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Original Article

Mapping the Landscape of AI in Mathematics Education

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Abstract
This study presents a comprehensive analysis of the evolving landscape of Artificial Intelligence (AI) applications in Mathematics Education through a bibliometric analysis. Data for this research was gathered from the Scopus database, using the keywords "Artificial Intelligence" and "Mathematics Education" with the document types limited to articles published in English without restricting the publication timeline. The work systematically explores the development, thematic, methodological trends, geographical distribution, and citation impact of scholarly output in the interdisciplinary sphere of AI and Mathematics Education. The findings uncover a significant growth in literature over the years, indicating a heightened interest and increasing recognition of the importance of AI in enhancing teaching, learning, and assessment in Mathematics Education. The study also illuminates dominant research themes, influential publications, prolific authors, and active institutions contributing to this research domain. Our bibliometric analysis offers a valuable perspective for scholars, educators, and policymakers interested in understanding the trajectory of AI's role in Mathematics Education and provides a solid basis for future research directions in this vibrant and dynamic field.

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1. Introduction

Artificial intelligence (AI) has gained considerable attention in the field of education, particularly in mathematics education, due to its potential to enhance teaching and learning experiences. AI-based systems offer personalized support, improved accessibility to relevant courses, and effective communication between teachers and students (bin Mohamed et al., 2022). Intelligent tutors, for instance, can replicate instructors' intelligence and deliver individualized advice, comments, or assistance, fostering students' personal growth and progress (Qiu et al., 2022). These systems can also detect and respond to students' cognitive-affective states, such as boredom and confusion, offering timely interventions to disrupt negative cycles and optimize learning outcomes (Baker et al., 2010).

In the context of mathematics education, AI has found various applications, such as the ASSISTments platform, which combines tutoring assistance with assessment reporting to teachers and students (Heffernan & Heffernan, 2014). This platform enables teachers to create or utilize pre-built ASSISTments, assign them to students, and provide immediate feedback while collecting valuable student-level data for teachers' insights (Heffernan & Heffernan, 2014). The platform's success is evident in its ability to engage a large number of students and its frequent use in research studies (Heffernan & Heffernan, 2014). Additionally, AI has contributed to the development of intelligent tutoring systems and integrated platforms supporting micro-intelligence in mathematics education (bin Mohamed et al., 2022).

The importance of AI in mathematics education is further highlighted by the inclusion of AI strategies in national education agendas. Countries recognize that AI can significantly impact students' educational experiences, leading to higher mathematics scores and fostering collaboration among students (bin Mohamed et al., 2022). By leveraging AI technologies, teachers can diagnose individual learning

