Trends of Using Artificial Intelligence in School Mathematics Education: A Bibliometric Analysis

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Abstract

Artificial Intelligence (AI) is emerging as a prominent mathematics education innovation with the ability to process extensive data, absorb complex patterns, and support decision making choices in a time of technological advancement. This study aims to explore research themes on AI applications in mathematics education at the school level, focusing on performance evaluation and thematic mapping. A bibliometric approach was employed, analyzing 998 publications retrieved from Google Scholar via Publish or Perish (PoP) between 2019 and 2024, with 202 articles meeting the criteria for final analysis. Data processing utilized Microsoft Excel and VOSviewer for visualization. Key findings revealed a consistent upward trend in annual publications. Citation counts were notably high, peaking at 373 citations, indicating that studies on AI in mathematics education have attracted significant scholarly attention and are considered highly influential within the academic community. Indonesia, South Korea, and the United States emerged as the top three contributors to the literature. Thematic mapping highlighted underexplored areas, including "ai tool", "attitude", "challenge", "generative artificial intelligence", "higher education", and "middle school student". These results underscore the necessity for expanded research on underrepresented topics, providing mathematics educators with guidance to design more relevant curricula and instructional strategies, while enabling researchers to identify concrete directions for advancing AI applications in mathematics education.

Keywords: *Artificial Intelligence; Bibliometrics; Google Scholar; Mathematics Education; School.*

Abstrak

Artificial Intelligence (AI) muncul sebagai inovasi pendidikan matematika yang menonjol dengan kemampuan memproses data skala besar, belajar pola rumit, dan membuat keputusan cerdas di masa kemajuan teknologi. Tujuan utama studi ini adalah mengidentifikasi topik penelitian penggunaan AI dalam pendidikan matematika matematika sekolah untuk dianalisis dari aspek kinerja dan pemetaan. Metode penelitian berbasis analisis bibliometrik diterapkan dengan mengambil 998 publikasi ilmiah sebagai sumber data. Pengumpulan data dilakukan melalui platform Google Scholar menggunakan tools Publish or Perish (PoP) untuk publikasi yang terbit dalam kurun waktu 2019-2024, diperoleh 202 artikel sebagai sampel yang sesuai. Data yang telah dikumpulkan dianalisis menggunakan perangkat lunak Microsoft Excell dan VOSviewer. Hasil analisis bibliometrik menunjukkan tren publikasi terus mengalami peningkatan sepanjang tahun. Jumlah sitasi tercatat sangat tinggi, dengan puncaknya mencapai 373 sitasi, yang menunjukkan bahwa studi tentang AI dalam pendidikan matematika telah menarik perhatian ilmiah yang signifikan

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dan dianggap sangat berpengaruh dalam komunitas akademik. Indonesia, South Korea, dan United States adalah 3 negara paling produktif melakukan publikasi pada topik terkait. Analisis pemetaan pemanfaatan AI dalam pendidikan matematika sekolah mengungkap signifikansi perluasan tema penelitian yang terbarukan dan frekuensi yang belum banyak dilakukan, yakni pada tema "ai tool", "attitude", "challenge", "generative artificial intelligence", "higher education", dan "middle school student". Implikasi dari temuan ini sanga penting untuk perluasan penelitian pada topik-topik yang kurang terwakili, dengan memberikan panduan bagi pendidik matematika untuk merancang kurikulum dan strategi pembelajaran yang lebih relevan, sekaligus memungkinkan para peneliti mengidentifikasi arah konkret dalam pengembangan penerapan AI pada pendidikan matematika.

Kata Kunci: Artificial Intelligence; Bibliometrik; Google Scholar; Pendidikan Matematika; Sekolah.

INTRODUCTION

The emergence of Industry 4.0 has transformed multiple sectors, particularly impacting educational systems worldwide. In this era, technologies such as Artificial Intelligence (AI) are emerging as prominent innovations, with the ability to process data on to analyze extensive datasets, extract meaningful insights from recurring correlations, and implement optimized data-driven resolutions. This opens up new opportunities in various fields, including education (Maulida et al., 2024). In the context of mathematics education, AI has the potential to revolutionize the way students learn and interact with more complex concepts (Opesemowo & Adewuyi, 2024). The application of AI in mathematics learning not only helps personalize learning, but also improves teaching effectiveness by providing faster and more accurate feedback for both students and educators.

