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Research Paper

The Use of Artificial Intelligence in Primary School Mathematics: A Bibliometric Analysis

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Abstract

The role of technology, particularly artificial intelligence, in the increasingly advanced digital age has the potential to revolutionize the educational landscape in unprecedented ways. This study aims to analyze and elucidate trends related to the utilization of artificial intelligence in mathematics activities within primary schools, as well as to uncover potential research opportunities for the future. Articles for this study were retrieved from the Scopus database using the search string "artificial intelligence" AND (mathematics OR mathematical) AND ("primary education" OR "elementary education" OR "primary school" OR "elementary school"). Article analysis was conducted using Harzing's Publish or Perish and VOSviewer. The study's findings indicate that the topic of artificial intelligence and primary school mathematics has been investigated from 1974 to 2023, with a total of 66 articles published in the Scopus database. The year 2022 witnessed the highest number of publications, with 17 articles published from 1974 to October 2023. Mapping the results revealed 36 keyword items grouped into 5 clusters. In conclusion, the findings of this bibliometric analysis suggest that there is potential for further scholarly exploration on the topic of utilizing artificial intelligence in mathematics education within primary schools.

Keywords *artificial intelligence; bibliometric analysis; mathematics; primary school*

INTRODUCTION

Recent technological advancements have transformed Indonesian society from an industrial society into an information society, as evidenced by the increasing use of information and communication technology (Zamjani et al., 2020). One of the prominent technological developments widely discussed in the modern era is Artificial Intelligence (AI). Artificial intelligence is the simulation of human intelligence modeled within a machine (computer system) and programmed to think like a human, enabling it to perform tasks that typically require human resources (Mohamed et al., 2022). Artificial intelligence is also a field of research and innovation that has created computers, machines, and other artifacts with human-like intelligence characterized by perception, learning, adaptability, and creativity (Chen et al., 2020).

In this era, artificial intelligence has become a significant issue intensively studied in various countries, governments, and sectors of life (Mijwil et al., 2022). Artificial intelligence is increasingly integrated into everyday life, and many countries have allocated significant resources for research in this field (Wong et al., 2020). One of the reasons for this is the substantial impact

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that artificial intelligence has had on human life in recent years (Wu & Yang, 2022). Additionally, modern society has realized that knowledge and skills learned solely for the purposes of the workforce and collaboration are considered insufficient for preparing for the highly automated and digitized Industry 5.0 revolution. In the digital technology era, every individual can already connect with their family and friends every day and at any time. In this situation, digitization provides ease of access to information, which can be tailored without being restricted by time and place (Nasrullah et al., 2017; Zamjani et al., 2020).

Artificial intelligence is actively utilized in everyday life, with its usage rapidly expanding across various fields (Kang et al., 2022). Therefore, knowledge about artificial intelligence and its prudent utilization is crucial for individuals of all age groups to prepare them for a society driven by artificial intelligence in the future (Kajiwara et al., 2023). Understanding the scope and effectiveness of artificial intelligence technology is essential for overcoming challenges and fostering a fulfilling life (Wang & Liu, 2021). In this regard, the use of artificial intelligence can augment human capabilities and enhance daily living through the application of increasingly advanced technology (Mohamed et al., 2022). Conversely, preparing children to be adaptable to artificial intelligence is imperative for their future careers. Equipped with these skills, they can effectively contribute to the evolving societal landscape (Podpečan, 2023).

The application of artificial intelligence technology continues to evolve and is not limited to just the industry; it has also become popular in the field of education and has garnered significant research attention (Mohamed et al., 2022). Moreover, the role of technology in this increasingly advanced digital era has the potential to reshape the educational landscape in unprecedented ways. In general, artificial intelligence in education can be categorized into two types: learning about artificial intelligence, which means educating to understand AI, and learning with AI, which involves using artificial intelligence for learning or educational administration (Holmes et al., 2019; Park, 2023)However, the integration of artificial intelligence in education encounters resistance from certain quarters. For instance, the advent of artificial intelligence variants like ChatGPT instigates apprehension among many educators due to its perceived implications on their instructional roles, particularly in terms of assigning tasks and questions to students (Karaali, 2023).

Numerous studies exploring the role of Artificial Intelligence in primary school mathematics education have been undertaken, revealing a diversity of perspectives on its application. Research conducted by Karaali (2023) indicates that certain educators harbor reservations regarding the integration of artificial intelligence into educational practices. These concerns encompass apprehensions about the efficacy of teaching writing and critical thinking skills, which may be compromised by readily accessible artificial intelligence resources for students. Conversely, the utilization of artificial intelligence tools like ChatGPT has exhibited limitations in accurately addressing quantitative queries. Moreover, there exists a segment of individuals who harbor skepticism towards and refrain from embracing artificial intelligence due to a lack of comprehension regarding its educational benefits and role (Kajiwara et al., 2023). They are also cognizant of the potential for errors or biases in AI-generated responses, particularly concerning quantitative mathematical problems (Karaali, 2023). Furthermore, recent advancements in artificial intelligence, which have spurred increased interest in computational thinking, underscore the inadequate understanding of children's proficiency in computational thinking due to a lack of psychometric assessments (Li et al., 2021). Meanwhile, another constraint is the scant exploration of artificial intelligence topics in mathematics education studies, particularly at the primary school level (Mohamed et al., 2022).

Based on several of these studies, it has been observed that there exists a scope for further research concerning the utilization of artificial intelligence in primary school mathematics learning. The latest studies emphasize combining AI-related keywords with several other variables relevant to mathematics education in primary schools. Hence, the study poses two primary inquiries as follows. What is the overview and publication trend regarding the utilization of artificial intelligence in primary school mathematics studies? What are the prospects for exploring the integration of artificial intelligence in mathematical activities for primary school students in future research endeavors?

