
Cite/paper	21.47
Authors/paper	3.37
h-indeks	31
g-indeks	57

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Table 1 explains how to analyze research metadata with the keywords "augmented reality" AND "mathematics" using the Harzing's Publish or Perish application. Based on this metadata, it can be seen that this research is still rarely carried out because there are still few papers found in the Scopus database related to the specified keywords. Table 2 below shows the results of research data obtained from the Scopus database and analyzed to find the 20 best articles with the highest number of citations using the keywords "augmented reality" AND "mathematics". To explain how the highest number of citations is, it will be explained in table 2. To see the highest number of citations in the world of research and scientific literature, it is important to understand how crucial this measurement is in measuring the impact and relevance of scientific work. Citation analysis also provides valuable insights in exploring important contributions in various fields of knowledge.

Table 2. Publication Data Augmented Reality in Mathematics Learning

No.	Author	Title	Year	Number of Citations
1	Ibáñez, C.	Augmented reality for STEM learning: A systematic review	2018	451
2	K.R. Bujak, I. Radu, R. Catrambone, B. MacIntyre, R. Zheng, G. Golubski	A psychological perspective on augmented reality in the mathematics classroom	2013	327
3	H. Kaufmann, D. Schmalstieg, M. Wagner	Construct3D: A virtual reality application for mathematics and geometry education	2000	228
4	P. Sommerauer, O. Müller	Augmented reality in informal learning environments: A field experiment in a mathematics exhibition	2014	211
5	N.F. Saidin, N.D.A. Halim, N. Yahaya	A review of research on augmented reality in education: Advantages and applications	2015	164
6	M.L. Yuan, S.K. Ong, A.Y.C. Nee	Augmented reality for assembly guidance using a virtual interactive tool	2008	113
7	H.-C.K. Lin, M.-C. Chen, C.-K. Chang	Assessing the effectiveness of learning solid geometry by using an augmented reality-assisted learning system	2015	102
8	S. Cai, E. Liu, Y. Yang, J.-C. Liang	Tablet-based AR technology: Impacts on students’ conceptions and approaches to learning mathematics according to their self-efficacy	2019	75

9	E. Demitriadou, K.-E. Stavroulia, A. Lanitis	Comparative evaluation of virtual and augmented reality for teaching mathematics in primary education	2020	73
10	Y.-S. Hsu, Y.-H. Lin, B. Yang	Impact of augmented reality lessons on students' STEM interest	2017	72

Table 2 shows the 10 best articles with the highest number of citations discussing Augmented Reality for mathematics learning contained in the Scopus database. Based on the table above, the article (Ibáñez & Delgado-Kloos, 2018) has the highest number of citations, namely 451 from 1996 to 2023. The research currently being analyzed has a main focus on developing renewable technology as a solution to mathematics learning by implementing augmented reality technology. which can be used as a follow-up topic in future research. Research trends on Augmented Reality for mathematics learning reduced from Scopus are categorized based on year of publication from parts of the world which can be seen in Table 3.

Table 3. Publication Trend Data Augmented Reality in Mathematics Learning

Year of Publication	Number of Publication
2023	33
2022	25
2021	34
2020	24
2019	19
2018	7
2017	13
2016	4
2015	3
2014	2
2013	3
2012	1
2011	2
2008	1
2007	1
2006	1
2000	1
1996	1
Total	175
Average	9,7