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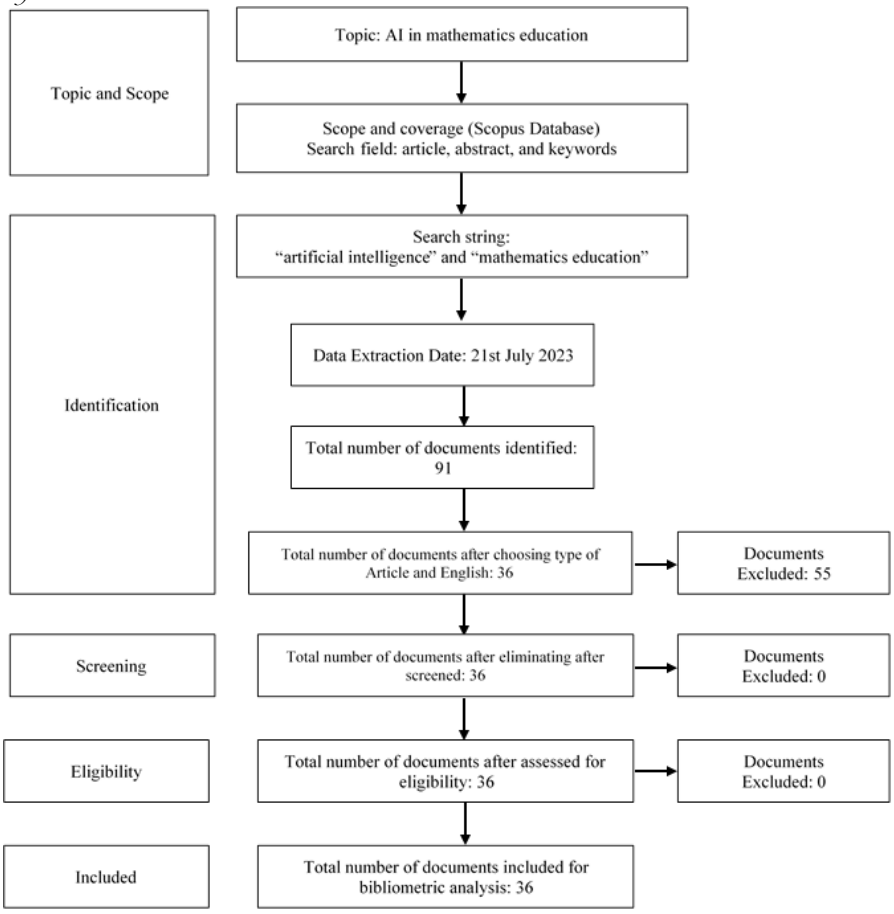
problems and provide personalized support, optimizing students' learning performance (Orhani, 2021). AI-based learning in mathematics empowers students to tackle complex and challenging problems, leading to improved problem-solving skills (Soesanto et al., 2022). As AI continues to evolve and integrate further into mathematics education, it holds the potential to revolutionize the way students learn, teachers teach, and the entire educational landscape functions.

This study aims to comprehensively explore the AI research landscape within the domain of mathematics education, focusing on several key research questions. Firstly, the investigation seeks to uncover the publication trends concerning AI in mathematics education, shedding light on the frequency and growth of academic contributions in this field. Secondly, the study aims to analyze citation trends, aiming to identify influential works and their impact on the advancement of AI in mathematics education. Thirdly, the distribution of AI journal rankings in mathematics education will be examined to understand the prominence and quality of publications in this area. Lastly, the geographic distribution of research publications related to AI in mathematics education will be assessed, providing insights into the global involvement and regional disparities in this field. By addressing these research questions, this study endeavors to provide valuable insights and foster further advancements in the integration of AI within mathematics education.

2. Method

This study utilized the Scopus database and VOSviewer, renowned for its comprehensive interdisciplinary coverage, to locate relevant data sources pertaining to "AI in mathematics education (Nandiyanto & Al Husaeni, 2022; Supriyadi, Suryadi, et al., 2023; Supriyadi, Turmudi, et al., 2023)." The process of data refinement, illustrated in Figure 1, comprises several sequential steps, namely identification, screening, eligibility, and inclusion (Moher et al., 2009).

Figure 1
Bibliometric Analysis Scheme



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During the initial identification step, researchers conducted a search on the Scopus database using the following keywords: "artificial intelligence" AND "mathematics education." This search yielded a total of 91 papers. Subsequently, the screening process ensued, wherein articles meeting specific criteria, such as being in English and in the form of journal articles, were selected. Following the screening, 36 publications were deemed eligible and retained, while 55 were excluded from further consideration. The next stage involved a manual assessment of the eligible publications to determine their suitability for inclusion in the study. The data for this study was collected from the Scopus database on July 21, 2023. The research methodology employed bibliometric analysis to accomplish its objectives. The findings will be presented through graphical representations utilizing Microsoft Excel and direct visualizations obtained from the Scopus database.

