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Digital Technology in Mathematics Education: A Bibliometric Analysis and PAGER-Based Scoping Review

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ABSTRACT

Digital technology increasingly shapes mathematics education, but rapid publication growth makes the field difficult to map. This study analyzes Scopus-indexed research from 2011 to 2025 using Scoping Review and Bibliometric Analysis (ScoRBA). Bibliometric analysis examined publication trends, authors, affiliations, countries, and keywords, while PAGER synthesis interpreted representative studies. From 172 initial documents, 49 English-language journal articles were included and eight were reviewed qualitatively. Findings show growth after 2017, with China, the United States, and Spain as leading contributors. Keyword analysis revealed three clusters: mathematics learning with e-learning and technology, STEM-oriented digital integration, and digital learning systems with mathematical software and accessibility-oriented e-learning. The PAGER synthesis indicates that digital technology is most meaningful when integrated with purposeful pedagogy, teacher guidance, accessibility, and evidence-based instructional design.

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1. INTRODUCTION

Digital technologies have reshaped educational practices by expanding the ways in which learners access information, communicate with teachers and peers, visualize abstract ideas, and participate in learning activities beyond the physical classroom. In mathematics education, this development is particularly significant because mathematical ideas are often abstract, symbolic, and cumulative. Digital environments, dynamic software, online platforms, simulations, learning management systems, and interactive applications can help students explore representations, test conjectures, and receive feedback in ways that are difficult to achieve through conventional classroom routines alone. The integration of such technologies is therefore not only a technical issue, but also a pedagogical issue that affects how mathematical knowledge is represented, discussed, and constructed.

Research on digital technology in mathematics education has grown alongside the wider expansion of e-learning, online learning, blended learning, and technology-enhanced learning. Previous studies have shown that online platforms and mathematical software can support interaction, visualization, self-paced learning, and student engagement (Dilling & Vogler, 2023; Engelbrecht et al., 2020; Raza & Reddy, 2021) further argued that the internet has transformed the mathematics classroom by expanding the boundaries of formal learning spaces and by enabling new forms of interaction among humans, media, and mathematical ideas. These developments suggest that technology should not be viewed only as an auxiliary tool for presenting material, but as a component of the learning ecology that can influence mathematical thinking and participation. Systematic reviews and meta-analytic evidence further indicate that the effectiveness of digital technology in mathematics education depends not only on tool availability, but also on instructional design, teacher support, and the integration of technology into meaningful mathematical activity (Borba et al., 2016; Bray & Tangney, 2017; Hillmayr et al., 2020).

Recent surveys and reviews also show that digital technologies in mathematics education are increasingly discussed in relation to teacher practice, mathematical representation, curriculum purposes, and evidence of learning effectiveness (Clark-Wilson et al., 2020; Drijvers & Sinclair, 2024; Engelbrecht & Borba, 2024). Specific tools such as GeoGebra have been examined through systematic review and meta-analysis, indicating both positive potential and the need for careful pedagogical design (Juandi et al., 2021; Yohannes & Chen, 2023). These issues are closely related to teacher professional development, classroom expertise, and technology-enhanced pedagogical design, which influence whether digital tools become meaningful resources for learning rather than merely technical additions (Bozkurt & Ruthven, 2017; Clark-Wilson & Hoyles, 2019; Thurm & Barzel, 2020).

At the same time, the increasing number of publications in this area creates a challenge for researchers and practitioners. Empirical studies are often situated in specific contexts, grade levels, platforms, or technological interventions. While such studies are valuable, they may not provide a broad picture of how the field is developing globally. Researchers who wish to understand the intellectual structure of the field need evidence about publication trends, major contributors, country-level participation, institutional productivity, and conceptual relationships among topics. Teachers and curriculum developers also require synthesis that connects research patterns to practical implications, such as which digital strategies appear promising, which barriers remain persistent, and which future directions require more rigorous investigation.

