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The use of digital tools in mathematics teaching: Bibliometric approach

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ABSTRACT

In the current study, academic research on the application of digital tools in math education was analyzed via bibliometric analysis methods and general trends, structural evolution, and thematic concerns in the subject under analysis. Using the keyword term 'application of digital tools in math education' from the Web of Science database, 486 articles till January 2025 were systematically analyzed. Throughout the research, open-source RStudio and R software bibliometric were used in bibliometric analysis. The study shows that research on the use of digital tools in mathematics teaching has had a tremendous surge in recent years. It has been found that interest in digital tools has grown particularly after 2006, and this growth has been enhanced after 2014. Due to the COVID-19 pandemic, the use of digital tools in education has become a necessity and this has caused studies after 2020 to grow significantly. ZDM-Mathematics Education and Computers & Education journals are particularly notable among the journals in which the studies were published most frequently. Among the most contributing nations are the USA (186 articles), Spain (98 articles), Germany (78 articles) and China (65 articles). In author collaboration analysis, it was discovered that the most active author was Drijvers P. According to results from keyword analysis, the most frequent words were 'mathematics' (f = 52), 'education' (f = 38) and 'digital tools' (f = 30). Evidence based on bibliometric findings suggests that computer tools possess attributes such as concretization of abstract mathematics, improvement in pupil outcomes and the creation of interactive learning environments. However, by studying publication variation between countries, it has been observed that research funding and collaborative academic publications influence the productivity of publications. Additionally, keeping in view the limitations of bibliometric analysis, it is suggested that future studies must investigate more rigorously the adoption of artificial intelligence-based digital tools in the education of mathematics.

Keywords: digital tools, mathematics education, bibliometric analysis, Web of Science

INTRODUCTION

The original intended study on the use of digital tools for learning and teaching in education was conducted in Singapore. In the framework of this plan, an effort was made to integrate technology in school courses to help students adopt a culture of thinking, acquire lifelong learning habits and become socially responsible. Singapore developed a new plan in 2002 to maintain the application of information technologies in teaching-learning processes. In this plan, information technologies' applications in the learning and teaching process were clarified (Hew & Brush, 2007). Because of this clarification, teachers were able to apply information technologies to their learning processes more conveniently. To integrate the advantages of digital learning and traditional (face-to-face) methods, it is necessary to know the advantages and disadvantages of these methods (Atan & Kocasaraç, 2022). While e-learning is useful in terms of efficient use of time as well as easy accessibility via the internet, decrease in social interaction is considered a disadvantage (Gherhes et al., 2021). These technologies therefore need to be used in a manner that is balanced in teaching and learning processes. There are various benefits of digital learning and teaching resources: They facilitate the development of 21st century skills, develop students' problem-solving skill and sensitivity (Bransford et al., 2000), facilitate successful transfer of knowledge, provide systematic learning through animation, audio-video integration, facilitate development of skills through communication of teachers-students, and enrich scientific content to make it more engaging (Al Rawashdeh et al., 2021). It also has some benefits such as making lessons more enjoyable and enabling game-based learning. The benefits can be justified based on constructivist learning theory and Technological Pedagogical Content Knowledge (TPACK) model. Constructivist theory argues that learners construct knowledge actively and that learning is constructed from individual experiences (Piaget, 1970; Vygotsky, 1978). For example, dynamic geometry software such as GeoGebra enables students to build meaning for mathematical concepts by visualizing and transforming them and thereby creating a constructivist learning environment (Bray & Tangney, 2016). On the other hand, TPACK enables teachers to teach effectively by combining technology

(TK), pedagogical knowledge (PK), and knowledge of content (CK) (Mishra & Koehler, 2006). It is through tools such as Kahoot or Desmos that teachers can expand mathematics instruction by implementing learner-centered pedagogical strategies in conjunction with technology (Antunes & Cambrainha, 2020; Licorish et al., 2018). Such conceptual frameworks detail how digital technologies shape students' learning and teachers' practice in mathematics teaching.

In recent years, rapid development in information and communication technologies has initiated enormous changes in education, especially in mathematics education, as in all aspects of life. Due to these advancements, digital technologies have come to be applied effectively in mathematics classes. Digital technologies applications in mathematics lessons assist in making abstract mathematical concepts more concrete (Baki, 1996; Bujak et al., 2013; Fabian & Topping, 2019), allow mathematical relationships to be investigated (Hoyles, 2018; Seloraji & Eu, 2017), cause students to become actively involved in the learning process (Bray & Tangney, 2016; Furner & Marinas, 2007), increase interest and confidence in doing mathematics (Kyriakides et al., 2016), and create collaborative learning environments (Bujak et al., 2013; Fabian & Topping, 2019).

Literature has mentioned three different educational functions of digital technology in teaching mathematics (Drijvers et al., 2011; Drijvers, 2018):

1. Using digital tools to do maths: In this category, described as outsourcing in mathematics, digital tools serve as a mathematical tool for the student by executing specific operations in the learning of mathematics. By doing this, the students can focus more on important issues (Arcavi et al., 2017; Drijvers, 2018, 2019, 2020; Drijvers et al., 2011, 2018). Even if the student solves a math problem using an electronic device, he/she is not detached from the process; he/she decides on how to use the tool, how to analyze and interpret the results he/she gets. Therefore, outsourcing in mathematics serves an instructional purpose (Arcavi et al., 2017; Drijvers et al., 2018).
2. Use of digital tools for practicing skills: Under this category, the use of digital tools provides students with the practice setting to improve skills (Drijvers, 2018, 2019, 2020; Drijvers et al., 2011). Through digital resources, students can recalculate as frequently as they wish without depending on the teacher (Arcavi et al., 2017; Drijvers et al., 2011, 2018). Furthermore, students can learn mathematics whenever and for as long as they desire without constraints from time with the help of digital software (Drijvers et al., 2011). Students can be assigned randomly distributed tasks and given automatic feedback on their responses using digital tool applications (Arcavi et al., 2017; Drijvers, 2018, 2019, 2020; Drijvers et al., 2011, 2018).
3. Utilization of digital tools for concept development: This is about utilization of digital tools to facilitate development of concepts. Compared to other types of learning, concept development is a more sophisticated goal of learning, therefore the utilization of digital tools in achieving this goal needs higher proficiency (Arcavi et al., 2017; Drijvers, 2018, 2019, 2020; Drijvers et al., 2018). Digital technologies with clear images and models of topics might help students learn mathematics better (Arcavi et al., 2017; Drijvers et al., 2018). In addition, thanks to digital instruments, students can learn at their own pace when and how long they want to learn mathematics without time constraints (Drijvers et al., 2011). Digital instruments are able to provide randomised exercises and provide students with immediate feedback on their solutions (Arcavi et al., 2017; Drijvers, 2018, 2019, 2020; Drijvers et al., 2011, 2018).