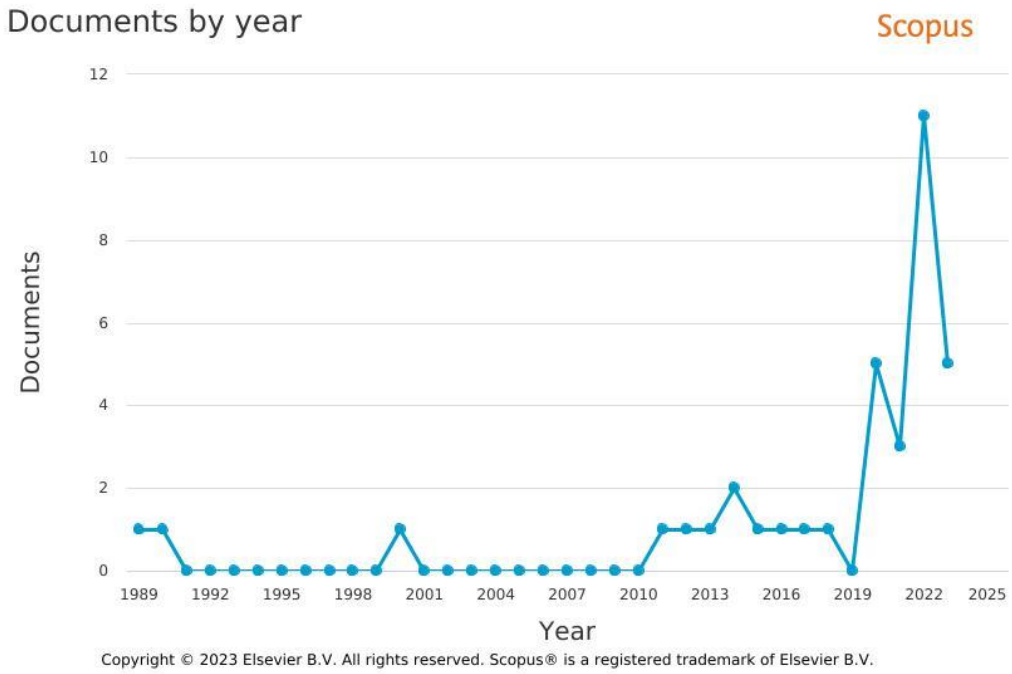
3. Results and Discussion

Year Analyzes

Over the course of time, an increasing interest has emerged in the application of artificial intelligence (AI) within the domain of mathematics education. Scholars have extensively explored the potential advantages of integrating AI technologies into the processes of teaching and learning mathematics. A comprehensive investigation of publication trends in this domain is essential to comprehend the evolutionary trajectory it has taken.

Figure 2.

Annually publication of AI in Mathematics Education



The provided table presents a chronological account of the number of publications related to AI in mathematics education from 1989 to the current year, 2023. A meticulous analysis of this data unveils intriguing patterns. In the initial years spanning from 1989 to 2011, the quantity of publications was notably limited, with only one or two papers produced per annum. This unequivocally indicates that AI's involvement in mathematics education was nascent during this period, with researchers merely commencing the exploration of its prospects.

However, a discernible turning point materialized around 2012, marked by a conspicuous upswing in the number of publications. This period spanning from 2012 to 2018 witnessed the emergence of seven publications, signifying a mounting interest and recognition of the potential impact of AI in enhancing mathematics education. Curiously, the data exhibits a gap for the year 2019, possibly attributable to diverse factors such as incomplete data collection or a temporary lull in research activities during that period. Nonetheless, the upward trend persisted into 2020, with five publications, substantiating the steady and

continuous endeavor towards research in this realm. Conversely, the year 2021 recorded a slight decline with only three publications, potentially indicative of fluctuating research interest or other external factors influencing the publication rate.

Remarkably, the year 2022 witnessed a substantial surge in publications, totaling eleven papers. This surge suggests a revitalized enthusiasm and a deeper exploration of the potential applications of AI in mathematics education during that specific year. As of 2023, the data indicates the publication of five papers, signifying ongoing research efforts and an enduring interest in the field, though it is noteworthy that this data might not encompass the entire year.