LITERATURE REVIEW

Artificial intelligence keeps transforming into a growing future and can be effectively used in education to construct a new digitally interconnected world (Mijwil et al., 2022). Within the field of education, technology is bringing about significant changes in classroom learning methods, resulting in increased accessibility and improved quality of educational services for the community (Zamjani et al., 2020). Artificial intelligence techniques can expedite developments in the education sector, enhancing productivity through engaging learning activities (Mijwil et al., 2022). Furthermore, the development of artificial intelligence in education offers several benefits, such as empowering learners, personalizing learning, and supporting self-directed, student-centered learning (Ouyang & Jiao, 2021). Artificial intelligence based education is also closely intertwined with the role of teachers as contributors to artificial intelligence technology development, such as serving as models to train artificial intelligence algorithms and verifying the accuracy of automated artificial intelligence assessment systems (Celik et al., 2022). To support these efforts, many researchers have explored the role of artificial intelligence in enhancing learning activities, including searching, selecting, and adapting various study materials for use in their learning activities (Cardona et al., 2023).

The rapid advancements in artificial intelligence have created a need to integrate AI-related topics and content into educational activities (Podpečan, 2023). The demand for artificial intelligence as an asset for the future in the field of education is increasing and its benefits are recognized. In education and learning, artificial intelligence techniques are beneficial because they can mimic human thinking and decision-making, reducing uncertainties in achieving effective learning outcomes (Almohammadi et al., 2017). To support this issue, major countries around the world have made significant efforts to meet the demand for high-level artificial intelligence education, such as efforts to understand artificial intelligence and its usage (Park, 2023). In some European countries, guidelines for safe and child-friendly use of artificial intelligence technology have been established (Charisi et al., 2022; Podpečan, 2023). Apart from Europe, the United States is one of the most active countries in publishing research on the use of artificial intelligence in education, particularly its effectiveness in the learning process, especially in subjects like mathematics (Mohamed et al., 2022). Artificial intelligence continues to evolve and innovate, allowing students to develop and enhance their mathematical and cognitive skills in learning (Mohamed et al., 2022).

The utilization of artificial intelligence applications in education, including mathematics education, has been on the rise and has garnered significant attention in recent years (Mohamed et al., 2022). The application of artificial intelligence in educational institutions takes various forms, ranging from computers to robots and chatbots, with the aim of assisting educators in efficiently managing administrative tasks and enhancing the quality of instruction (Chen et al., 2020). Chatbots, being a form of artificial intelligence, hold strong educational potential as they can provide prompt and contextually relevant information through both verbal and written interactions (Kang et al., 2022). Another type of artificial intelligence widely used in the field of education is ChatGPT (Kang et al., 2022).

RESEARCH METHOD

This study is a type of bibliometric analysis (Belmonte et al., 2020; López-Robles et al., 2019; Moreno-Guerrero et al., 2020). This approach was chosen for its potential to measure and analyze publications recorded in a research database (Carmona-Serrano et al., 2021). This study aims to analyze and elucidate trends related to the utilization of artificial intelligence in mathematics activities within primary schools, as well as to uncover potential research opportunities for the future. Bibliometrics is a method of analysis that employs quantitative data to examine the bibliographic characteristics of an ever-growing body of literature (Lopes et al., 2017). In this study, we interpret various indicators such as author productivity, country of origin, and the quantity of scholarly work produced over time. We also map the academic outcomes associated

with the study, establishing standards of collaboration among authors, research groups, and research institutions, parameters related to other social network analyses, and identifying the primary research domains (De Pinho et al., 2015; Lopes et al., 2017).

This research is complemented by a co-word analysis focused on the keywords found in the publication metadata in the Scopus database (Herrera-Viedma et al., 2020; Marín-Marín et al., 2021). This study is centered on the analysis of the keywords present in a volume of documents recorded in Scopus. Specifically, the identification and analysis in this study highlight the interconnections and relationships of the topics investigated across various types of publications under review. Moreover, the co-word analysis in this study allows for predicting potentially relevant topics for current research and creating a map that displays nodes related to the performance areas, the location of subdomains within the terminology, and the evolution of an issue or topic (Marín-Marín et al., 2021). The study also includes several indicators related to the topics under examination, such as publication year, total number of articles published, citation count, h-index, and g-index (López-Robles et al., 2019; Marín-Marín et al., 2021).

The initial steps we took in this study involved determining the data sources that we considered suitable for our research area (Moral-muñoz et al., 2020). Articles in this study were retrieved through the Scopus database using the search string "artificial intelligence" AND (mathematics OR mathematical) AND ("primary education" OR "elementary education" OR "primary school" OR "elementary school") in October 2023. Based on our search results, there were 66 types of publications, including conference papers, articles, reviews, books, editorials, book chapters, and conference reviews. We exported the article data in RIS format for import into the analysis tools. For completeness of metadata in this study, we selected several items in the Scopus database, including citation information, bibliographical information, abstracts and keywords, funding details, and other information. The next step involved analyzing the articles with the assistance of Harzing's Publish or Perish and VOSviewer. We used Harzing's Publish or Perish to describe the citation metrics of a number of articles. VOSviewer was employed to map the results of metadata export from the Scopus database. The mapping activities we conducted utilized a type of analysis and calculation method involving co-occurrence analysis. The unit of analysis was keywords, and the counting method involved full counting. We restricted the minimum number of keyword occurrences to three to illustrate the relationships among the generated keywords.

FINDINGS AND DISCUSSION

Overview and Publication Trends of the Utilization of Artificial Intelligence in Primary School Mathematics Studies

This section presents findings from analytical activities employing Harzing's Publish or Perish and VOSviewer tools. A summary of the citation metrics resulting from this analysis is presented in Figure 1.