Digital artificial intelligence (AI) tools have become more and more part of mathematics education in the last decade. In particular, over the 2020s, applications such as ChatGPT, Ernie Bot, and MathE have introduced new hope through delivering student-centered learning experiences tailored to individual students' needs (Azevedo et al., 2024; Getenet, 2024; Yoon et al., 2024). As noted by Inoferio et al. (2024), not just do these tools improve student engagement but also help reduce mathematics anxiety through scaffolding on more traditional digital devices like dynamic geometry software like GeoGebra and game-based software like Kahoot. For instance, there is Ernie Bot, whose effective results in Chinese primary schools have been established by offering math exercises according to the self-paced approach of each student, therefore enhancing differentiated instruction (Yoon et al., 2024).

It is crucial for researchers as well as practitioners that identification of the position of publications on the use of digital tools in mathematics education within the broader literature is essential. It promotes a more profound understanding of the learning potential of these tools, invites their improved application, and supplements the effort to realize the full potential of technology in teaching and learning. In line with this, the present study makes use of a bibliometric analysis to examine overall features, structural characteristics, as well as thematic development of research on digital tool utilization for math education. While previous research had tested the effect of digital tools on student mathematics learning outcomes (Hillmayr et al., 2020; Saat et al., 2024), systematic bibliometric analysis to map the world research trends, co-authorship network, and theme evolution across time remains an emerging agenda. The present research endeavors to bridge this with an expansive overview of the advancement of research and future study themes in the field.

METHODOLOGY

Bibliometric analysis method is used for quantitatively measuring and analyzing research trends in each subject. The method was first used in the 1960s and is now a standard analysis approach in academic studies (Pritchard, 1969). With methods like keyword analysis, simultaneous co-occurrences of words, cluster analysis and bibliometric mapping, it allows rigorous analysis of academic output in each discipline (Song & Wang, 2020). Retrospective analyses help in the envisioning of popular concepts and research themes that are being undertaken in studies on a specific subject matter or target group and revealing tendencies over time (Bolaños et al., 2022). For the current research, the open-source bibliometric packaging and R-Studio program were used to analyze a complete analysis of publications on the use of digital tools for mathematics teaching (Aria & Cuccurullo, 2017, 2022).

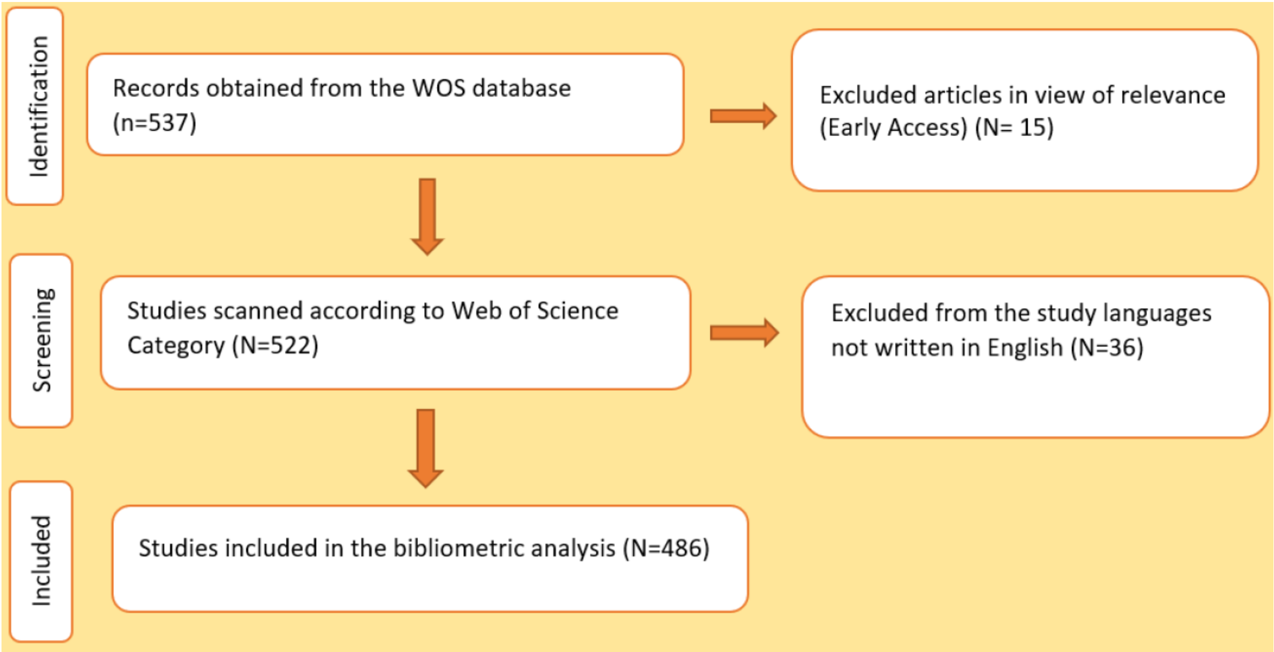

Figure 1. Workflow chart of the article process (Source: Authors' own elaboration, using Biblioshiny software)

The bibliographic data used in the study were retrieved from the Web of Science (WOS) database up to January 2025. The data were retrieved using Web of Science advanced search engine with the following query statement: TS = 'use of digital tools in mathematics teaching' and PY = (2000-2025). Inclusion criteria:

1. Mathematics and educational research publications,
2. Referred published journal,
3. Written in English.
4. Excluded papers:
   (i) No access to abstract,
   (ii) Book reviews and news items.'

Before bibliometric analysis using R-Studio, duplicate records were excluded and missing data publications (e.g. no citation information or author) were excluded from analysis.

This study incorporates publications accessed from the Web of Science database alone. The article selection process workflow chart of the 486 accessed data is given in **Figure 1**.

Although the WoS was chosen because it offers access to peer-reviewed studies in education and mathematics education, literature which is relevant to other academic databases such as Scopus, ERIC or Google Scholar was not included for analysis. This might restrict the reach of the study and additional elaborate analysis may be obtained by including publications from other databases.