The use of AI in mathematics learning provides significant benefits by enhancing personalization, adaptability, engagement, and confidence in students' learning. For instance, AI-powered chatbots can deliver instant feedback, while digital whiteboards and tablets enable interactive and collaborative classroom activities that improve students' understanding of mathematical concepts (Auna & Hamzah, 2024). AI also enables more interactive and collaborative teaching through integration with digital devices such as tablets, digital whiteboards, and AI-based chatbots (Semwaiko et al., 2024).

Despite the huge potential of AI in mathematics education, its implementation also faces a number of challenges. Limited access to technological infrastructure, the digital divide between regions, and teachers' readiness to utilize these technologies are major barriers (Bulut et al., 2024; Setälä et al., 2025). Many schools, especially in rural or underserved areas, do not have the necessary technological infrastructure to effectively implement AI (Leong & Zhang, 2024). Furthermore, growing apprehensions exist regarding students' overreliance on AI systems potentially diminishing their higher-order cognitive abilities, necessitating meticulous implementation strategies and monitored application of AI-assisted tools in mathematics pedagogy.

The investigation of artificial intelligence themes within mathematics pedagogy can be effectively conducted through bibliometric analytical techniques.. Empirical findings from Julius et al. (2021) established bibliometric analysis as an indispensable tool for tracking evolving knowledge landscapes in mathematics education studies.Bibliometric analysis can be used to explain and map the accumulated scientific knowledge and identify developments in certain fields, by systematically processing large amounts of unstructured data (Donthu et al., 2021). One of the large databases that is often used by journal publications to publish researchers' findings is Google Scholar.

Google Scholar serves as a very important database in educational research as it provides broad access to a variety of academic literature, including journals, books, proceedings, and theses (Zandroto & Purba, 2024). The platform allows users to easily track the latest developments in education through its features of indexing trusted sources, collaboration between researchers, and citation metrics. However, it should be recognized that Google Scholar has limitations, such as inconsistencies in the quality of indexed sources and the lack of in-depth filtering features (Beel & Gipp, 2009). Therefore, the role of research through bibliometric analysis through Google Scholar database critically and selectively is essential to be able to optimize its use as a large database that supports the development of research.

Systematic bibliometric investigations provide a valuable framework for understanding how AI is applied in mathematics education, enabling researchers to identify emerging trends, influential works, and substantive contributions within the field. Several previous studies have conducted bibliometric analysis of AI usage in mathematics education and education in general (Hwang & Tu, 2021; Ivanova et al., 2024; Triansyah et al., 2023; Tupulu et al., 2024). These studies used the Scopus and Web of Science databases to show research results in the application domain, technology adopted, the role of AI, and the relationship between citations, and then provide suggestions on research issues. However, it indicates that there is no bibliometric analysis research through the Google Scholar database on the utilization of AI in school mathematics learning and provides updated issues. In fact, the Google Scholar database is often used by academics to find references to research findings. Therefore, this study uses Google Scholar database to examine the trend of AI usage in school mathematics learning. This research integrates Microsoft Excel and VOSviewer software to assist researchers in conducting bibliometric analysis.

RESEARCH METHODS

This study employs a descriptive bibliometric methodology to systematically examine publication patterns and characteristics within the research domain of artificial intelligence applications in mathematics education. The analysis focuses on quantifying and mapping scholarly outputs to identify emerging trends through scientific articles and journals (Donthu et al., 2021; Supinah & Soebagyo, 2022).

The data collection process was carried out by utilizing the Publish or Perish (PoP) application to review articles indexed in the Google Scholar database on March 8, 2025. The search strategy incorporated (“Artificial Intelligence” OR “Machine Learning”) AND (“Mathematics Education”) AND (“School” OR “Class”). A total of 998 articles were identified as the initial population. Article selection was carried out through a stepwise screening process: first, titles and abstracts were reviewed to ensure relevance; second, duplicate entries were

removed; and third, full-text validation was conducted to confirm compliance with inclusion criteria. As a result, 202 articles were retained as research samples, limited to international journals published between 2019 and 2024 focusing on AI in school mathematics education.

The validated dataset was stored in Microsoft Excel for descriptive analysis and categorization, while the RIS format was imported into VOSviewer. VOSviewer was employed for bibliometric mapping, including co-authorship analysis, keyword co-occurrence, and citation network visualization. In addition, manual validation and peer checking were performed to minimize bias and ensure data accuracy.