Source Analyzes

The tabulated data offers valuable insights into the dissemination of publications concerning the integration of artificial intelligence (AI) in mathematics education across various academic sources throughout the years. A thorough analysis of this data is essential to glean a comprehensive understanding of the trends and developments within this domain. Commencing from the inaugural publication in 1989, the esteemed journal "Educational Studies in Mathematics" emerged as a pioneering platform for contributions in this burgeoning field. However, it was not until the early 2000s that a discernible surge of interest in the intersection of AI and mathematics education materialized, with the inception of "Journal of Applied Developmental Psychology" in 2000.

The chronological progression reveals a steady ascent in the number of publications, indicative of a maturation of the field and a mounting acknowledgment of AI's potential in enhancing mathematics education. Significantly, the watershed moment arrived in 2012 when publications began to permeate diverse sources, exemplified by the inclusion of "Natural Hazards," signifying the expansion of AI applications beyond conventional educational journals. Subsequent years bore witness to an upsurge in publications across a myriad of platforms. Notably, "Eurasia Journal of Mathematics, Science and Technology Education" showcased scholarly works in both 2016 and 2023, underscoring the sustained interest in this subject over time.

Table 1
Source Publication of AI in Mathematics Education

Source title	Number Publication
Advances in Engineering Education	1
AI Magazine	1
Behavioral Sciences	1
Computers and Education	1
Education Sciences	1
Educational Studies in Mathematics	1
Eurasia Journal of Mathematics, Science and Tech.	2
For the Learning of Mathematics	1
Frontiers in Education	1
Frontiers in Psychology	1
IEEE Transactions on Learning Technologies	1
Interactive Learning Environments	1
Interactive Technology and Smart Education	1
International Journal of Artificial Intelligence	2
International Journal of Educational Research	1
International Journal of Engineering Pedagogy	1
International Journal of Information and Learn.	1
International Journal of Mechanical Engineering	1
Journal of Applied Developmental Psychology	1

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Source title	Number Publication
Journal of Baltic Science Education	1
Journal of Cleaner Production	1
KI - Kunstliche Intelligenz	3
Mathematical Problems in Engineering	1
Mathematics	1
Natural Hazards	1
Proceedings of the ACM on Programming Languages	1
Science and Education	1
Scientific Programming	1
Sustainability (Switzerland)	2
ZDM - International Journal on Mathematics Educ.	1
ZDM - Mathematics Education	2

Recent years have witnessed the ascendancy of prominent journals such as "Sustainability (Switzerland)" and "Frontiers in Education" as notable outlets for publishing research on the subject, accentuating the relevance of AI in sustainable development and innovative educational paradigms. Furthermore, the year 2022 witnessed a discernible increase in publications across journals like "Mathematical Problems in Engineering," "Science and Education," and "Interactive Technology and Smart Education," reflecting a growing cross-disciplinary fascination with the subject.

Noteworthy are the recent inclusions of AI-related studies in 2023, featured in esteemed journals such as "Behavioral Sciences," "Education Sciences," and "Interactive Learning Environments." These publications serve to underscore the ongoing exploration and avant-garde research in the realm of AI and its applications in mathematics education. In aggregate, the data elucidates a dynamic and evolving research landscape, showcasing the burgeoning momentum of AI's integration in mathematics education. The diversity of publication sources attests to the multifaceted nature of the research, thus exemplifying its interdisciplinary appeal. As we continue to advance in this intellectually stimulating domain, it portends excitement to witness the contributions of these publications in shaping the future of mathematics education through the transformative power of AI.