FINDINGS

Overview Information of Publications

Between 1998 and 2025, a total of 486 articles were published on how digital technologies can be utilized in the teaching of mathematics. The total number of the keywords in the data set is 1561. The keywords are the summary of the articles and assist in revealing the ideas that have been researched in the studies. The publications that have single authors are 76 and they have 72 studies. The number of authors per study was estimated at 3.28. There were 16368 references used in the studies reviewed. Author profiles, references and other basic information of publications accessed (**Table 1**).

Types of studies reviewed were grouped into articles (n = 277), book chapters (n = 36), papers (n = 159), book chapters and reviews (n = 2) and other types of papers (n = 2) (**Table 2**). Articles were used as the point of departure for analysis because publications that were printed in peer-reviewed journals and underwent a formal peer review process were taken into consideration, and articles were included to reflect current trends and innovative practices of the field. Book chapters were added to provide detailed explanation of theoretical approaches. To guarantee homogeneity of publication types, English-written publications with abstract access and published in the field of educational research or mathematics education were selected. News items and book reviews were excluded since they are not suited for the content analysis of science.

Table 1. General Information

Description	Results
Timespans	2000-2025
Sources (Journals, Books etc.)	244
Documents	486
Documents average age	6.22
Average citation's per doc	7938
Document Contents	
Keywords plus (ID)	434
Author Keywords (DE)	1561
Authors	
Authors single-authored docs	72
Authors collaboration	
Single-authored docs	76
Co-authors per doc	3.28
International co authorship %	16. 05

Table 2. Distribution of publication types

Publication types	Number of publications
Article	277
Book chapter	36
Proceeding paper	2
Editorial material	1
Editorial material: book chapter	2
Proceeding paper	159
Review	9

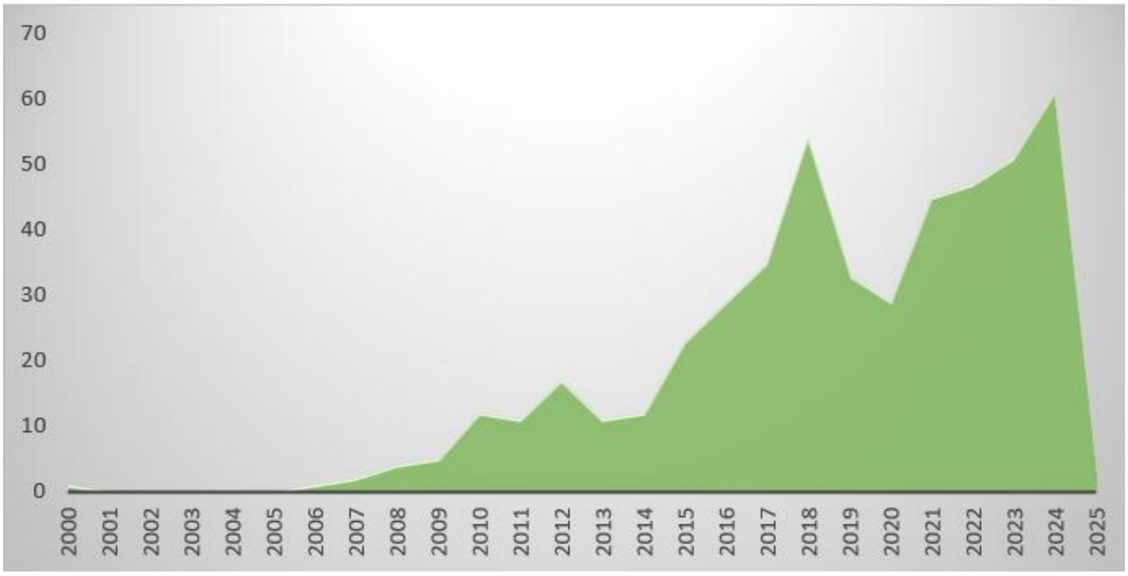

Figure 2. Distribution of studies according to years (Source: Authors' own elaboration, using Biblioshiny software)

Within Bibliometric R-Studio analysis, the effects of different types of publications on keywords, citations and collaborative networks were combined and thematic emphasis explored within a standard framework. According to **Figure 2**, one finds that during 2000-2005 there were no or few studies of digital tools in mathematics education.

Analyzing the Studies by Years

The distribution of studies on the use of digital tools in mathematics teaching over time according to years is given in **Figure 2**.

From 2006 onwards, the number of studies picked up, meaning that digital tools have started to be acknowledged more within education but once again in terms of numbers. From 2014 onwards, an enormous quantity of studies has been observed. Despite a downturn in 2019 and 2020, studies picked up again from 2020. As of 2024, studies grew to 61, to the peak. Since 2025 has just started the year 2025, the year data is not yet available.

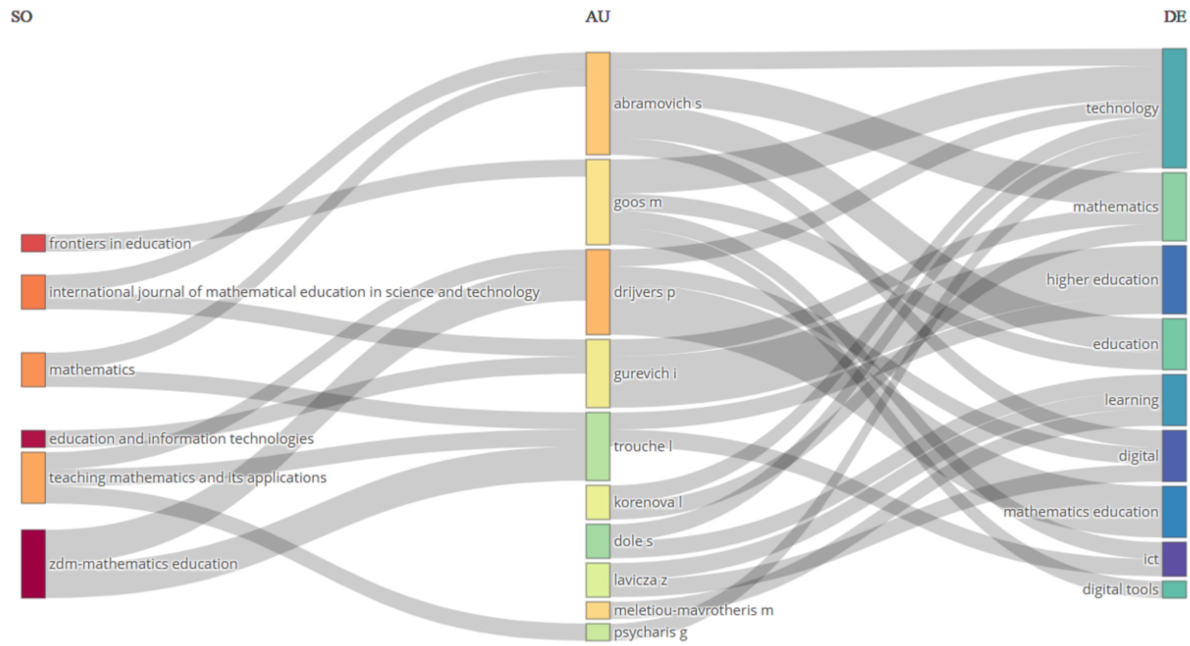

Figure 3. Triple field diagram (Source: Authors' own elaboration, using Biblioshiny software)