Publication years:	1974-2023
Citation years:	50 (1974-2024)
Papers:	66
Citations:	337
Cites/year:	6.74
Cites/paper:	5.11
Cites/author:	166.21
Papers/author:	27.22
Authors/paper:	2.83
h-index:	9
g-index:	17
hI,norm:	6
hI,annual:	0.12
hA-index:	5
Papers with ACC >= 1,2,5,10,20:	
18,8,5,1,0	

Figure 1. Citation metrics

Figure 1 illustrates that many studies investigating the application of artificial intelligence in primary school mathematics have been carried out between 1974 and 2023, based on the Scopus database. During this period, 66 articles have gathered a significant number of citations, specifically 337, indicating the continuous importance of this study issue within the academic community. A mean of 5.11 citations per article suggests a moderate level of effect. However, a mean of 166.21 citations per author highlights the substantial influence of prominent authors in the field of this study. An h-index of 9 signifies that a minimum of 9 publications have received at least 9 citations each. Additionally, a g-index of 17 signifies that the 17 most referenced works jointly obtained a minimum of 289 citations, emphasizing numerous influential studies in this area.

Furthermore, a normalized h-index (hI, norm) of 6, which considers the influence of authors in publications, emphasizes the significant contributions made by senior authors. An hI, annual value of 0.12 suggests a steady annual acknowledgement rate for these works. The analysis of citations also indicated that 18 works were cited at least once, whereas only one work earned more than 20 citations. This situation suggests that although a few works had a significant influence, the majority had comparatively less influence. This analysis facilitates comprehension of the reception and utilization of these articles over an extended duration, offering valuable insights into the development and impact of research subjects in associated disciplines.

Another finding derived from the analysis using Harzing's Publish or Perish was the identification of the top ten most cited articles by researchers, as depicted in **Table 1**.

Table 1. Top Ten Articles with The Most Citations

Cites	C/Y	Authors	Title	Year
56	6.22	(Pareto, 2014)	A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning	2014
43	14.33	(Papadopoulos et al., 2020)	A systematic review of the literature regarding socially assistive robots in pre-tertiary education	2020
40	3.33	(Hirashima & Kurayama, 2011)	Learning by problem-posing for reverse-thinking problems	2011
27	6.75	(Julià & Antolí, 2019)	Impact of implementing a long-term STEM-based active learning course on students' motivation	2019
18	9.00	(Heinze et al., 2010)	An action research report from a multi-year approach to teaching Artificial Intelligence at the K-6 level	2010
18	1.38	(S. Lee et al., 2021)	AI-Infused Collaborative Inquiry in Upper Elementary School: A Game-Based Learning Approach	2021

17	2.83	(Budiharto et al., 2017)	EduRobot: Intelligent Humanoid Robot with Natural Interaction for Education and Entertainment	2017
13	13.00	(D. Lee & Yeo, 2022)	Developing an AI-based chatbot for practicing responsive teaching in mathematics	2022
12	0.75	(Curzon, 2007)	Serious fun in computer science	2007
8	2.00	(Troussas et al., 2019)	Adaptive e-learning interactions using dynamic clustering of learners' characteristics	2019

Table 1 describes the top ten articles based on the number of citations in the context of educational technology research, offering an overview of research areas of significant interest and influence in the last decade. The overall data shows variations in the number of citations and citations per year (C/Y), which provides insight into the sustainability and impact of the publication. The article with the most citations is "A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning" by Pareto (2014), which has been cited 56 times with a C/Y of 6.22, showing its long-term impact in teaching arithmetic concepts through games. This was followed by "A systematic review of the literature regarding socially assistive robots in pre-tertiary education" by Papadopoulos et al. (2020) with 43 citations and a very high C/Y of 14.33, signifying strong acceptance and fast-growing importance in educational robotics. Hirashima & Kurayama (2011) with "Learning by problem-posing for reverse-thinking problems" and Julià & Antolí (2019) with "Impact of implementing a long-term STEM-based active learning course on students' motivation," with 40 and 27 citations, respectively, demonstrate the importance of innovative learning methods in STEM education. Articles by Heinze et al. (2010) and S. Lee et al. (2021), both reaching 18 citations, discuss artificial intelligence teaching at a basic level and AI-powered collaborative inquiry, highlighting the importance of technology in basic education.

"EduRobot: Intelligent Humanoid Robot with Natural Interaction for Education and Entertainment" by Budiharto et al. (2017), with 17 citations, explores the use of humanoid robots in education and entertainment, illustrating the integration of technology, education, and social aspects. Articles by D. Lee & Yeo (2022) and Curzon (2007), with 13 and 12 citations, respectively, focus on using artificial intelligence for teaching approaches and computer science education, reflecting a growing interest in responsive and engaging educational methods. Finally, "Adaptive e-learning interactions using dynamic clustering of learners' characteristics" by Troussas et al. (2019), with 8 citations, highlights the importance of personalization in e-learning. These findings suggest that although research on artificial intelligence has been ongoing since 1974, the most cited reference articles were published in 2014. Collectively, these data illustrate the trend in educational research towards incorporating artificial intelligence technology as a learning approach.

Further findings concerning publication trends on the utilization of Artificial Intelligence in primary school mathematics activities, as depicted on the Scopus database since the inception of publication, reveal a fluctuating developmental trajectory based on the availability of publications. The number of publications on this issue indicates a need for further development, as depicted in Figure 2.