RESULTS AND DISCUSSION

This research employs a bifurcated bibliometric approach integrating quantitative performance analysis with spatial network mapping. The performance evaluation specifically investigates temporal publication trends, high-impact publications based on citation frequency, and country-level contributions to the research domain. Meanwhile, mapping analysis includes circles network visualization, frames overlay visualization, and density visualization. The purpose of bibliometric analysis is to simplify and present large amounts of bibliometric data, so as to reveal the intellectual structure and current trends developing in a field or research topic (Donthu et al., 2021).

1. Distribution of Publications by Years

Data from the search results of articles in international scientific journals through PoP related to trends in the use of AI in mathematics education in schools during the period 2019 to 2024 show fluctuations, as shown in Figure 1. Figure 1 shows the development of usage of artificial intelligence (AI) in school mathematics education from 2019 to 2024. At the beginning of the period, namely in 2019 (f=7), 2020 (f=9), 2021 (f=14), and 2022 (f=17), the implementation of AI in mathematics education was still relatively low and only experienced a very small increase. However, starting in 2023 (f=44), there is a more significant

increase, indicating that the application of AI is starting to develop more rapidly. This trend continues until it peaks in 2024 (f=111), where the use of AI in mathematics education jumps sharply. This significant surge can be attributed to the widespread availability of generative AI tools such as ChatGPT, which gained global popularity after late 2022, and the increasing integration of AI-based applications into educational practices during the post-pandemic recovery period. Furthermore, several governments and institutions introduced policies and funding initiatives in 2023–2024 to encourage AI adoption in education, thereby accelerating research output in this area. The main factors driving this trend include advances in AI technology that are becoming more accessible, as well as a growing understanding of its benefits in improving the effectiveness of mathematics learning. In addition, educational policies that support the integration of technology in the learning process are accelerating the adoption of AI in the academic environment. Studies conducted by Canonigo (2024) and Torres-Peña et al. (2024) revealed that the application of AI in mathematics learning contributes to improving learning efficiency, expanding the range of material accessibility, and encouraging students' creativity.

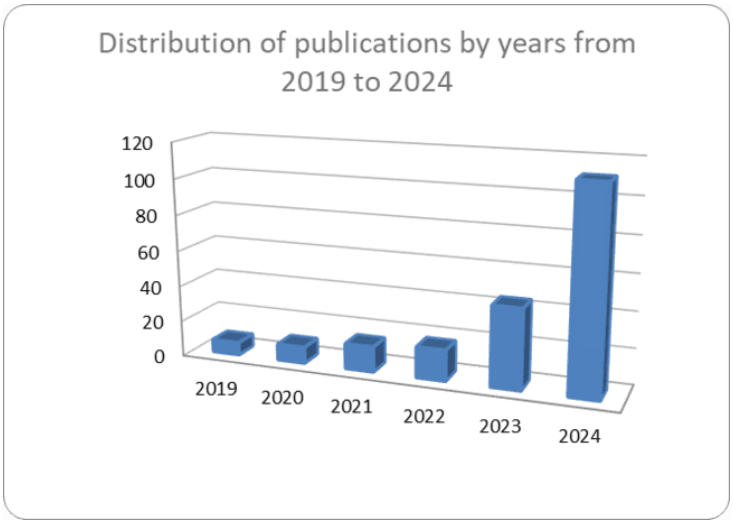

Figure 1. Histogram of Publication Distribution by Years

The growth pattern seen in the graph in Figure 1 is consistent with the findings of (Wardat et al., 2023), who explained that technology implementation in education tends to experience significant acceleration after going through the

initial stage of adaptation. This suggests that the development of AI in mathematics education is not only temporary, but is part of a long-term change that continues to evolve along with technological advances and educational policies that support innovation.

2. Articles with the Most Citations

The large number of citations to specific titles by researchers in research on the use of AI in school mathematics education, as shown in Table 1, supports the relevance and significance of this topic.