Table 3. Impact of journals

Journal name	h index	g index	m index	TC
Computers and Education	10	11	0,625	742
ZDM-Mathematics Education	10	17	0,625	321
Education and Information Technology	7	11	1,167	125
Education Sciences	6	11	0,857	140
Computer Applications in Engineering Education	5	8	0,625	85
Eurasia Journal of Mathematics, Sciences and Technology Education	4	5	0,444	30
International Journal of Science and Mathematics Education	4	5	0,286	104
Cogent Education	3	4	1,000	17
Contemporary Educational Technology	3	3	0,750	13
Educational Technology and Society	3	3	0,375	76

Structural and Thematic Development

A triple domain diagram was used in order to provide an overview of the research into the use of digital instruments in teaching mathematics between the years 1998-2004. The diagram graphically demonstrates the relationship between three key factors: authors, keywords and journals (**Figure 3**).

In **Figure 3**, the left column is the journals, the middle section is the authors, and the right column is the keywords. The grey links start with the journal names, pass through the authors and then the keywords. The relational size is shown in each section by the rectangles' sizes. That is, the larger the rectangle, the more the field contributes. Also, for the ease of reading the graph, the count of items in each field is limited to 10. This graph shows the relationships between the most contributing authors in the field in the data, their most frequent keywords, and most read journals. Intriguing. In the left portion, looking at the journals from the viewpoint of the use of digital tools in mathematics education, one finds oneself curious to observe that the journal 'ZDM-Mathematics Education', occupying the maximum rectangle area, has the greatest number of publications. Looking at the authors whose work got published in the middle section, it is possible to see that the author who has contributed most to the area is 'Abramowich, S.'. In the region displaying keywords on the right, it is seen that the word with the biggest rectangle size is 'technology' and most active authors make use of it.

Table 3 shows top 10 journals as per h index, g index, m index and number of total citations among those journals that have publications on the application of digital tools in teaching mathematics.

Analyzing **Table 3**, the first place is occupied by Zdm-Mathematics Education with h index (f = 10) and g index (f = 17). Based on the h index alone, second place is occupied by ZDM-Mathematics Education (f = 10) and Computers & Education (f = 10) with the same number, and third place is occupied by Education and Information Technologies (f = 7). According to the g index, Computers & Education (f = 11) ranked second with the same number and Computer Applications in Engineering Education (f = 8) ranked third. According to the M index, Education and Information Technologies (f = 1,167) ranked first, Cogent Education (f = 1) ranked second, and Education Sciences (0,857) ranked third. If the total number of citations of the journals is viewed, Computers & Education (f = 742) and ZDM-Mathematics Education (f = 321) came in first and second places, respectively.

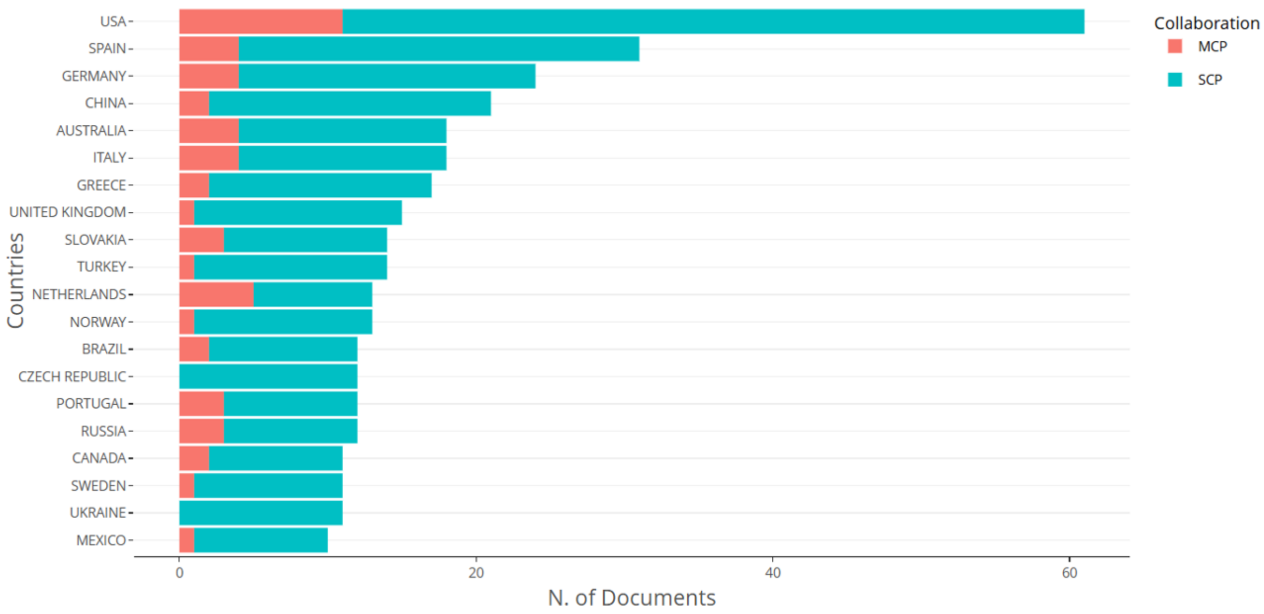

Figure 4. Countries of corresponding authors and number of articles (Source: Authors' own elaboration, using Biblioshiny software)