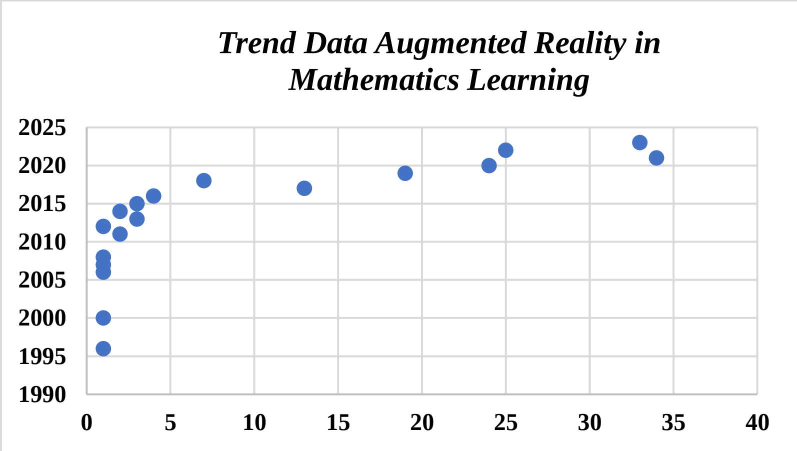

Figure 1. Trend Data Augmented Reality in Mathematics Learning

The development of research regarding Augmented Reality for mathematics learning shown in table 3 shows that in the time period from 1996 to 2023 research is increasingly developing. Research was still rarely carried out between 1996 and 2018. However, research between 2019 started to gain interest as shown by the number of papers increasing between those years. Research on Augmented Reality for mathematics learning found in the Scopus database between 1996 and 2003 shows a stable level. However, in 1997, 1998, 1999, 2001, 2002, 2003, 2004, 2005, and 2009 no research was found related to the keywords being searched for.

Using the VOSviewer application produces computational mapping of articles related to Augmented Reality for mathematics learning. Each image explains the relationship and connection between one item and another. Each term is given a label in the form of a colored circle. The circles have different sizes depending on the frequency of their appearance (Sharma et al., 2023). The size of the circle explains the positive correlation with the frequency of occurrence of the term in the title (Gökçe & Güner, 2021b). The circle will get bigger if the terms in it appear frequently in the title. The results of computational mapping visualization based on VOSviewer are divided into three parts, namely network visualization (Figure 2), overlay/difference visualization for each year (Figure 3), and density visualization (Figure 4) (Grzybowska, 2021). Analyzing the display of bibliometric applications VOS (Visualizing of Similarity) is an effective approach in exploring and understanding the relationship between bibliographic entities, such as scientific journals, research, or authors in the academic field. First, users can enter their bibliographic data into the VOS application to create a visual map displaying those entities and the connections between them (B. Li et al., 2020b; Zhou et al., 2023b). Afterwards, they can analyze this display by paying attention to elements such as the size and color of the nodes representing the entities, as well as the thickness and length of the lines connecting the entities, illustrating the quantitative or qualitative relationships between them. Additionally, through display analysis, users can identify trends, thematic groups, or dominant research foci in the literature they examine.

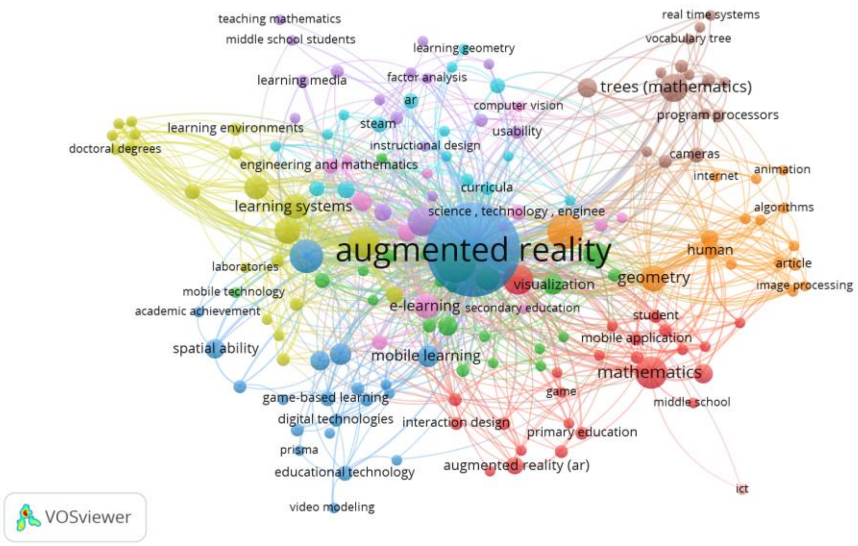

Figure 2. Augmented Reality Network Visualization for Mathematics Learning

Network Visualization of the VOS Augmented Reality for Mathematics Learning application combines the concept of mathematical visualization with augmented reality technology and VOS (Visualizing of Similarity) bibliometric analysis. Mathematics is presented through visual representations that make it possible to interactively explore and understand the relationships between various mathematical concepts and related research. Through displays to explore complex scientific networks and see connections between articles, theories, and mathematical concepts, as well as visualize how related research areas intersect and contribute to each other. By viewing interactive visualizations, you can identify trends and patterns in the scientific mathematics literature and see how mathematical concepts develop over time. Thus, exploring various branches of mathematics to pursue further mathematical research related to related keywords. Some keywords related to this research include science, technology, engine, mobile learning, learning system, and so on. Research that has circles with small dimensions shows that this research is still rarely carried out, such as Augmented Reality, video modeling, basic education, image processing, and so on. Thus, it is possible that research using these keywords will become research that is needed in the future.