Country Analyzes

The tabulated data offers a comprehensive overview of the geographical origins of publications related to artificial intelligence in mathematics education. It delineates the number of publications attributed to each country or territory, thereby illuminating the diverse landscape of research in this domain across the globe. The United States emerges as the foremost contributor, exhibiting an impressive ten publications, an indicator of robust research activity within the nation, underscoring its prominence in this field. Following closely is China, with seven publications, manifesting a remarkable surge in AI-related research in mathematics education within its borders in recent times. Germany, Spain, and Taiwan have each produced three publications, indicative of substantial engagement in exploring AI's impact on mathematics education in these countries. Similarly, Canada, Sweden, and the United Kingdom have two publications each, reflective of their moderate yet noteworthy presence in the research arena. Equally notable are Denmark and Egypt, each boasting one publication, underscoring the burgeoning attention that AI in mathematics education research is garnering in diverse geographical locations.

In essence, the data in this table furnishes invaluable insights into the geographic dispersion of research concerning artificial intelligence in mathematics education. The multifarious representation of countries and territories signifies the truly global interest and involvement in this burgeoning field. Multiple regions across the globe are collectively contributing to the advancement of knowledge and practices at the intersection of AI and education, affirming the collaborative and international nature of this emerging area of study. It will undoubtedly prove captivating to observe how research from different corners of the world synergistically shapes the future of mathematics education through the integration of artificial intelligence.

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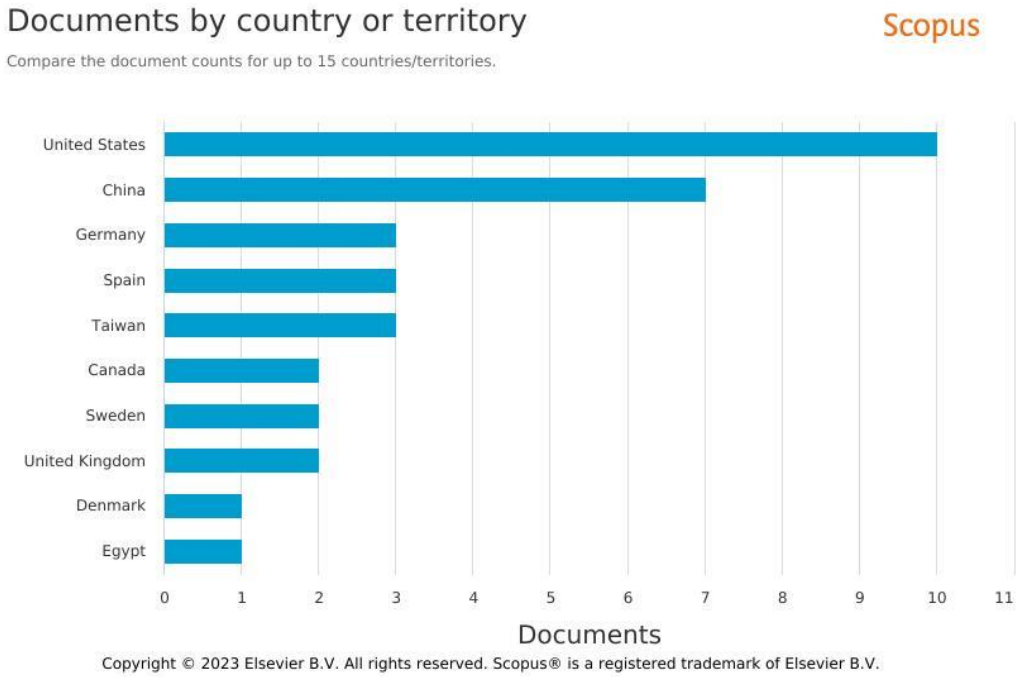
Figure 3
Publication based Country of AI in Mathematics Education



Affiliation Analyzes

The tabulated data furnishes comprehensive information on the top 10 affiliations associated with publications related to the fusion of artificial intelligence and mathematics education, offering an enumeration of the number of publications attributed to each affiliation. Evidently, multiple affiliations have made noteworthy contributions to this burgeoning realm of research. Of particular significance are four affiliations - Universitat de València, Örebro Universitet, Capital Normal University, and Universität zu Köln - each boasting two publications, a testament to their sustained dedication and active engagement in exploring the synergistic integration of AI within mathematics education.