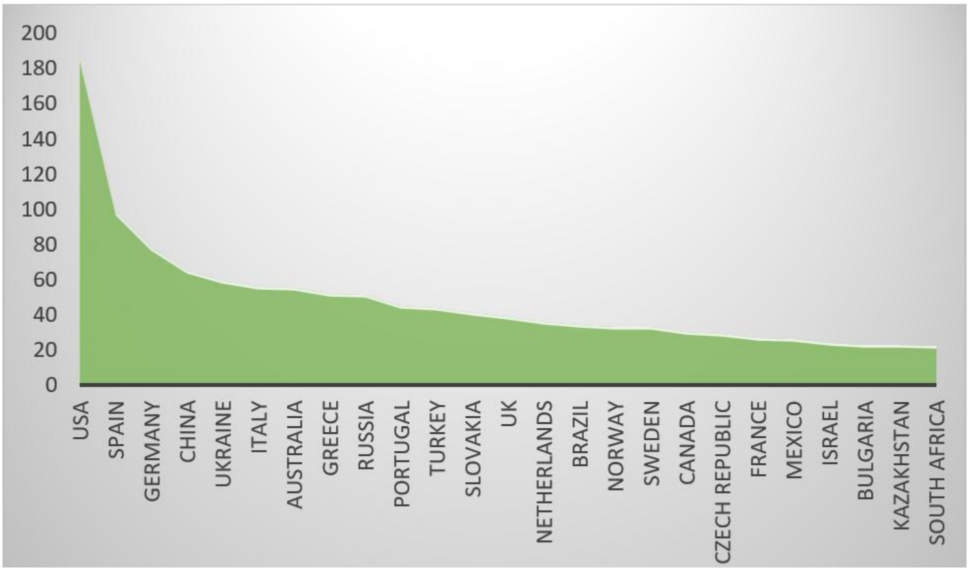

Figure 5. Scientific productivity of countries (Source: Authors' own elaboration, using Biblioshiny software)

Viewing Countries

Figure 4 shows the countries of the corresponding authors and the number of articles generated by the countries. **Figure 5** visually presents the scientific productivity of the countries.

Figure 4 shows countries of corresponding authors living in these countries and scientific contribution in these countries. SCP (Single Country Publications) indicates publications of researchers employed in the same country, and MCP (Multiple Country Publications) indicates collaborative work of researchers living in different countries. SCP and MCP values summed up indicate the sum total of articles produced by countries. According to these figures, the United States of America contributed the most. Spain (Spain), Germany (Germany), China (China) and Australia (Australia) follow the United States of America.

Figure 5 illustrates that the United States of America (f = 186) occupies first place among publications regarding the use of digital tools to teach mathematics. Spain (f = 98), Germany (f = 78) and China (f = 65) occupy second, third and fourth places, respectively.

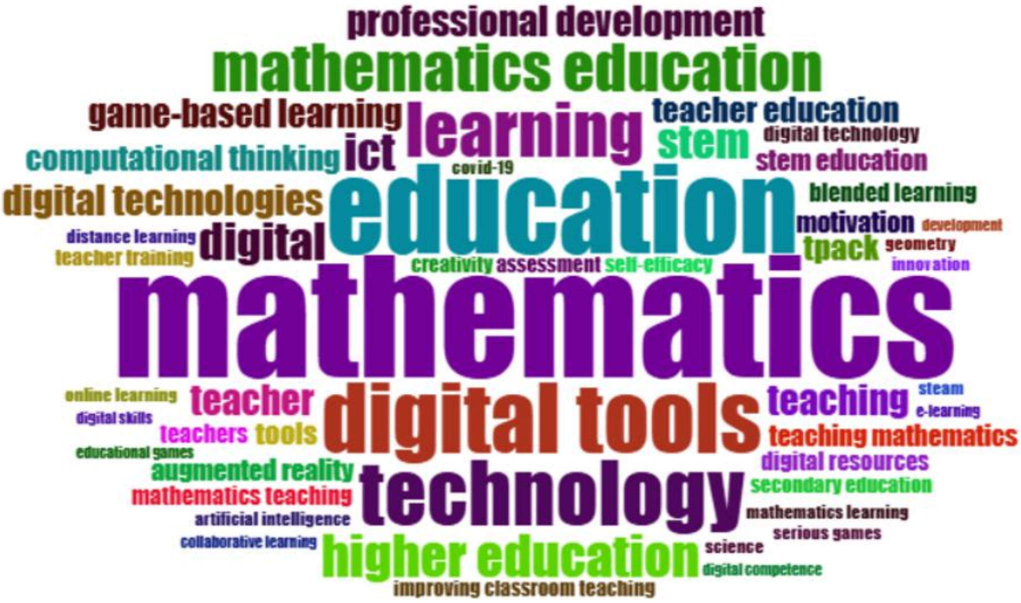

Figure 6. Word cloud (Source: Authors' own elaboration, using Biblioshiny software)

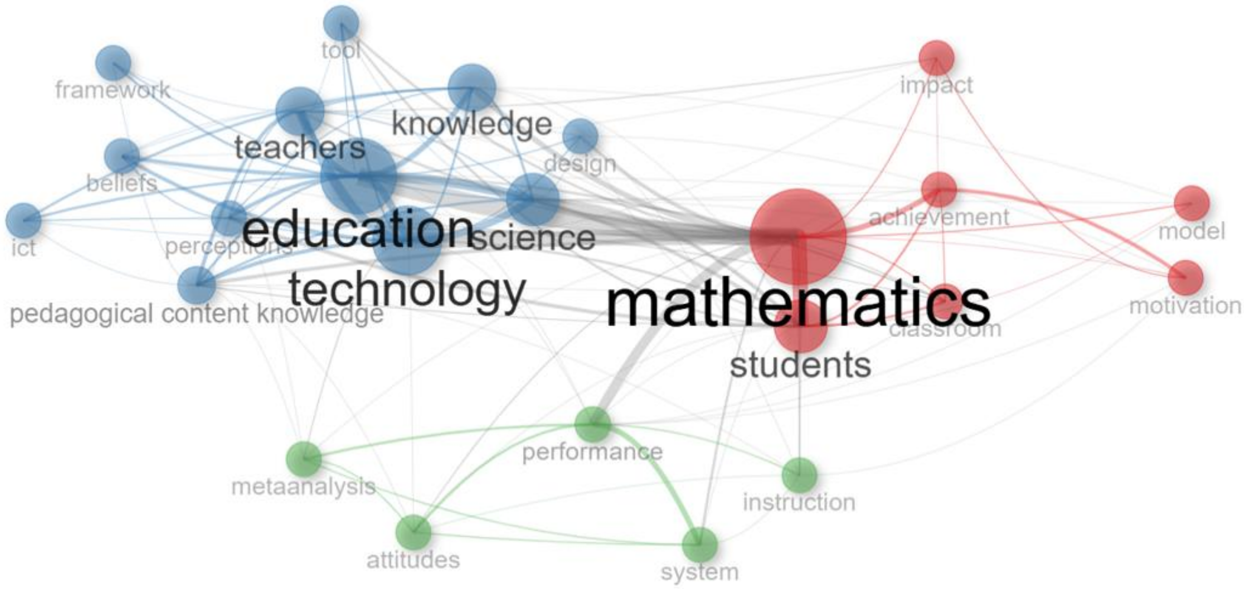

Figure 7. Co-occurrence analysis (Source: Authors' own elaboration, using Biblioshiny software)

Word analysis

The keyword frequency employed by the authors in research on the use of digital tools in mathematics education is presented in **Figure 6**. The relationships among these keywords, their centrality and frequency of usage were represented in the form of word clouds.