Table 1. Articles with the Most Citations

No.	Citation	Title	Source	Year
1	373	ChatGPT: A revolutionary tool for teaching and learning mathematics	ejmste.com	2023
2	295	The application of AI technologies in STEM education: a systematic review from 2011 to 2021	Springer	2022
3	109	Personalizing algebra to students' individual interests in an intelligent tutoring system: Moderators of impact	Springer	2019
4	98	A new era of learning: Considerations for ChatGPT as a tool to enhance statistics and data science education	Taylor & Francis	2023
5	85	Artificial intelligence in education: mathematics teachers' perspectives, practices and challenges	iasj.net	2024

An analysis of the trends in the implement of AI in school mathematics education in the last 5 years revealed that the publications of Wardat et al. (2023) (f=373), Xu & Ouyang (2022) (f=295), Walkington & Bernacki (2019) (f=109), Ellis & Slade (2023) (f=98), and Tashtoush et al. (2024) (f=85) are the articles with the highest number of citations. This publication can be a theoretical and practical foundation for educators and other researchers. Research by Ellis & Slade (2023) and Wardat et al. (2023) emphasized the role of AI, especially Chat

GPT used in mathematics learning, systematically evaluating educational AI through intersectional stakeholder analysis, with particular attention to classroom practitioners' operational realities and learners' developmental needs. Xu & Ouyang (2022) identified that AI in the context of STEM education falls into six specific categories, and discussed the characteristic elements and impact of applying AI in the learning process which tend to show positive benefits. In line with Walkington & Bernacki (2019) in their research explaining that the use of Intelligent Tutoring System supports the personalization of mathematics learning and has an impact on learning outcomes, researchers also point out the influence of student involvement in their interests outside of school can be a moderating factor. Meanwhile, the study by Tashtoush et al. (2024) focuses more on how math teachers in schools perceive the use of AI systems and applications in math teaching, as well as the challenges they face.

3. Distribution of Publications by Country

Meanwhile, how publications in these disciplines are distributed by country is shown in Figure 2.

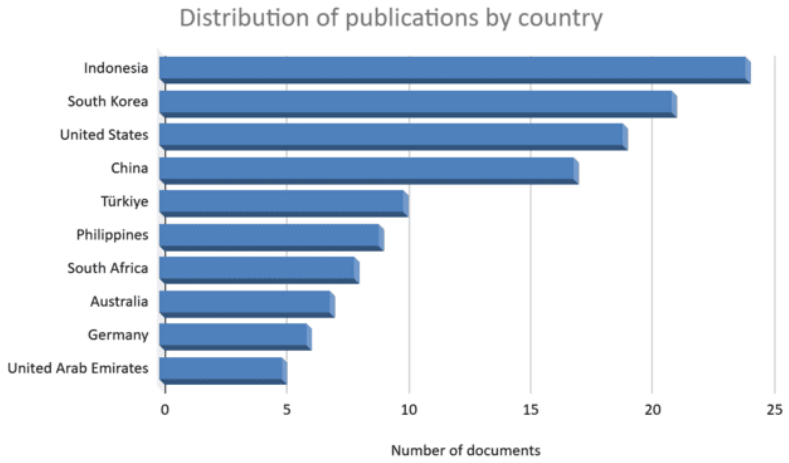

Figure 2. Distribution of Publications by Country

The publication progression was also analyzed based on the author's country of affiliation, reflecting the geographical distribution of research in a

given field (Akhmadieva et al., 2023). Figure 2 ranks publication output by country, revealing Indonesia as the predominant contributor among the top 10 most productive nations in this research domain (f=24). This is followed by South Korea (f=21), United States (f=19), China (f=17), Turkiye (f=10), and others. The publication's output distribution suggests a positive correlation between national research productivity and prioritization of AI integration in mathematics pedagogy, with leading nations demonstrating stronger institutional commitment to educational technology innovation. This approach is important for understanding research contributions globally as well as identifying potential trends in specific regions. It is in line with Kurdi & Kurdi (2021) that identifying important trends and patterns in research output can add insight into the impact of researchers, institutions, or research topics comprehensively. This study employs first-author institutional affiliations as a primary metric, enabling precise identification of national research contributions while simultaneously mapping global collaborative networks in AI education research. Thus, the information obtained can provide a comprehensive picture of the geographical distribution of scientific publications while revealing the potential development of research trends in different regions.

4. Circles Network Visualization

Visualization of publication development requires the representation of relationships between terms in the form of interconnected networks (Husaeni et al., 2022). The results of this visualization were analyzed with the help of VOSviewer software, obtained 1,132 terms with 116 most relevant terms, using a minimum threshold of occurrence of 3 times. Bibliometric visualization in VOSviewer allows mapping of interrelationships between studies graphically, thus helping in identifying research trends as well as the structure of relationships from a lot of data (van Eck & Waltman, 2014). The results of circles network visualization mapping are shown in Figure 3.