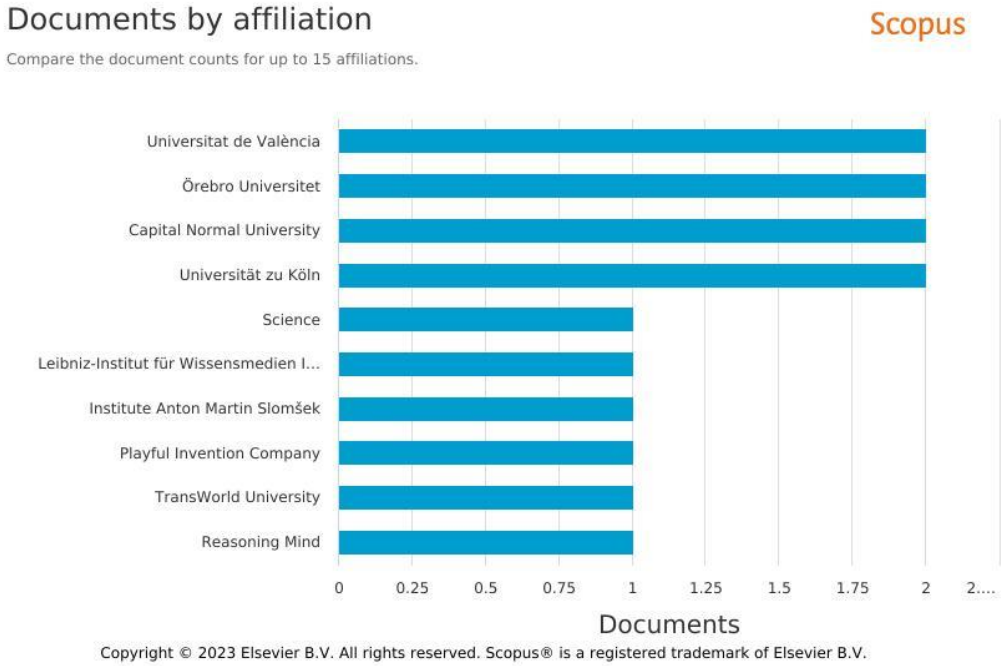


Figure 4. Publication based Affiliation of AI in Mathematics Education

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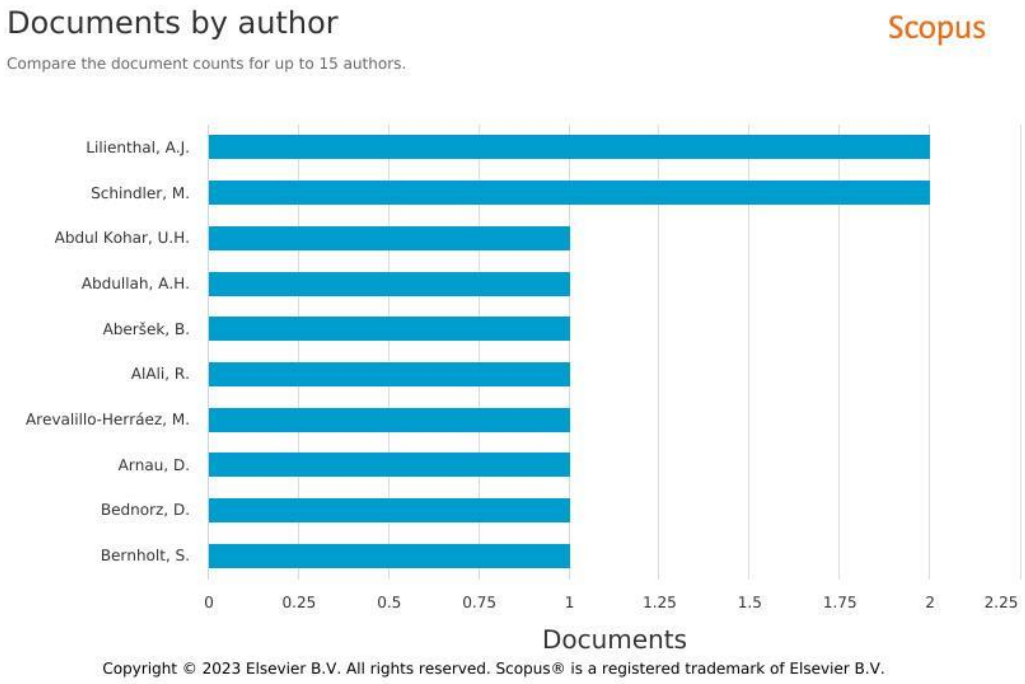
Furthermore, numerous other affiliations have also been instrumental in this research domain. Notably, Science, Leibniz-Institut für Wissensmedien IWM, Institute Anton Martin Slomšek, Playful Invention Company, TransWorld University, and Reasoning Mind, have each contributed one publication, signifying their dynamic and proactive involvement in advancing knowledge and best practices in this realm. This wealth of data underscores the lively and multifaceted participation of diverse affiliations in the pursuit of research pertaining to artificial intelligence in mathematics education. The involvement spans academia, industry, and research institutions, exemplifying the interdisciplinary and collaborative nature of this pioneering research. Collectively, these affiliations act as stalwart contributors to enriching the field of AI in mathematics education, continually pushing the frontiers of innovation and transformative educational practices. The comprehensive insights garnered from this table exemplify the momentum and vitality of research in this emerging and dynamic field. As these affiliations persist in their exploration of the boundless potential of AI in mathematics education, it is foreseeable that further groundbreaking advancements will ensue, ultimately benefiting learners and educators worldwide.

Author Analyzes