The most significant keywords and the relationships among these keywords are visualized in the word cloud in **Figure 6**. The most frequently found words were 'mathematics' (f = 52)', education' (f = 38), and 'digital tools' (f = 30), showing the dominance of technology in teaching mathematics. In particular, the increasing number of keyword occurrences pointing to actual digital tools reflects a trend towards more specialized studies. The bibliometric analysis captures growing interest in digital tools in various forms like dynamic geometry software (e.g., GeoGebra), game-based learning environments (e.g., Kahoot, Desmos), and AI-based personalized learning systems. Co-occurrence analysis is used to make the most frequent keywords' relationship in the studies clearer and to visualize keywords' frequency of co-occurrence and the network map. **Figure 7** shows the network map analysis of the study keywords concerning the application of digital tools in mathematics education. Keywords were kept as few as possible for ease of visualization.

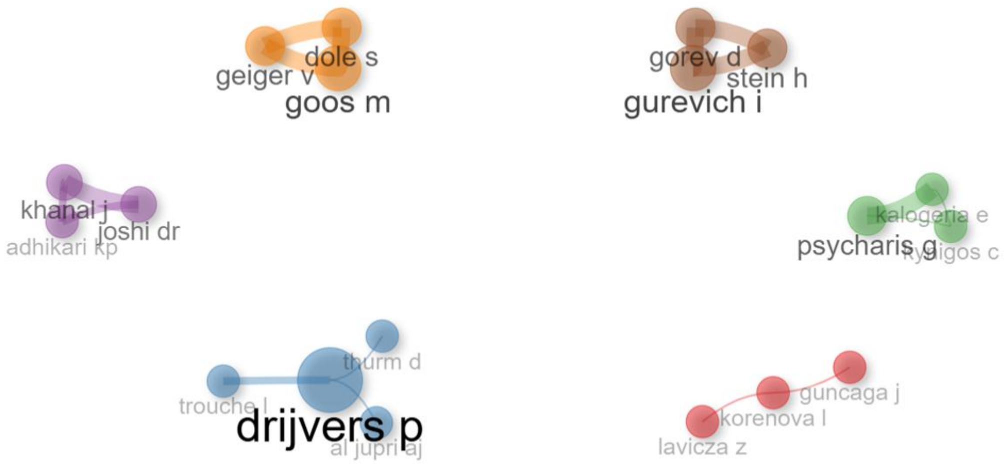

Figure 8. Co-operation between authors (Source: Authors' own elaboration, using Biblioshiny software)

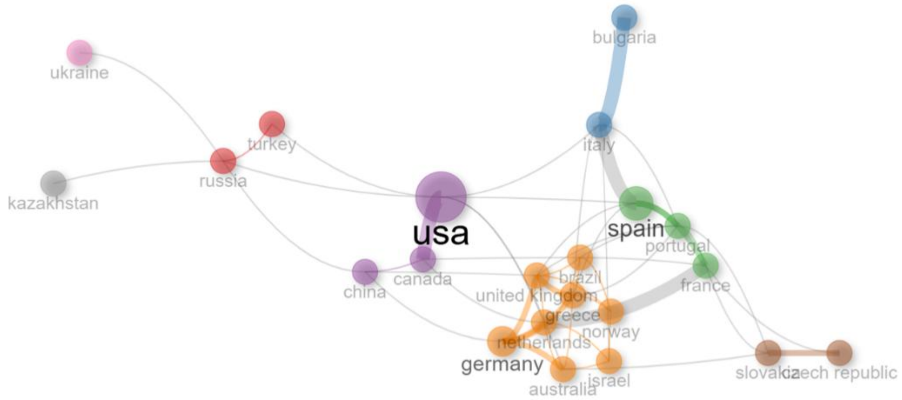

Figure 9. Country cooperation (Source: Authors' own elaboration, using Biblioshiny software)

When the map of the keyword network in **Figure 7** is examined, it is evident that the keywords are concentrated in three distinct clusters. The map indicates the frequency of the co-occurrence of keywords using the thickness of the lines representing the links between the keywords, and the size of the links representing the density of the number of links. As per the analysis, the term 'mathematics' is the term that is closest to other keywords and of the largest size. If the keyword clusters are looked at, the terms 'mathematics', 'students' and 'achievement' are the ones that lead in the red colored cluster. The second blue cluster has the words 'technology', 'science' and 'education', while the third green cluster has the words 'instruction' and 'performance'. This assignment reflects the thematic groups and usage relationships of the words. 3.6

Co-operation Networks

Collaboration networks represent social relations and collaboration among authors and countries. In plotting such network plots, bibliophagy parameters were set with regard to authors and countries. The parameters include automatic edit for network layout, 25 nodes, two edges and 25 labels as the minimum. These parameters were used to visualize collaboration among authors and countries.

Figure 8 is a visualization of the co-operation network among authors.

The sets of authors depicted in the same color indicate the authors who worked together. Considering the density of co-authorships, one can observe that Drijvers is the most co-authoring author and thus the size of his circle is bigger than the rest. When analyzed in terms of link thickness, high cooperation among Psycharis and Kalogeria within the green cluster, Khanal and Joshi within the purple cluster, Goos, Geiger, and Dole within the orange cluster and among Gurevich, Gorev, and Stein within the brown cluster are evident, respectively. This signifies the authors' collaboration and work intensities. **Figure 9** shows the collaboration network map of countries based on the use of digital tools in teaching mathematics.

Figure 9 displays countries' cooperation as regards research on the use of digital tools to teach math.