Bibliometric analysis is useful for addressing this need because it enables researchers to analyze large bodies of literature quantitatively using bibliographic metadata. It can reveal publication growth, productive authors, influential sources, institutional contributions, international collaboration, and keyword co-occurrence patterns (Aria & Cuccurullo, 2017; Ellegaard & Wallin, 2015; Zupic & Čater, 2015). Visualization tools such as VOSviewer make it possible to represent relationships among keywords, authors, and documents as networks, thereby helping researchers identify thematic clusters and emerging topics (Van Eck & Waltman, 2010). However, bibliometric indicators alone do not fully explain what the studies say about classroom practice, methodological limitations, or future research needs.

For that reason, this article combines bibliometric analysis with a scoping review. Scoping review is appropriate when the purpose is to map the extent, range, and nature of research activity and to identify key concepts, evidence gaps, and implications for further investigation. The PAGER framework, which synthesizes evidence according to Patterns, Advances, Gaps, Evidence for Practice, and Research Recommendations, provides a structured way to connect bibliometric patterns with qualitative interpretation (Bradbury-Jones et al., 2022). By integrating bibliometric mapping and PAGER-based synthesis, the review can offer a more complete account of the research landscape than either approach could provide independently.

The gap addressed in this article is threefold. First, much of the available literature on technology use in mathematics education remains fragmented across particular tools, populations, and contexts. Second, there is a need for a focused mapping of digital technology research in mathematics education using a fifteen-year Scopus dataset from 2011 to 2025. Third, bibliometric mapping needs to be complemented by a structured interpretive synthesis so that trends are connected to advances, evidence for practice, and research recommendations. This combination is important because a high frequency of keywords or publications does not automatically indicate strong practical evidence or well-developed pedagogical models.

Accordingly, the purpose of this article is to analyze the development of research on digital technology in mathematics education indexed in Scopus from 2011 to 2025 through Scoping Review and Bibliometric Analysis. The bibliometric component maps publication trends, productive authors, affiliations, country contributions, and keyword relationships. The scoping component uses PAGER to examine selected representative studies in greater depth. The review is guided by six research questions: (1) How has the annual publication trend developed from 2011 to 2025? (2) Which authors, institutions, and countries are most productive? (3) How are contributions distributed across the field? (4) What thematic clusters emerge from keyword analysis? (5) Which topics appear as emerging or under-researched areas? and (6) What patterns, advances, gaps, practice evidence, and research recommendations emerge from the PAGER synthesis?

The contribution of this article is both theoretical and practical. Theoretically, it offers a structured map of how research on digital technology in mathematics education has developed over time and how its themes relate to broader STEM and technology-enhanced learning domains. Practically, it provides teachers, teacher educators, curriculum designers, and early-career researchers with a synthesis of dominant patterns and remaining gaps. In this way, the article is intended to support evidence-informed decision making and future research planning in mathematics education.

2. METHODS

2.1 Research Design

This study employed Scoping Review and Bibliometric Analysis as a combined evidence-synthesis design. The approach was selected because the study sought not only to count and map publications, but also to interpret the substantive content of representative studies. The bibliometric component was used to describe the publication landscape quantitatively, while the scoping review component was used to examine the content of selected studies through the PAGER framework. This design is consistent with methodological guidance that review studies should report data sources, search strategies, screening procedures, and synthesis decisions transparently (Hodiyanto et al., 2025; Kartika et al., 2023; Peters et al., 2020).

2.2 Data Sources and Search Strategy

The review used Scopus as the source database. Scopus was selected because it has broad coverage across peer-reviewed international journals and has been widely used in bibliometric studies in mathematics education and STEM education (Chin et al., 2022; Ha et al., 2020; Julius et al., 2021; Kartika et al., 2023; Phan et al., 2022). Although no single database can capture all relevant literature, Scopus provides standardized bibliographic metadata that can be exported and analyzed using bibliometric software. The search covered publications from 2011 to 2025. A fifteen-year period was chosen to capture both long-term development and recent growth in digital technology research.

The initial search strategy targeted publications containing terms related to digital technology and mathematics education in titles, abstracts, or keywords. The original search string used in Scopus was: TITLE-ABS-KEY (digital AND technology AND in AND mathematic AND education*) AND TITLE-ABS-KEY ("Mathematic") AND PUBYEAR > 2010 AND PUBYEAR < 2026. The search initially produced 172 documents. The dataset was then filtered by document type and language using the following limits: LIMIT-TO (DOCTYPE, "ar") and LIMIT-TO (LANGUAGE, "English"). After this screening step, 49 English-language journal articles were retained for the bibliometric analysis. The search was conducted on May 5, 2026, using Scopus as the source database.