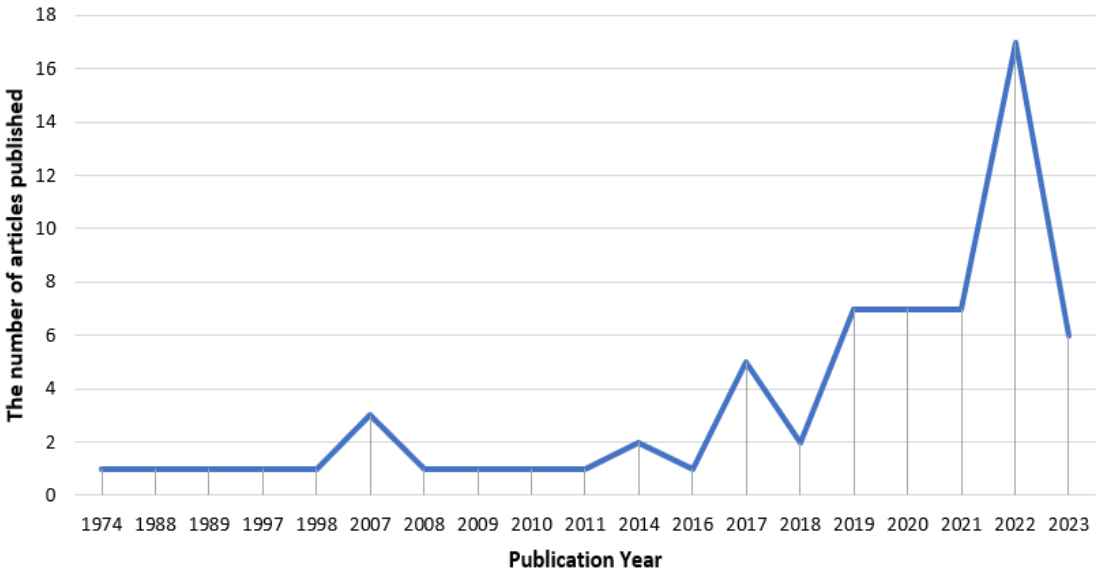

Figure 2. Publication trends in the use of artificial intelligence in primary school mathematics learning

Figure 2 shows the fluctuating number of articles on the use of artificial intelligence in primary school mathematics learning, published from 1974 to 2023. In the early period, from 1974 to 2007, the number of articles published was relatively low and stable, with only a few articles published every few years. This condition indicates that using artificial intelligence in mathematics learning in primary schools has not been widely researched or received significant attention in the academic community. However, starting in 2008, there was a slight increase in the number of publications, although the number remained relatively low. This increase suggests the beginning of growing interest in using artificial intelligence in education.

Since 2018, there has been a significant increase in articles published, peaking in 2022 with 17 articles. This surge reflects the rapid growth of interest and widespread acceptance of artificial intelligence technology in mathematics learning in primary schools. One factor that also contributed to the increase in this publication trend was the COVID-19 pandemic that transpired between 2019 and 2021, prompting educational institutions to employ artificial intelligence as a solution for distance learning (Mijwil et al., 2022). However, after its peak in 2022, the number of articles published decreased in 2023. This decrease could be attributed to several factors, such as a shift in research focus, the impact of previous publications that have provided a sufficient knowledge base, and some related articles still being in the review process for publication. Generally, this graph illustrates the evolution of interest in and acceptance of AI technology in primary school mathematics learning. Despite fluctuations in the number of publications, the topic has become a major concern in the academic community over the past few years

Scope of Study on the Utilization of Artificial Intelligence in Mathematics Activities for Primary School Students in the Future

This section delineates the outcomes of VOSviewer mapping conducted on a collection of articles retrieved from the Scopus database pertaining to the issue of artificial intelligence in primary school mathematics activities. Out of a total of 600 keywords appearing in all articles, 36 relevant keywords were selected for analysis in this study. These selected items were categorized into 5 clusters, denoted by colors: red, green, blue, yellow, and purple. Cluster 1 comprises 10 items, namely: big data, curricula, primary school, learning experiences, mathematics education, mathematics teachings, primary schools, school students, students, and teachers'.

Additionally, Cluster 2 comprises 9 items, including computer aided instruction, education

computing, engineering education, learning systems, mathematical technique, neural networks, primary education, secondary education, and teaching. Cluster 3 encompasses 8 items, namely active learning, algorithms, artificial intelligence, child, computer science, education, human and mathematics. Cluster 4 includes 7 items, such as educational robots, fuzzy logic, intelligent robots, primary school children, robotics, STEM (science, technology, engineering and mathematics), and STEM education. Finally, Cluster 5 involves 2 items: e-learning and natural language processing systems.

Clusters in VOSviewer mapping indicate the density and strength of connections or links between items. Each item from the 5 clusters illustrates its position in relation to other items that appear. The size of the circles of an item, along with the connections to other circles representing specific items, reflects the relationships between these items that appear together in a research topic (Marín-Marín et al., 2021; Moral-muñoz et al., 2020). For instance, inFigure 3, it is evident that the item "artificial intelligence" exhibits the largest circle size and is directly linked to circles of various sizes. This linkage signifies the frequency of associations between artificial intelligence items and the grouped items within a study or publication.

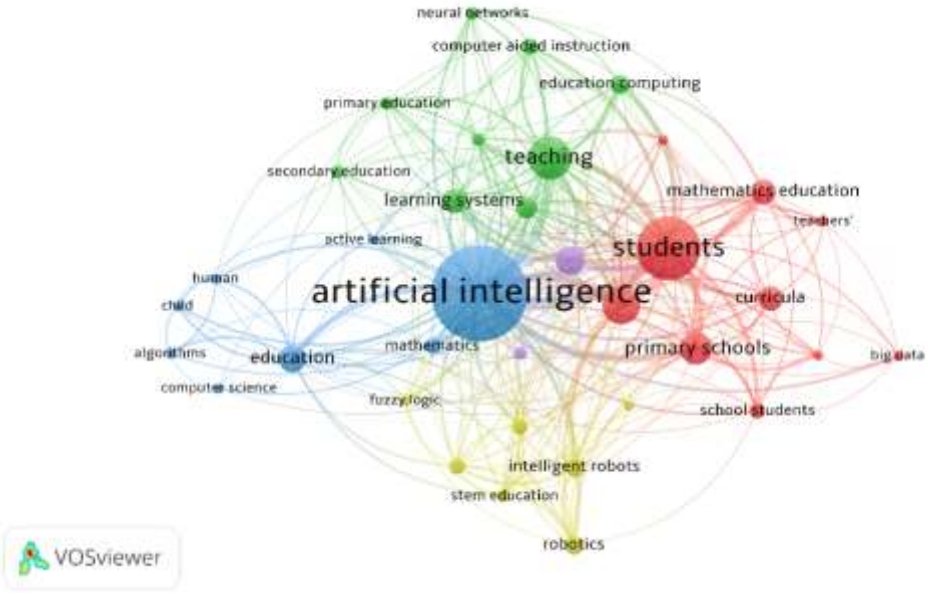

Figure 3. Network visualization of research on the use of artificial intelligence in primary school mathematics