The tabulated presentation proffers valuable insights into the foremost 10 authors whose contributions have left an indelible mark on the burgeoning field of artificial intelligence in mathematics education. Their rank is determined based on the number of research papers or publications they have authored within this specific domain. Notably, Lilienthal, A.J., and Schindler, M. (Schindler et al., 2022; Schindler & Lilienthal, 2022), command the lead with two publications each. Their seminal works have exerted a profound influence on the exploration of integrating artificial intelligence into mathematics education, likely serving as a guiding beacon for other scholars in the field.

Figure 5

Publication based Author of AI in Mathematics Education



Closely trailing behind are Abdul Kohar, U.H., Abdullah, A.H. (Jin et al., 2022), Aberšek, B. (Flogie & Aberšek, 2015), AlAli, R., Arevalillo-Herráez, M., Arnau, D., Bednorz, D., and Bernholt, S. (Wardat et al., 2023), each credited with one publication. Though their publication tally may not rival that of the leading authors, their individual contributions remain eminently noteworthy, enriching the discourse on the effective deployment of artificial intelligence in the realm of mathematics education. It is imperative to recognize that this tabulated data merely presents a snapshot of the prominent authors in the field up to the present moment. The efforts of these scholars bespeak the diverse reservoir of expertise and dynamic engagement within the academic community, fostering an enhanced comprehension of the manifold ways