Thickness of lines in the network map indicates countries' publication frequency and colors indicate the clusters countries belong to. United States of America (USA) is the most co-operating country with others and takes the most active place in the network. Nevertheless, the most powerful co-operation between countries is revealed through the orange cluster. The second most active country after the United States of America (USA) is Italy (Italy).

CONCLUSION AND DISCUSSION

The research on using computer tools to educate mathematics was examined through bibliometric analysis method by journal, author, citation and country in Web of Science (WOS) database and the established relations in this context were explained.

Data from Web of Science databases in the study were processed through the 'bibliophagy' web interface within the R-Studio software. The evaluation based on a total of 486 publications allows systematic exploration of the subject and its development over time in the form of bibliometric studies. In consideration of the existing bibliometric studies in literature, the study in hand is a first of its kind in that it provides content analysis in terms of topic and time.

The papers in the study have been through rigorous peer review processes, making the scientific rigor of the analysis more robust and capturing the central debates in the field, focusing on leading journals such as ZDM-Mathematics Education. The papers added a modern tone to the analysis by centering classroom applications of emerging technologies such as GeoGebra, Kahoot, and AI-based tools. But the articles were subject to less rigorous peer review processes, which may limit the generalizability of findings. For example, new methods (e.g. game learning or augmented reality) in articles may have been validated to a lesser degree than in articles, so results should be interpreted with caution from thematic field. Book chapter entries added richness to analysis with more detailed exposition of theory models (e.g. TPACK, constructivist learning) but added less to bibliometric metrics with fewer citations. These kinds of differences introduced some limitations on the homogeneity of analysis, but at the same time ensured that it was entirely representative of both theoretical and applied sides of the field. An examination of the annual publication of research on the use of computer tools in teaching mathematics reveals that the first such publication was made in 2000. Between the years 2000 and 2005, very few research was published, which could mean that integrating technology with teaching mathematics was still in its infancy during those years.

Hillmayr et al. (2020) state that the application of digital technologies in learning mathematics has expanded significantly since the early 2000s, and evidence was also indicating improved students' learning results in comparison to more traditional teaching methods. Although a reduction was experienced in research activity between 2019 and 2020, the overall rising trend particularly from the year 2014 is an indication of a growing interest in using digital tools in instruction and learning. The growth may partly be an effect of rapid technological advancements and more educator awareness of the pedagogical potentials of such tools. Specifically, it should be noted that the COVID-19 pandemic highly likely accelerated the adoption of digital technologies, prompting practitioners and researchers to familiarize themselves with new modes of teaching. Recent research, particularly publications since 2022, has emphasized the effectiveness of including digital technology tools—notably game-based learning apps in educational practices. The tools have been recognized to enhance pupil engagement and foster problem-solving skill development (Saat et al., 2024). These positive effects of digital technologies on teaching mathematics are also validated by the findings of Hillmayr et al. (2020) and are further validated by the findings of the present study, which show an ongoing trend towards an increasing number of studies focusing on the influence of these tools on teaching-learning processes. The triple domain diagram used in this study is a helpful way of identifying main sources of information, key researchers, and leading research topics for using digital tools to teach mathematics.

By showing these connections, the diagram not only gives insight into the current situation but also informs future research. One of the most noted results is that ZDM – Mathematics Education is shown to be the top-cited journal, which suggests its position as a source for scholarly discussion regarding how digital tools are implemented in math teaching. This indicates agreement with the impression that the journal is widely regarded and esteemed by researchers who carry out research in this area. Researchers conducting comparable research would do well to take special notice of what is being published in ZDM, to build on and extend from existing knowledge, as well as be kept abreast of changing debates and trends in the field. The most productive writers are Abramovich, S., who has published an enormous number of articles. This writer's appearance so frequently is a sign of a productive scholarly presence and of a distinct stake in the subject matter. Reading Abramovich's work may deliver valuable information on key ideas and methodological approaches, which can be potentially a reference point for researchers planning subsequent research. The fact that the term "technology" prominently occurs among keywords also underlines the salience of digital technology in mathematics education research. This is evidence of long-standing theoretical and practical interest in how technology affects pedagogical practices. Studies emphasizing this keyword will typically focus on the impact of learning technology on pedagogical strategies, student performance, and broader pedagogical paradigms. There is significant diversity between the highest contributor countries in the form of scientific publications on digital tools for teaching mathematics.

United States of America (USA) is the leading country in terms of publication amount. This means that the country has a good academic infrastructure and research foundation in educational technologies and math education. USA leadership in this sector is supported by enormous economic resources, advanced research infrastructure and many academics. Spain, Germany, China and Australia appear to be other countries contributing internationally effectively, next only to the USA. In addition, the reason why the USA leads in publication is because of high education technology and STEM project investments. Similarly, the European education collaboration and funding mechanism has seen Spain and Germany record many publications. China has, however, increased its scientific productivity by investing in education technologies over the past few years. The scientific production of these countries shows that they are deeply engaged in education digital transformation processes. The actions of European countries (Spain and Germany) in this regard might have been more significant with the impact of international cooperation projects (MCP) and research awards. In comparison with research conducted within one country (SCP), those articles resulting from joint efforts by researchers from multiple countries (MCP) reveal the value of scientific collaboration. These cooperation networks facilitate interdisciplinary practice and knowledge transfer among countries and optimize research effects. Countries with high MCP values obtain more international exposure on the global platform and establish studies that appeal to a wider circle of readers. It can be said that research on mathematics teaching using digital tools is done in detail by some nations and these countries contribute significantly both at national as well as global level. In the word cloud, the most frequent words used were 'mathematics' (f = 52), 'education' (f = 38) and 'digital tools' (f = 30).

This indicates that the incorporation of dijital tools into the learning process in mathematics education is viewed as a core concern in the research. The size and central positioning of these three concepts indicate the field's research priorities. On the keyword network map, it is noted that the words are clustered into thematic patterns and the connection among some words is tighter. According to the analysis, the red cluster (Student, Achievement, Mathematics) can be described as studies that have been done on the effect of mathematics computer tools in teaching and learning student achievement. "Mathematics", the most central node in the network, has strong links with the other terms and is the core subject of the field. Blue cluster (Education, Technology, Science) represents research on the intertwining of digital technology into the education system and its link to scientific progress. The major position of the word "technology" represents that digital technology (e.g. Kahoot, AI systems) is to transform education (Drijvers, 2018; Getenet, 2024). The words "education" and "science" represent how technology gets intertwined with teaching practices and scientific inquiry. Blue Cluster (Education, Technology, Science): This cluster represents research that is interested in the integration of digital tools into the education system and their relationship to scientific progress. The overarching nature of the term "technology" indicates that digital tools (e.g. Kahoot, AI systems) are what is driving the change in education (Drijvers, 2018; Getenet, 2024). The inclusion of the words "education" and "science" illustrates how technology is integrated into pedagogical practice and scientific investigation. A further sub-analysis was conducted to explore how specific digital technologies and tools used in mathematics instruction have evolved over time.