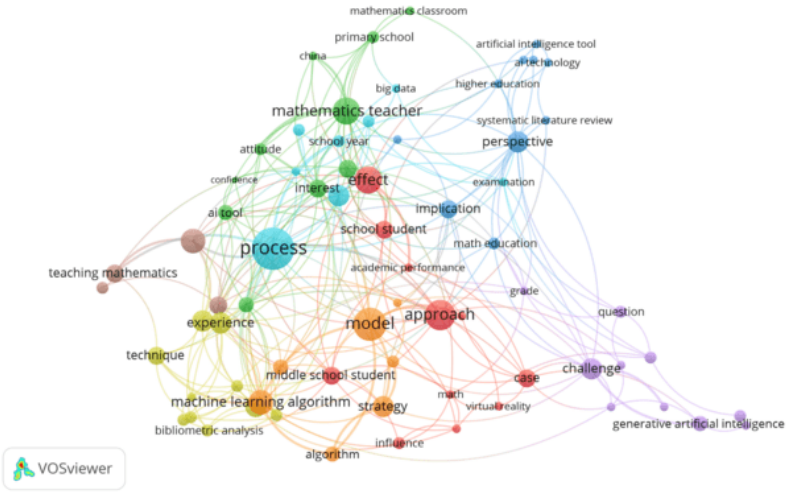

Figure 3. Output Circles Network Visualization

The network visualization generated through VOSviewer's clustering algorithm (Figure 3) reveals distinct thematic groupings, demonstrating mathematics learning synergized with AI is identified in 70 themes, among others:

1) Cluster 1 (in red) consists of 11 themes: academic performance, ai education, approach, case, effect, influence, math, middle school, middle school student, school student, virtual reality.
2) Cluster 2 (in green) consists of 10 themes: tools, attitude, china, confidence, tutoring system, interest, math class, math class, math teacher, elementary school.
3) Cluster 3 (in dark blue) consists of 10 themes: AI technology, artificial intelligence tools, secondary school mathematics education, higher education, implications, mathematics education, mathematics teaching, perspectives, relationships, systematic literature review.
4) Cluster 4 (in yellow) consists of 10 themes: articles, bibliometric analysis, computational thinking, experience, geogebra, papers, researchers, high school students, techniques, topics.
5) Cluster 5 (in purple) consists of 10 themes: benefits, calculators, challenges, emergence, techniques, future, generative artificial intelligence, classes, large language models, questions.

6) Cluster 6 (in light blue) consists of 8 themes: big data, case study, data, data analysis, exam, participants, process, school year.
7) Cluster 7 (in orange) consists of 7 themes: algorithm, generative ai, machine learning algorithm, model, potential, strategy, utilization.
8) Cluster 8 (in brown) consists of 4 themes: high school level, high school students, teaching mathematics.

Cluster 1 leans more toward research that measures and analyzes the direct impact of AI technology interventions. Terms such as "academic performance," "effect," and "influence" indicate that research in this area is empirical in nature, serving as a foundation for proving the practical value of AI in the classroom. Cluster 1 shows a primary focus on middle school students. Meanwhile, Cluster 2 research focuses on the process and affective aspects of learning. Themes such as "attitude," "confidence," and 'interest' indicate that researchers are not only concerned with grades, but also with how AI affects student motivation and engagement in conjunction with the presence of "tutoring systems" in mathematics classrooms. The theme "China" indicates the main contributor geographically with the subject domain of elementary school.

Cluster 3 focuses on intellectual and theoretical aspects, with discussion themes at a more abstract level such as "implications," "perspectives," and "relationships." This shows that it is not about testing a single tool, but rather about understanding the position of AI in the overall landscape of mathematics education. The theme of "systematic literature review" is also found in this cluster, supported by the themes of "AI tools" and subjects with a focus on "secondary school mathematics education" and "higher education." Cluster 4 centers on specific skills and tools that are taught or used, such as "computational thinking" and "Geogebra" software. This shows that there is a sub-field of research that views AI not only as a teaching aid, but also as a means to develop thinking skills relevant to the digital age. Not only that, the theme "high school students" shows the focus of the research subject and the theme "bibliometric analysis" shows the research methods that are often used.