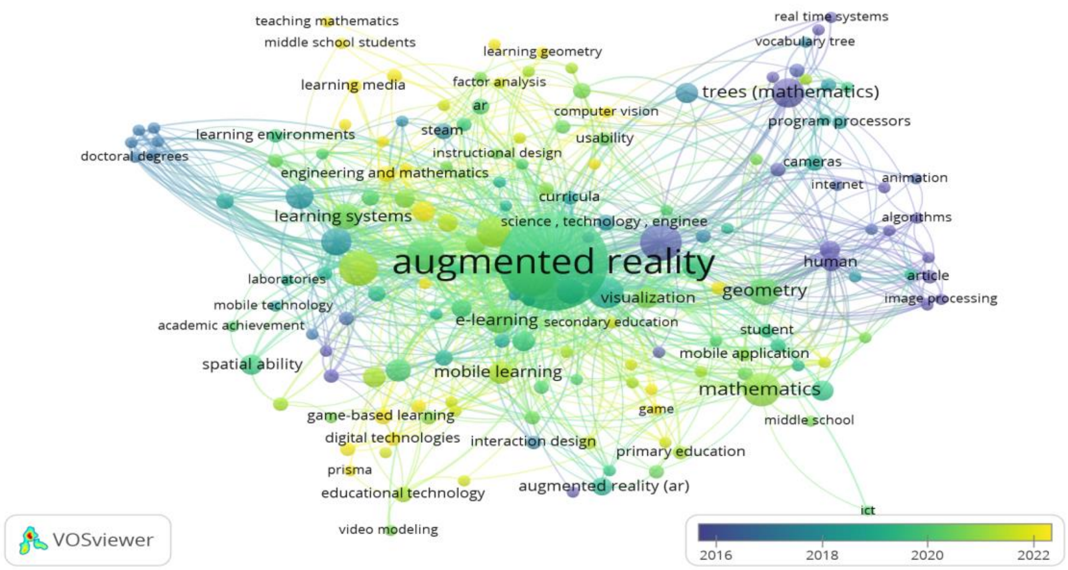

Figure 3. Augmented Reality Overlay Visualization For Mathematics Learning

This means how mathematical concepts relate to current research, who contributes, and how various mathematical topics relate to each other. The Augmented Reality Overlay for Mathematics Learning visualization on the VOS application creates a more in-depth learning experience, by connecting mathematical concepts to related scientific literature. Based on Figure 2, it can be seen that much research on keywords was carried out from 2016 to 2018. However, in 2022 there will still not be much research on related topics so this research can be carried out as a contribution to new research in the future.