Based on Figure 3 it is evident that the issue of artificial intelligence has been extensively studied in publications contained in the Scopus database. However, the fact that it has been extensively explored does not mean that it is no longer viable for further research. According to Figure 3 there are numerous connections between the keyword "artificial intelligence" and other keywords that have the potential to become variables in new research. The distance and the size of the circles indicate the degree of connection between the items or keywords. For example, the item "artificial intelligence" and the item "primary school children" have a significant distance between them, and the size of the circle for "primary school children" is relatively small. This connection suggests that the research area involving primary school children in the context of studying artificial intelligence is still wide open. To investigate the relationship between "primary school children" and other items in the study, one can click on the circle representing "primary school children". The visual display resulting from this click is depicted in Figure 4

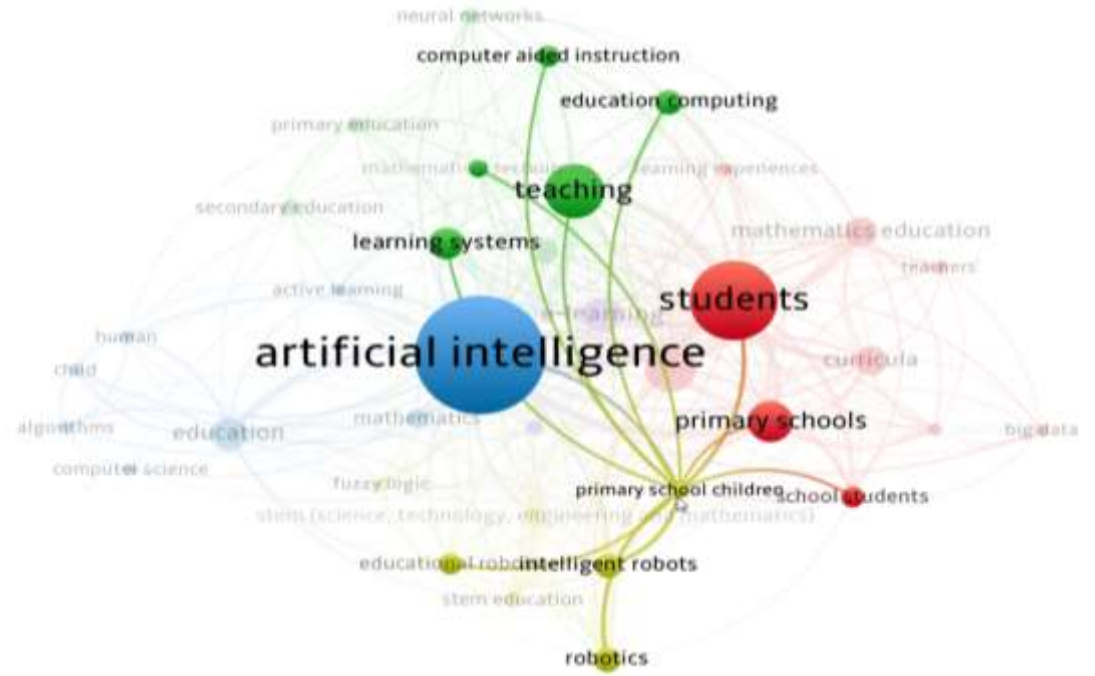

Figure 4. Network visualization for primary school children's items

Based on Figure 4 it is found that the keyword "primary school children" have appeared together in a publication with several other keywords, including artificial intelligence, students, teaching, primary schools, school students, education computing, learning systems, computer-aided instruction, mathematical techniques, intelligent robots, educational robots, and robotics. Additionally, from Figure 4 it can be observed that the keyword "primary school children" has not yet appeared together with keywords like "mathematics," "mathematics education," "STEM education," "active learning," "learning experiences," "computer science," or other keywords mapped in the network visualization. This presents an opportunity to link these keywords as variables in future studies on artificial intelligence.

In the results of VOSviewer mapping visualization, additional insights were gleaned from overlay visualization depicting the year of research, as depicted in Figure 5 Furthermore, density visualization was utilized to explore the latest publication opportunities, as illustrated in Figure 6 Based on Figure 5 it is found that research on the issue of artificial intelligence usage is mapped based on six periods according to the research years. The most recent research is indicated by the color yellow, while the oldest research is represented by the dark blue color (Marín-Marín et al., 2021; Moral-muñoz et al., 2020). When a keyword points to the yellow color, it indicates that the item belongs to a new type of variable being studied in the context of artificial intelligence.