2.3 Data Screening and Analysis

The inclusion criteria were: (1) publications indexed in Scopus; (2) publications appearing between 2011 and 2025; (3) journal articles; (4) English-language documents; and (5) publications retrieved by the specified search strategy. The exclusion criteria were: (1) documents outside the publication period; (2) conference papers, book chapters, reviews not classified as journal articles in the filtered dataset, and other non-article document types; (3) non-English documents; and (4) records not relevant to the targeted Scopus query. The screening process reduced the initial dataset from 172 documents to 49 included articles. Figure 1 summarizes this identification and screening process.

The analysis proceeded in two stages. First, bibliometric analysis was conducted to describe annual publication trends, author productivity, institutional affiliations, country or territory distribution, and keyword relationships. Descriptive results from Scopus were used to identify the number of documents by year, author, affiliation, and country. The dataset was then analyzed and visualized using RStudio with the bibliometrix package and VOSviewer. Bibliometrix supports comprehensive science mapping and bibliometric description (Aria & Cuccurullo, 2017), while VOSviewer supports visualization of co-occurrence networks, overlay maps, and density maps (Van Eck & Waltman, 2010).

Second, a qualitative scoping synthesis was conducted using the PAGER framework. PAGER was selected because it provides five categories that are useful for organizing findings in scoping reviews: Patterns, Advances, Gaps, Evidence for Practice, and Research Recommendations (Bradbury-Jones et al., 2022). From the 49 articles included in the bibliometric dataset, eight representative articles were selected for closer analysis. The selection was based on thematic representation across the keyword clusters and relevance to digital technology, e-learning, STEM-oriented digital tools, online platforms, serious games, and mathematical software. The selected studies included works (Boltsi et al., 2024; Dilling & Vogler, 2023; Engelbrecht et al., 2020; Ferro et al., 2021; Raza & Reddy, 2021; Samonte et al., 2023; Zhou et al., 2023; Žilinskienė & Demirbilek, 2015).

The PAGER synthesis was conducted by reading the representative studies and extracting information related to recurring research patterns, technological or pedagogical advances, knowledge gaps, practical implications, and recommendations for future research. The purpose of this stage was not to calculate effect sizes, but to understand the conceptual and practical meaning of the bibliometric patterns. For example, keyword analysis might show that e-learning and students are central terms, while PAGER analysis explains how e-learning is used, what benefits or challenges have been reported, and what kinds of empirical evidence remain limited.

This review has several methodological boundaries. First, the use of a single database means that relevant literature indexed in Web of Science, ERIC, Dimensions, Google Scholar, or national databases may not have been captured. Second, the specific search string may have influenced the resulting dataset, especially because the exact singular term "Mathematic" appeared in the original query. Future replications should compare this query with broader alternatives such as "mathematics education", "digital tools", "online learning", "technology-enhanced learning", "dynamic mathematics software", and "STEM education". Third, the PAGER analysis was based on selected representative studies rather than all 49 articles, which means that the qualitative synthesis should be interpreted as a thematic deepening of the bibliometric map, not as an exhaustive content analysis of every included article.

No human participants were directly involved in this review. Therefore, formal ethics approval and participant consent were not required. The review protocol was not pre-registered, which should be acknowledged as a limitation. Nevertheless, the manuscript reports the data source, search string, screening criteria, dataset size, analytical software, and synthesis framework to support transparency and replicability.

Bibliometric Data Compilation	Analyzing journal articles in the field of mathematics education that contain the keywords **"Digital Technology in Mathematics Education"** and **"mathematics"** in the title, abstract, or keywords, with a publication year range from **2011 to 2025**.
Search Query	TITLE-ABS-KEY (digital AND technology AND in AND mathematic AND education*) AND TITLE-ABS-KEY ("Mathematic*") AND PUBYEAR > 2010 AND PUBYEAR < 2026
Results	A total of **172 articles** related to digital technology in mathematics learning were identified over the last **15 years**.