Cluster 5 is a dynamic cluster, with the emergence of "generative artificial intelligence" and "large language models" placing this cluster in the context of the latest AI technology. Themes such as "challenges," "future," and "questions" indicate that research in this area is still in the exploratory stage. Researchers here are grappling with the potential, benefits, and risks of this new technology in mathematics education, making it a hot and rapidly growing area of research. Meanwhile, Cluster 6 focuses primarily on the use of AI for analytics. Research here shows the theme of using AI capabilities to process big data from test results or interactions with platforms. This cluster represents a shift from the use of AI as an instructional tool to a diagnostic and analytical tool.

Cluster 7 focuses more on technical and computational aspects. The theme of "machine learning algorithms" indicates that this research is at the intersection of computer science and education. Researchers here not only use ready-made AI tools, but may also develop, adapt, or analyze specific "models" and "algorithms" for educational purposes. Cluster 8 has a theme of AI in mathematics learning for high school level with different material complexity or pedagogical needs compared to other clusters.

5. Frames Overlay Visualization

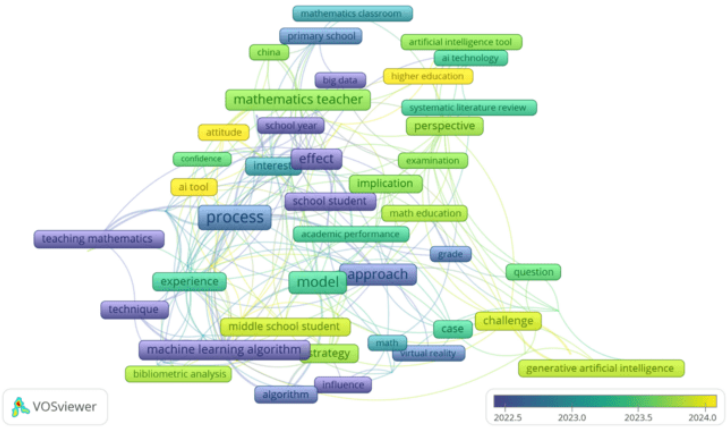

Figure 4. Output Frames Overlay Visualization

The results of Frames Overlay Visualization through VOSviewer software shown in Figure 4 indicate the trend of research themes of articles related

to the use of AI in school mathematics education, from the oldest year to the latest year marked with purple to yellow themes. This means that the themes “AI tool”, “attitude”, “challenge”, “generative artificial intelligence”, “higher education”, “middle school student” are the most recent themes related to the use of AI in school mathematics learning. These themes can be a reference of novelty for future research. This finding shows a shift in research focus towards more contemporary and applicable topics, which can serve as a foundation for further research development.

In line with Egara & Mosimege (2024) research, the use of AI tools in mathematics learning can increase motivation through immediate feedback and personalized exercises and can help them understand more complex concepts. In addition, research by (Subandi & Us, 2024) highlighted the challenges educators face in integrating generative artificial intelligence into the curriculum, indicating the need for better training and support for teachers. On the other hand, research by Sappaile et al. (2024) revealed that students' positive attitude towards the use of AI in learning can contribute to improved learning outcomes and can also contribute valuable insights especially in secondary school education. Thus, the themes that emerged in this visualization are not only relevant but also important for further research in the context of mathematics education.