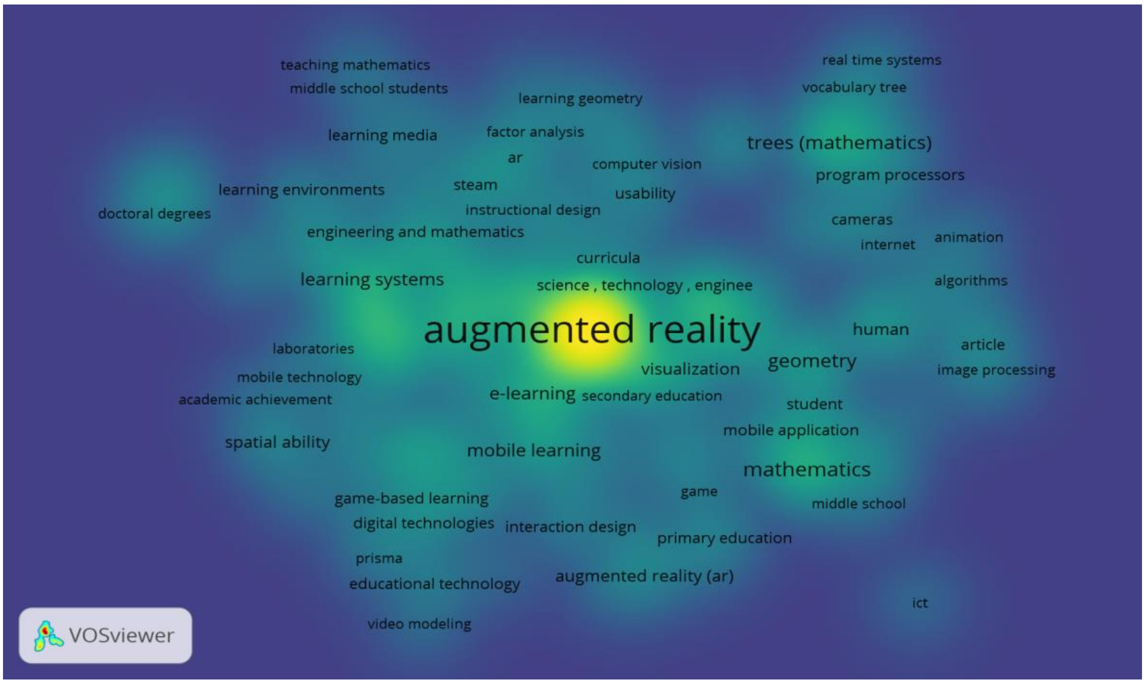

Figure 4. Density Augmented Reality Visualization for Mathematics Learning

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Based on Figure 4, it shows density visualization. Based on the description, density visualization is a density visualization where the brighter the yellow color and the larger the diameter of the circle containing the term, the more often the intensity of the term appears. If this is the case, it means that a lot of research has been carried out containing the term, but if the color dims closer to the background color, then the amount of research on the term has been carried out little. In Figure 4 the terms augmented reality, visualization, science, technology, engineering show the largest circle size with a bright yellow color, which means that a lot of research has been carried out on these terms. However, what is related to the keyword in this research, namely Augmented Reality for mathematics learning, shows that the yellow color is fading and the location is far away. This means that the topic of studying Augmented Reality for mathematics learning is still rarely done and can be used as a topic in conducting research to support the latest research. Apart from that, there are terms such as game based learning, mathematics, spatial ability, and so on whose color is dim and research on these terms is rarely carried out. Thus, choosing key words with dim colors will become a new topic that can expand the research on Augmented Reality for mathematics learning in the future which can be used as a discussion to further connect mathematics subjects with the use of technology in them.

The scarcity of research that focuses on the use of augmented reality in mathematics learning is a phenomenon that deserves attention. Mathematics is a subject that is often considered difficult by some students. Therefore, integrating technology such as augmented reality can be an innovative approach to make mathematics learning more interesting and effective. However, despite the great potential offered by this technology, we still see a lack of exploration of its use in the context of mathematics education. There are several factors that may explain the lack of research in this area. Implementing augmented reality technology in learning requires quite large resources, both in terms of hardware and software. Not all schools or educational institutions have access or sufficient funds to adopt this technology. Additionally, research into the use of augmented reality also requires significant time and effort, which may not always be available to researchers. In addressing the scarcity of research on the use of augmented reality in mathematics learning, we need to encourage more collaboration between educational scientists, technologists, and mathematicians. The development of broader and more inclusive research in this regard will help uncover the true potential of augmented reality in improving students' mathematical understanding and numeracy skills. By focusing on integrating this technology into the mathematics curriculum, we can open the door to more engaging and impactful learning approaches in overcoming difficulties in understanding mathematics.

CONCLUSION

So, based on the data obtained, it shows that the popularity and interest in "Augmented Reality for mathematics learning" research is unstable from 1996 to 2023. The results of this research can be followed up with newer and more updated research on Augmented Reality for mathematics learning research. The terms augmented reality, visualization, science, technology, engineering show the largest circle size with a bright yellow color, which means that a lot of research has been carried out on these terms. Thus, exploring various branches of mathematics to pursue further mathematical research related to related keywords. Some keywords related to this research include science, technology, engine, mobile learning, learning system, and so on. Research that has circles with small dimensions shows that this research is still rarely carried out, such as Augmented Reality, video modeling, basic education, image processing, and so on. Thus, it is possible that research using these keywords will become research that is needed in the future.

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