They include GeoGebra, a dynamic geometry software used to assist students in exploring geometric relations and strengthening their concept grasp. Kahoot, structured like a game for learning, has been effective in raising students' motivation and active learning in the classroom. Similarly, Desmos enables mathematical cognition through the availability of interactive graphics and data visualization and problem-solving instruments. These instruments developed differently throughout the decades. In the 2000s, dynamic geometry software like GeoGebra was on the rise. From the 2010s, interactive learning environments like Desmos and game-based instruments like Kahoot spread to classrooms. More recently, the 2020s have seen a rise in the use of artificial intelligence (AI)-driven systems and augmented reality (AR) applications in mathematics instruction. AI technologies now offer individualized learning pathways by analyzing students’ progress and adapting content to their needs, while AR tools provide immersive learning environments particularly valuable for visualizing complex or 3D geometric forms. A correlation analysis of author and country collaborations on research related to the use of digital tools in mathematics education reveals Drijvers (2018, 2019) to be the most productive and collaborative researcher in the field.

Positioned at the center of several co-authorship networks, Drijvers has established strong collaborations with numerous researchers. Her research primarily focuses on cognitive aspects of technology-enhanced mathematics learning, with a particular interest in dynamic geometry environments such as GeoGebra. A recurring theme throughout her research is how digital tools can be blended in harmony to strengthen students' conceptual understanding and turn them into competent problem-solvers. She also places a strong focus on how the pedagogical capacities of teachers can be enhanced to the fullest to leverage educational technologies. On a bigger picture when considering international trends of cooperation, the United States presents itself as a hub in the network of countries cooperating in this area. The U.S. has large-scale research collaborations with other countries, often with internationally funded projects many of which are financed through agencies like the National Science Foundation (NSF). These collaborative research efforts tend to address matters such as dynamic geometry software, game-based learning, and learning analytics. For instance, studies on using GeoGebra in classroom teaching or developing customized learning environments based on data-driven intelligence have become central components of such collaborative research efforts. There is potential future research that can throw more light on global patterns in the use of technology in teaching mathematics by analyzing the thematic focus and project types of these collaborations more. Italy ranks second to the USA in an active role in co-operation. Moreover, the most intense co-operation between countries was within the orange cluster. This shows that intellectual exchange between specific countries is strong, and research productivity is traded globally. Bibliometrics is one of the methods to measure and evaluate the quality of science, sources and the impact of the author's work in the study field, based on the development of the topic (Bouyssou & Marchant, 2011).

By applying this method of analysis, it was found that computer tools are increasingly applied to teach mathematics, and these tools have a positive impact on the learning results of students. The integration of technology into the education system has seen an increase in research on both theoretical and practical grounds. The pandemic period has significantly increased the use of digital tools and research in this field. Sub-analysis of the post-pandemic thematic distribution of publications (2020 onwards) reveals a dramatic rise in the use of distance learning platforms (e.g. Zoom, Google Classroom) and interactive digital tools (e.g. GeoGebra, Desmos). Zoom was a ubiquitous platform for synchronous courses, with Google Classroom also being used on a regular basis to share assignments, track student work and give feedback. GeoGebra and Desmos were critical in representing mathematical ideas and constructing interactive learning spaces, whereas Kahoot was well-known for enhancing learner motivation. Pandemic publications stress the construction of learner-focused learning spaces with an emphasis on hybrid models of learning and synchronous/asynchronous pedagogical methods.

RECOMMENDATIONS

Research in the future can explore the intersection between technology use and mathematics education more deeply. In particular, the effect of the COVID-19 pandemic on the use of digital tools and their long-term effect on student activity and idea acquisition can be examined by using empirical research. Apart from Web of Science, databases such as Scopus and ERIC can be used to search for a wider range of education-focused journals. To better understand the trends in the field of educational technology, bibliometric contrasts between various branches or time frames can prove to be essential. Competencies of teachers in technology use, the correspondence of teaching practices with computer tools, and various factors affecting the success of students can be studied intensely through such studies.

Computer-based AI programs (e.g., Century AI, Smart Tutoring) specifically in math education have the potential to increase conceptual understanding and problem-solving skill by providing instruction sensitive to students' needs. Experimental or longitudinal research designs could be used to examine the impact of such programs on learning in, for instance, algebra or geometry. Also, student data from sites like GeoGebra or Desmos offer the prospect of analyzing the mistakes made and difficulties encountered in the learning process. This data can be used to help teachers improve instructional strategies by offering instant feedback. Nevertheless, ethical issues regarding the transfer of data, especially privacy and security, need to be seriously considered in the process. Adaptive learning systems that provide content to align with the student's knowledge level and learning speed can improve participation and conceptual understanding. The effects of these systems on student achievement, self-efficacy and persistence can be examined. Further, empirical studies may be conducted to determine to what extent these systems are congruent with constructivist learning theory and the TPACK model, how the data are applied by teachers in their teaching practice, and what transformations occur in student-teacher relationships.

LIMITATIONS

This study bibliographically examines literature on the use of computer tools to educate math under the canopy of documents in publications listed in the Web of Science (WoS) database.

However, limiting the study to the WoS database may potentially exclude studies published in a specific country or in local journals. Some of the studies conducted in developing countries focused on the use of digital tools for the teaching of mathematics may not have been examined because they did not meet the WoS indexing criteria. Additionally, the fact that the WoS database is focused on predominantly English-language publications may have been responsible for exclusion of important studies in other languages and, as a result, underestimation of the body of literature. The fact that other notable scholarly databases such as Scopus and ERIC were not included under the analysis is another limitation restricting the study.

Even though Scopus offers access to more global publications from a wide range of disciplines, ERIC focuses more on research studies in the field of education. Exclusion of these databases may have contributed to a lack of full evidence of thematic diversity in the use of digital tools as well as omission of some pertinent studies. In future studies, a more comparative and inclusive bibliometric review can be conducted using databases such as Scopus and ERIC. This will generate a more balanced view of practices across settings and a more accurate representation of international trends.

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