6. Density Visualization

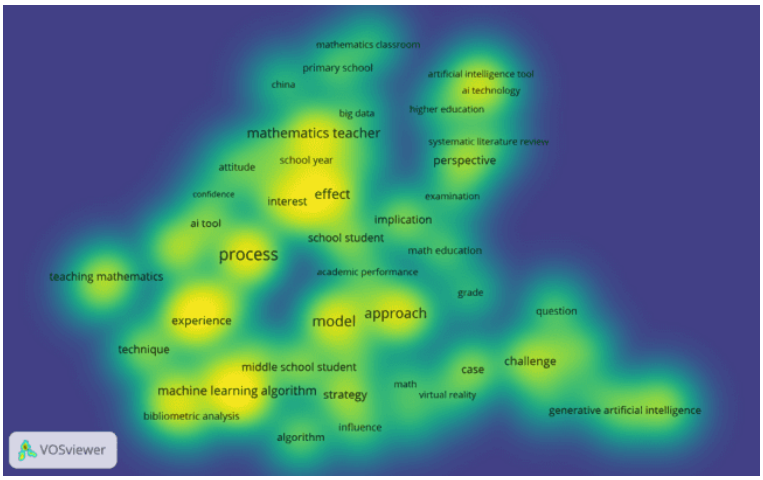

Figure 5. Output DensityVisualization

Based on Figure 5, the Density Visualization output generated through the VOSviewer application illustrates the distribution of research topics related to artificial intelligence (AI) in school mathematics learning. This visualization indicates that terms with brighter colors represent the high frequency of research that has been conducted on the topic, while darker colors indicate topics that are still less explored, thus having significant potential for further study in future research. The theme density analysis in this visualization reveals that some themes, such as "mathematics teacher", "process", "effect", "model", "approach", and "machine learning algorithm", are areas that have received a lot of attention in research. Meanwhile, there are quite a number of themes that show that they have not been explored much. Themes such as "generative artificial intelligence", "virtual reality", "challenge", "higher education", "primary school", "middle school student", "academic performance", "attitude", and "grade" show examples of topics where the level of exploration is still relatively limited, thus opening up significant opportunities for further development and research in the future.

In line with this research, Akgun & Greenhow (2022) highlighted the importance of more in-depth exploration of the challenges in AI integration, including ethical aspects and technical limitations, especially in the context of learning. Meanwhile, Yulianti et al. (2023) revealed the great potential of generative artificial intelligence (AI) in creating dynamic and interactive learning content, although they emphasized that further research is still needed to optimize its use. On the other hand, Su et al. (2022) and Cevikbas et al. (2023) confirmed that virtual reality (VR) has the potential to increase student engagement and understanding of mathematical concepts, but its implementation is still constrained by technical and financial limitations.

Based on these findings, the visualization of VOSviewer and related research shows that although some topics have been sufficiently explored, there are still significant research gaps. The biggest research gap was found in the development and implementation of generative artificial intelligence, the utilization of virtual reality, and the challenges of AI in mathematics education. The low number of studies on this topic is due to the novelty of technologies such

as generative AI, which are not yet being used optimally, as well as significant practical obstacles. These obstacles include the high cost and technical limitations of VR implementation, coupled with the complexity of ethical issues surrounding the integration of AI in education. Generative AI is a promising research topic for the future, in line with the results of bibliometric studies on the Scopus and WoS databases by Ivanova et al. (2024). Meanwhile, the need for VR research in education is supported by the results of bibliometric analysis using the WoS database by Rojas-Sánchez et al. (2023) and the challenges of applying AI in mathematics education are supported by the results of bibliometric analysis using the Scopus database by Subroto et al. (2024).

Further research in this area is expected to contribute significantly to the development of more innovative and effective AI-based mathematics education. In the field of generative AI, research can explore the development of AI models capable of providing adaptive and personalized feedback on real-time math problem solving. Investigations into the long-term impact of generative AI use on students' critical thinking and mathematical creativity are also crucial areas. Second, for virtual reality, further research could focus on designing low-cost VR simulations that are more widely accessible, as well as measuring their effectiveness in visualizing abstract mathematical concepts (e.g., three-dimensional geometry or calculus). Finally, regarding the challenges of AI integration, in-depth studies are needed to formulate an ethical framework and concrete learning designs for mathematics learning, the potential for algorithmic bias in assessment, and the exploration of the most effective teacher training models to equip them with relevant digital pedagogical competencies.

CONCLUSION

Several conclusions can be drawn after conducting a bibliometric analysis of trends in the use of AI in school mathematics education. First of all, it is clear that the field of AI in school mathematics education has grown rapidly in the years 2019 - 2024 by experiencing an increasing publication trend, peaking at

111 publications (54.9%) in 2024. The growing use of AI in mathematics education is not temporary, but part of a long-term change that continues to evolve as technology advances and educational policies support innovation. The many citations on AI research topics such as Chat GPT and its application in STEM education support its relevance and significance to lead to more optimal utilization of AI. However, educators must also understand the possible negative impacts and ethical questions that arise. The number of citations for publications tends to be high, with the highest numbers being 373, 295, and 109 citations, respectively. From the sample of international journal articles, it can be distributed that Indonesia, South Korea, and the United States are the highest countries of publication affiliation. Moreover, the mapping analysis of AI utilization in school mathematics education through VOSviewer software revealed the significance of the expansion of renewable research themes and frequencies that have not been done much, namely on the themes of "ai tool", "attitude", "challenge", "generative artificial intelligence", "higher education", and "middle school student". These findings underscore a critical research imperative, suggesting that mathematics education scholars and practitioners must prioritize further investigation into AI applications for school-level mathematics instruction.

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