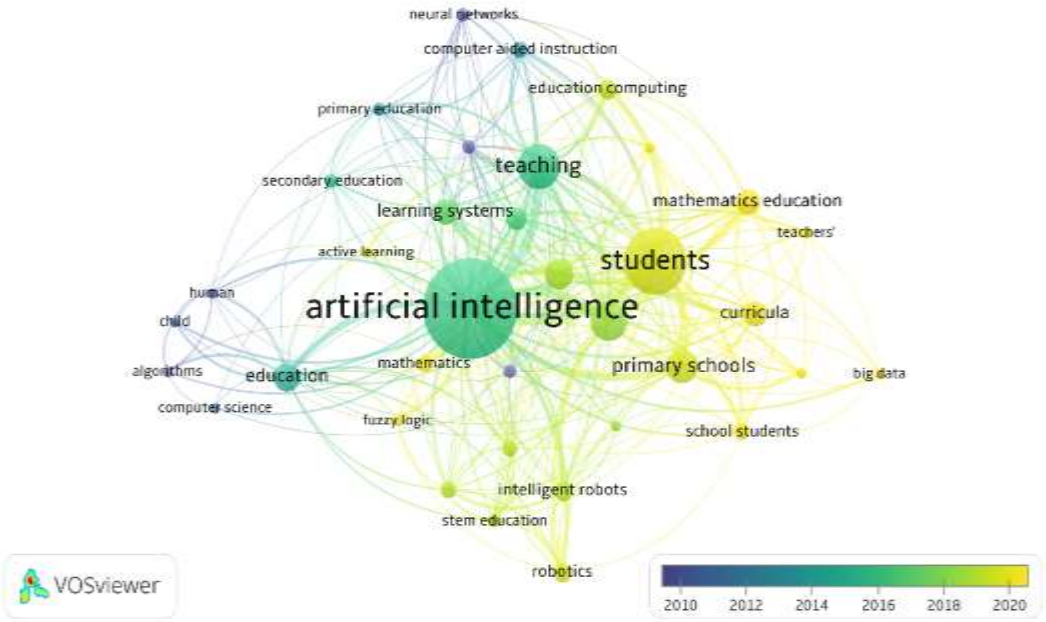

Figure 5. Overlay visualization of research on the use of artificial intelligence in primary school mathematics

Based on Figure 5 the latest research on artificial intelligence in the Scopus database is focused on several keywords, including e-learning, elementary schools, intelligent robots, stem (science, technology, engineering and mathematics), stem education, educational robots, primary school children, active learning, robotics, fuzzy logic, primary schools, mathematics, curricula, school students, big data, teachers', mathematics education, education computing, learning experiences, mathematics teachings, and students. Conversely, older studies related to artificial intelligence research present in the Scopus database include investigations into neural networks, mathematical techniques, human, child, algorithms, computer sciences, natural language processing systems, computer aided instruction, primary education, secondary education, engineering education, education, teaching, and learning systems.

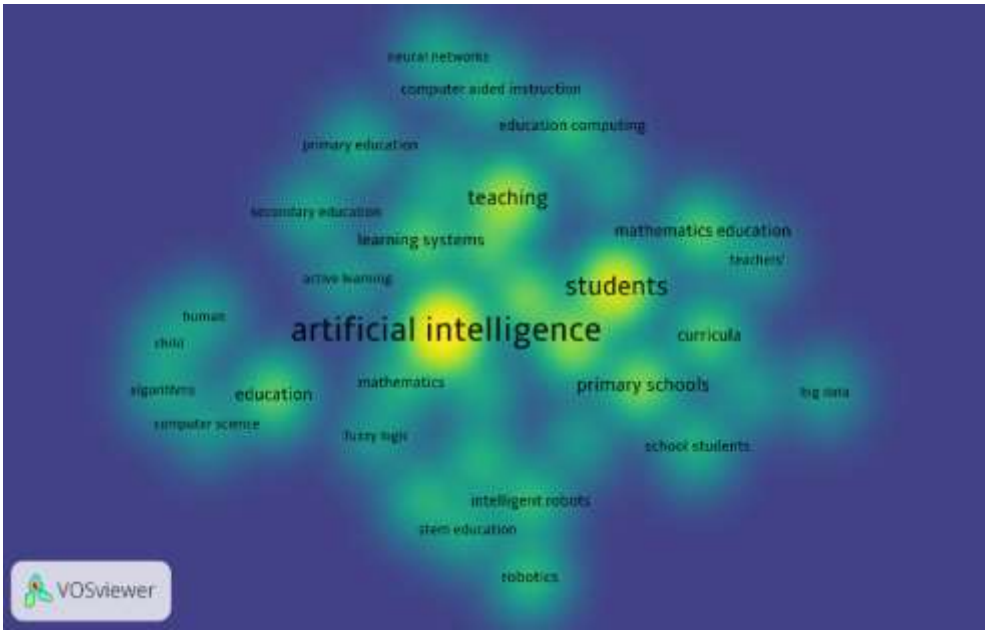

Figure 6. Density visualization of research on the use of artificial intelligence in primary school mathematics

Furthermore, in Figure 6 it was observed that the keyword "artificial intelligence" is depicted in bright yellow. This bright yellow coloration signifies that this keyword has been extensively researched. Conversely, dull or faded colors indicate that the keyword is relatively understudied (Marín-Marín et al., 2021; Moral-muñoz et al., 2020). Through density visualization mapping, several new variables were discovered that could be identified as potential subjects for further study, offering novelty and originality. Based on Figure 6 it is apparent that there are still numerous keywords that can be explored as new research variables in the context of artificial intelligence. Some keywords that can be employed in conjunction with artificial intelligence variables and elementary school math activities for future research include "primary school children," "mathematical teaching," "STEM (science, technology, engineering, and mathematics)," "mathematical techniques," and "mathematics."

CONCLUSIONS

This study provides a comprehensive overview of research concerning the utilization of artificial intelligence (AI) in primary school mathematics studies spanning from the inaugural publication year, 1974, to 2023. Over the span of 49 years, a total of 66 articles have contributed to this discourse, accumulating 337 citations. Pareto's seminal work, titled " A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning," published in 2014, emerged as the most influential contribution in this domain.