Data Screening 1	In this screening stage, the data were focused only on articles written in **English**.
Search Query	TITLE-ABS-KEY (digital AND technology AND in AND mathematic AND education*) AND TITLE-ABS-KEY ("Mathematic*") AND PUBYEAR > 2010 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English"))
Results	A total of **49 English-language articles** related to digital technology in mathematics learning were identified.

Figure 1. Identification and screening process for the Scopus dataset.

3. RESULTS AND DISCUSSION

3.1 Annual Publication Trend

This subsection addresses RQ1 by describing how the annual publication trend on digital technology in mathematics education developed from 2011 to 2025. The bibliometric analysis identified a fluctuating but generally increasing publication trend over the 2011-2025 period. The included dataset contained 49 English-language journal articles after screening. At the beginning of the period, publication activity was very limited. Only one included article appeared in 2011, no included article appeared in 2012, and publication counts remained low in several early years. This suggests that digital technology in mathematics education, as captured by the search strategy, was not yet a highly concentrated topic in the early part of the period.

A clearer increase appeared from 2017 onward. The number of included publications became more stable and then expanded more sharply after 2021. The year 2022 showed a noticeable increase, followed by a slight decrease in 2023 and renewed growth in 2024. The highest number of included publications was observed in 2025. This pattern suggests that the topic has gained increasing attention in recent years, likely influenced by the wider expansion of online learning, digital platforms, post-pandemic educational technology adoption, and the strengthening of STEM-oriented learning agendas.

The trend should nevertheless be interpreted carefully. The dataset is shaped by the search query, database coverage, and screening criteria. Therefore, the increase does not represent every publication about digital technology in mathematics education, but rather the growth of publications retrieved by the specified Scopus search. Even with this limitation, the trend indicates that the field is developing and that digital technologies have become more visible in mathematics education research.

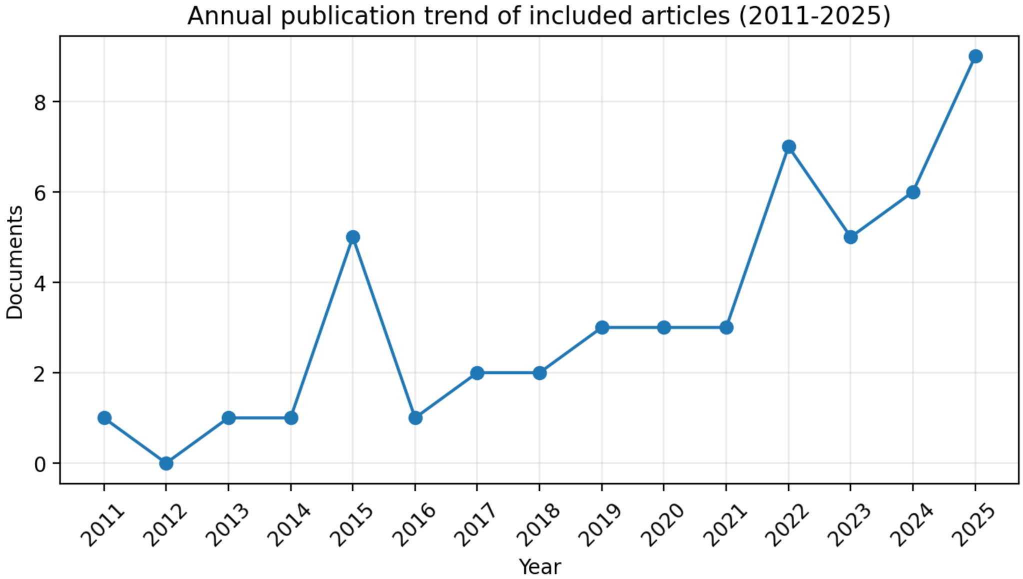

Figure 2. Annual publication trend of included articles from 2011 to 2025.

3.2 Author and Institutional Contributions

This subsection addresses part of RQ2 by identifying the most productive authors and institutions contributing to research on digital technology in mathematics education. Author productivity was relatively dispersed. The most productive author in the dataset was Chao, J. Y., with two publications. Other authors appearing among the top contributors, including Abad, F. M., Aboud, Y. Z., Agnini, A., Akazaf, M., Al-Barakat, A. A., Al-Qatawneh, S. S., AlAli, R. M., and Alam, F., each contributed one publication. This distribution suggests that no single author or small group of authors dominated the dataset.