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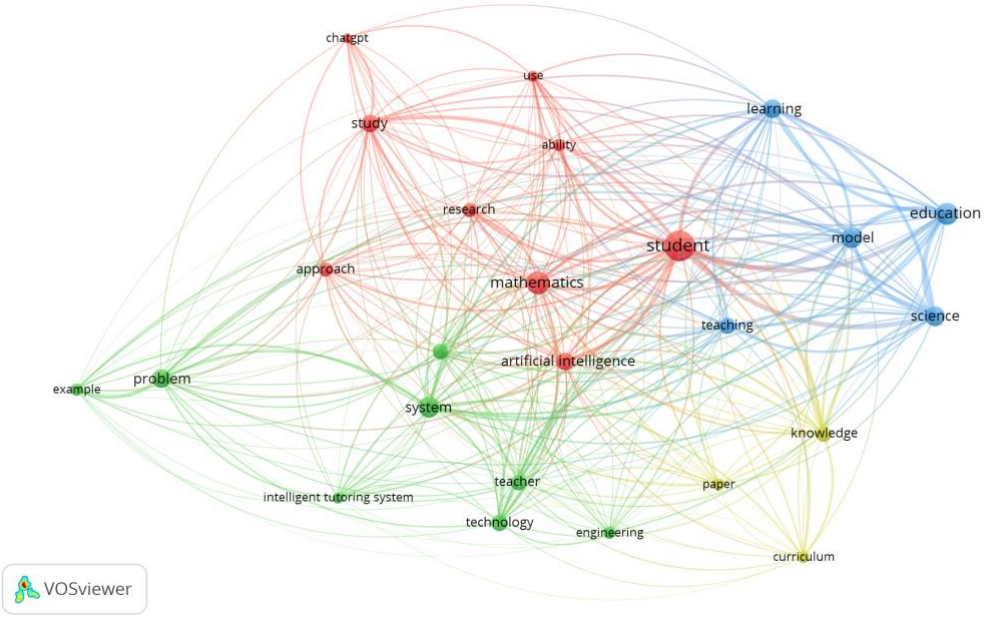
artificial intelligence can amplify mathematics education. As the field continues its inexorable progress, one can expect the emergence of additional researchers and authors, contributing further to the exploration of AI-driven methodologies in the context of mathematics education.

Cluster Analyzes

The VOSviewer software imposes a minimum of two relationships between terms (Al Husaeni & Nandiyanto, 2022; Al Husaeni & Nandiyanto, 2023). When applied to the phrases "artificial intelligence" and "mathematics education," the mapping results in four distinct clusters, each represented by a differently colored circle of varying size. The size of each circle corresponds to the frequency of the associated term, with larger circles indicating more frequent usage (Al Husaeni & Nandiyanto, 2023). As such, the prominence of a term is visually represented by the size of its corresponding circle. The present study reports the outcomes of thirteen VOSviewer mapping clusters generated using the aforementioned keywords.

Figure 6

Network Visualization of of AI in Mathematics Education



This academic discourse explores the application of artificial intelligence (AI) in mapping keywords through VOSviewer. The analysis reveals four distinct clusters with precise themes and subjects. Cluster 1 encompasses AI, the ChatGPT system, research methodologies, mathematics, and its usage in academic settings (Supriyadi & Kuncoro, 2023; Wardat et al., 2023). Cluster 2 focuses on AI in engineering, particularly in intelligent tutoring systems for mathematics education, problem-solving, and technology integration in teaching. Cluster 3 revolves around AI models' role in education, learning, and scientific pedagogy. Lastly, Cluster 4 emphasizes AI's significance in curriculum development and knowledge dissemination. Presented in a formal lexicon, this comprehensive exploration caters to an academic audience seeking a refined understanding of AI's multifaceted impact in diverse educational contexts.

4. Conclusion

There are valuable insights into the evolution of artificial intelligence (AI) in mathematics education over the years. The analysis of publication trends reveals a gradual but steady increase in interest and research in this field, with notable turning points around 2012 and 2022, indicating a growing recognition of AI's potential in enhancing mathematics education. The data also highlights the global interest and collaboration, with contributions from various countries and affiliations. The research landscape is seen to be dynamic and evolving, with diverse clusters of keywords revealing the multifaceted nature of AI's impact in mathematics education. The seminal works of leading authors have left a profound influence on the field, and as research continues to progress, it is expected that more scholars will contribute to the exploration of

AI-driven methodologies in mathematics education. The findings underscore the transformative power of AI and its significance in shaping the future of mathematics education on a global scale.

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