Examining the publication trends, it is observed that the highest volume of publications occurred in 2022, totaling 17 articles. This trend exhibits an upward trajectory in publications from 2019 through 2022. Employing keyword analysis with a minimum threshold of three occurrences, 36 keyword items were identified, which coalesced into five distinct clusters. This mapping of the issue illuminates various facets of artificial intelligence integration in primary school mathematics studies.

Drawing insights from the bibliometric analysis, there exists potential for further scholarly exploration in the realm of utilizing artificial intelligence in primary school mathematics studies. Potential avenues for future research may involve the integration of additional keywords alongside artificial intelligence, such as primary school children, mathematical teaching, STEM (science, technology, engineering and mathematics), mathematical techniques, and mathematics.

LIMITATION & FURTHER RESEARCH

This article acknowledges limitations pertaining to the exclusive utilization of Scopus databases as the primary data sources. Consequently, a recommendation is made to conduct further investigation into this issue, with particular emphasis on expanding data sources to include alternative databases such as ERIC and the WoS database. Furthermore, it is imperative to deliberate upon the inclusion of several other pertinent keywords to augment the richness of data sources in forthcoming research endeavors. Finally, it is highly recommended that future research adopts a systematic literature review approach to further explore and validate the findings unearthed in this bibliometric analysis study.

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REFERENCES

Almohammadi, K., Hagras, H., Alghazzawi, D., & Aldabbagh, G. (2017). A survey of artificial intelligence techniques employed for adaptive educational systems within e-learning platforms. *Journal of Artificial Intelligence and Soft Computing Research*, *7*(1), 47–64. https://doi.org/10.1515/jaiscr-2017-0004

Belmonte, J. L., Segura-Robles, A., Moreno-Guerrero, A. J., & Parra-González, M. E. (2020). Machine learning and big data in the impact literature. A bibliometric review with scientific mapping in web of science. *Symmetry*, *12*(4), 1–15. https://doi.org/10.3390/SYM12040495

Budiharto, W., Cahyani, A. D., Rumondor, P. C. B., & Suhartono, D. (2017). Edurobot: intelligent humanoid robot with natural interaction for education and entertainment. *Procedia Computer Science*, *116*, 564–570. https://doi.org/10.1016/j.procs.2017.10.064

Cardona, M. A., Rodríguez, R. J., & Ishmael, K. (2023). *Artificial Intelligence and the Future of Teaching and Learning: Insights and Recommendations*.

Carmona-Serrano, N., Moreno-Guerrero, A. J., Marín-Marín, J. A., & López-Belmonte, J. (2021). Evolution of the autism literature and the influence of parents: A scientific mapping in web of science. *Brain Sciences*, *11*(1), 1–16. https://doi.org/10.3390/brainsci11010074

Celik, I., Dindar, M., Muukkonen, H., & Järvelä, S. (2022). The promises and challenges of artificial intelligence for teachers: a systematic review of research. *TechTrends*, *66*(4), 616–630. https://doi.org/10.1007/s11528-022-00715-y

Charisi, V., Chaudron, S., Gioia, R. Di, Vuorikari, R., Planas, M. E., Sanchez, I., & Gómez, E. (2022). *Artificial Intelligence and the Rights of the Child Towards an Integrated Agenda for Research and Policy*. Joint Research Centre (Seville site). https://doi.org/10.2760/012329

Chen, L., Chen, P., & Lin, Z. (2020). Artificial intelligence in education: a Review. *IEEE Access*, *8*, 75264–75278. https://doi.org/10.1109/ACCESS.2020.2988510

Curzon, P. (2007). Serious fun in computer science. *ACM SIGCSE Bulletin*, *39*(3), 1–1. https://doi.org/10.1145/1268784.1268785

De Pinho, L. A., Mota, F. B., Conde, M. V. F., Alves, L. A., & Lopes, R. M. (2015). Mapping knowledge produced on problem-based learning between 1945 and 2014: a bibliometric analysis. *Creative Education*, *06*(06), 576–584. https://doi.org/10.4236/ce.2015.66057

Heinze, C., Haase, J., & Higgins, H. (2010). An action research report from a multi-year approach to teaching Artificial Intelligence at the K-6 level. *In Proceedings of the National Conference on Artificial Intelligence*, *3*, 1890–1895.

Herrera-Viedma, E., López-Robles, J. R., Guallar, J., & Cobo, M. J. (2020). Global trends in coronavirus research at the time of COVID-19: A general bibliometric approach and content analysis using SciMAT. *Profesional de La Informacion*, *29*(3), 1–20. https://doi.org/10.3145/epi.2020.may.22

Hirashima, T., & Kurayama, M. (2011). Learning by problem-posing for reverse-thinking problems. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *6738 LNAI*, 123–130. https://doi.org/10.1007/978-3-642-21869-9_18

Holmes, W., Bialik, M., & Fadel, C. (2019). *Artificial Intelligence in Education. Promise and Implications for Teaching and Learning.* The Center for Curriculum Redesign, Boston, MA.

Julià, C., & Antolí, J. Ò. (2019). Impact of implementing a long-term STEM-based active learning course on students' motivation. *International Journal of Technology and Design Education*, *29*(2), 303–327. https://doi.org/10.1007/s10798-018-9441-8

Kajiwara, Y., Matsuoka, A., & Shinbo, F. (2023). Machine learning role playing game: Instructional design of AI education for age-appropriate in K-12 and beyond. *Computers and Education: Artificial Intelligence*, *5*, 1–19. https://doi.org/10.1016/j.caeai.2023.100162

Kang, K.-A., Kim, S.-J., & Kang, S. R. (2022). Elementary school students' awareness of the use of

artificial intelligence chatbots in violence prevention education in South Korea: a descriptive study. *Original Article*, *28*(4), 291–298.