The dispersed pattern has two implications. First, the field appears to be broad and open, with contributions coming from different researchers rather than from a tightly concentrated research community. Second, the lack of a dominant author cluster may indicate that the topic intersects with multiple subfields, including mathematics education, STEM education, educational technology, online learning, and engineering education. As a result, scholars may enter the field from different disciplinary backgrounds and methodological traditions.

Institutional productivity showed a similar pattern. Three affiliations had the highest number of documents: Wuhan University of Technology, Financial University under the Government of the Russian Federation, and National Taipei University of Education, each with two publications. Several other institutions contributed one document each, including Gain Consulting Services, Phu Yen University, Dishler Laser Institute, Brain Cognitive Structure Mapping, National School of Mines of

Rabat, School of Wuhan Maritime Vocational College, and Hubei Province Key Laboratory. The small difference between the leading institutions and other institutions indicates that the dataset is not strongly centralized around one university or research center.

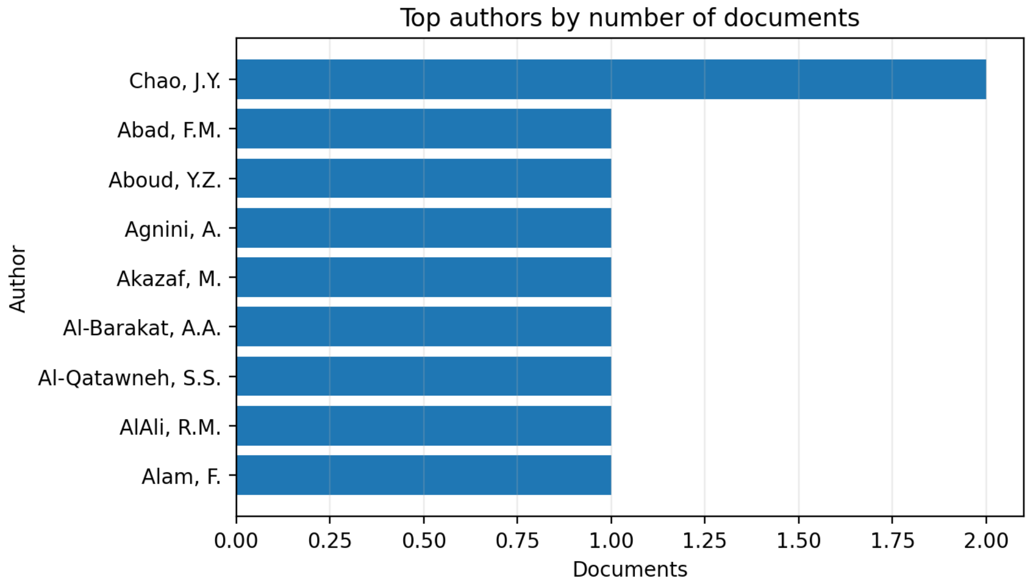

Figure 3. Top authors by number of documents.