Karaali, G. (2023). Artificial intelligence, basic skills, and quantitative literacy. *Numeracy*, *16*(1), 1–20. https://doi.org/10.5038/1936-4660.16.1.1438

Lee, D., & Yeo, S. (2022). Developing an AI-based chatbot for practicing responsive teaching in mathematics. *Computers and Education*, *191*. https://doi.org/10.1016/j.compedu.2022.104646

Lee, S., Mott, B., Ottenbreit-Leftwich, A., Scribner, A., Taylor, S., Park, K., Rowe, J., Glazewski, K., Hmelo-Silver, C. E., & Lester, J. (2021). AI-infused collaborative inquiry in upper elementary school: a game-based learning approach. *In Proceedings of the AAAI Conference on Artificial Intelligence*, *35*(17), 15591–15599.

Li, Y., Xu, S., & Liu, J. (2021). Development and validation of computational thinking assessment of chinese elementary school students. *Journal of Pacific Rim Psychology*, *15*, 1–22. https://doi.org/10.1177/18344909211010240

Lopes, R. M., Faria, D. J. G. dos S. de, Fidalgo-Neto, A. A., & Mota, F. B. (2017). Facebook in educational research: a bibliometric analysis. *Scientometrics*, *111*(3), 1591–1621. https://doi.org/10.1007/s11192-017-2294-1

López-Robles, J. R., Otegi-Olaso, J. R., Porto Gómez, I., & Cobo, M. J. (2019). 30 years of intelligence models in management and business: A bibliometric review. *International Journal of Information Management*, *48*, 22–38. https://doi.org/10.1016/j.ijinfomgt.2019.01.013

Marín-Marín, J. A., Moreno-Guerrero, A. J., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in education: a bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education*, *8*(1), 1–21. https://doi.org/10.1186/s40594-021-00296-x

Mijwil, M. M., Aggarwal, K., Mutar, D. S., Mansour, N., & Singh, R. S. S. (2022). The position of artificial intelligence in the future of education: an overview. *Asian Journal of Applied Sciences*, *10*(2), 102–108. https://doi.org/10.24203/ajas.v10i2.6956

Mohamed, M. Z. bin, Hidayat, R., Suhaizi, N. N. binti, Sabri, N. binti M., Mahmud, M. K. H. bin, & Baharuddin, S. N. binti. (2022). Artificial intelligence in mathematics education: A systematic literature review. *International Electronic Journal of Mathematics Education*, *17*(3), 1–11. https://doi.org/10.29333/iejme/12132

Moral-muñoz, J. A., Herrera-viedma, E., Santisteban-espejo, A., & Cobo, M. J. (2020). Software tools for conducting bibliometric analysis in science: An up- to-date review. *El Profesional de La Informa-Ción*, *29*(1), 1–20. https://doi.org/https://doi.org/10.3145/epi.2020.ene.03 Manuscript

Moreno-Guerrero, A. J., López-Belmonte, J., Marín-Marín, J. A., & Soler-Costa, R. (2020). Scientific development of educational artificial intelligence in web of science. *Future Internet*, *12*(8), 1–17. https://doi.org/10.3390/FI12080124

Nasrullah, R., Aditya, W., Satya P, T. I., Nento, Meyda Noorthertya Hanifah, N., Miftahussururi, & Akbari, Q. S. (2017). *Materi Pendukung Literasi Digital*. http://gln.kemdikbud.go.id/glnsite/wp-content/uploads/2017/10/literasi-DIGITAL.pdf

Ouyang, F., & Jiao, P. (2021). Artificial intelligence in education: The three paradigms. *Computers and Education: Artificial Intelligence*, *2*, 1–6. https://doi.org/10.1016/j.caeai.2021.100020

Papadopoulos, I., Lazzarino, R., Miah, S., Weaver, T., Thomas, B., & Koulouglioti, C. (2020). A systematic review of the literature regarding socially assistive robots in pre-tertiary education. *Computers and Education*, *155*, 1–20. https://doi.org/10.1016/j.compedu.2020.103924

Pareto, L. (2014). A teachable agent game engaging primary school children to learn arithmetic concepts and reasoning. *International Journal of Artificial Intelligence in Education*, *24*(3), 251–283. https://doi.org/10.1007/s40593-014-0018-8

Park, J. (2023). A case study on enhancing the expertise of artificial intelligence education for pre-service teachers. *Preprints*, 1–11. https://doi.org/10.20944/preprints202305.2006.v1

Podpečan, V. (2023). Can you dance? A study of child–robot interaction and emotional response using

the nao robot. *Multimodal Technologies and Interaction*, *7*(9), 1–14. https://doi.org/10.3390/mti7090085

Troussas, C., Krouska, A., & Virvou, M. (2019). Adaptive e-learning interactions using dynamic clustering of learners' characteristics. *In 2019 10th International Conference on Information, Intelligence, Systems and Applications, (IISA)*, 1–7. https://doi.org/10.1109/IISA.2019.8900722

Wang, W., & Liu, Z. (2021). Using artificial intelligence-based collaborative teaching in media learning. *Frontiers in Psychology*, *12*, 1–11. https://doi.org/10.3389/fpsyg.2021.713943

Wong, G. K. W., Ma, X., Dillenbourg, P., & Huen, J. (2020). Broadening artificial intelligence education in K-12: Where to start? *ACM Inroads*, *11*(1), 20–29. https://doi.org/10.1145/3381884

Wu, S. Y., & Yang, K. K. (2022). The effectiveness of teacher support for students' learning of artificial intelligence popular science activities. *Frontiers in Psychology*, *13*, 1–10. https://doi.org/10.3389/fpsyg.2022.868623

Zamjani, I., W, Rakhmah, D. N., Azizah, S. N., Waruwu, H., & Hariyanti, E. (2020). *Platform Pembelajaran Digital Dan Strategi Inklusivitas Pendidikan Di Indonesia*. Pusat Penelitian Kebijakan, Badan Penelitian dan Pengembangan dan Perbukuan, Kementerian Pendidikan dan Kebudayaan.