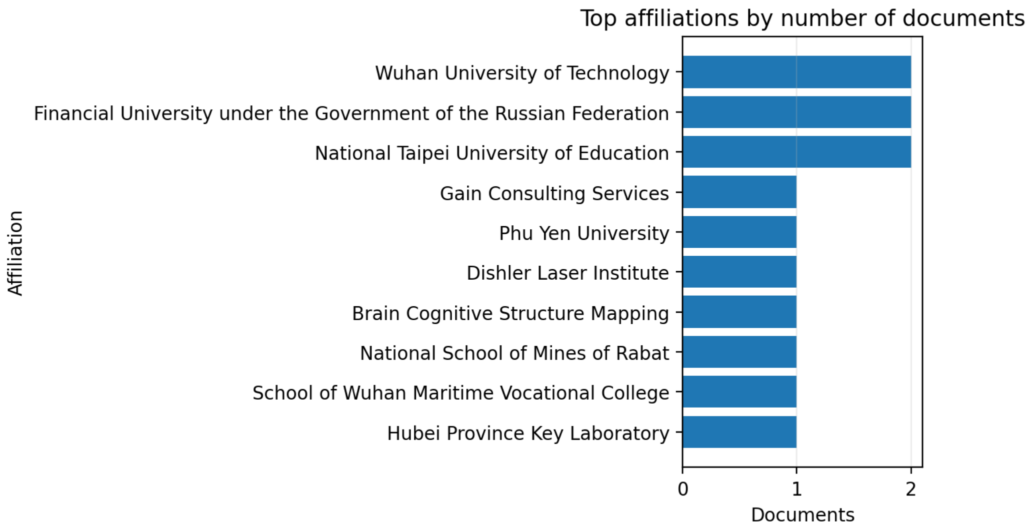

Figure 4. Top affiliations by number of documents.

3.3 Country and Territory Distribution

This subsection addresses the country-level component of RQ2 and further responds to RQ3 by explaining how research contributions are distributed across countries and territories. Country and territory analysis showed stronger concentration than author or institutional analysis. China had the highest number of documents with 10 publications, followed by the United States with seven publications and Spain with six publications. Australia, Germany, Italy, and the Russian Federation each contributed three publications. Brazil, Canada, Morocco, the Netherlands, Saudi Arabia, South Africa, Taiwan, and Ukraine each contributed two publications.

This distribution indicates that research on digital technology in mathematics education has an international character but is more visible in countries with stronger research capacity and broader access to technology-supported educational infrastructure. The prominence of China, the United States, and Spain may reflect national investments in educational technology, STEM education, and digital learning research. The presence of countries from Asia, Europe, North America, Africa, and South America also suggests that the topic has global relevance even though publication intensity varies across regions.

The country distribution also points to an important gap. If research remains concentrated in countries with relatively strong digital infrastructure, the evidence base may underrepresent contexts where technological access, teacher training, and curriculum implementation differ substantially. Future research should therefore pay greater attention to low-resource contexts, rural schools, and regions where digital inequality may shape both access to technology and the effectiveness of technology-enhanced mathematics learning.

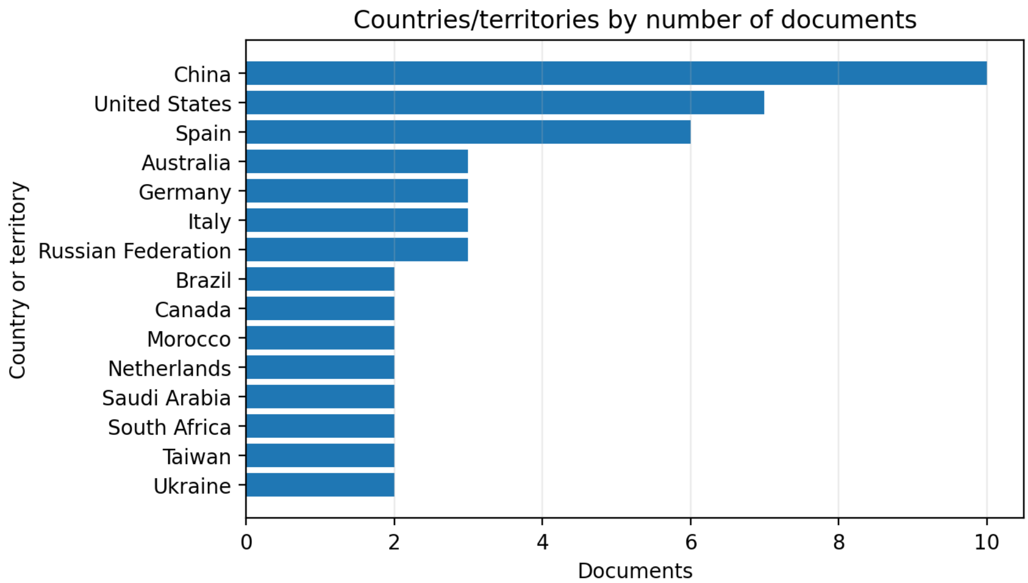

Figure 5. Countries and territories by number of documents.

3.4 Keyword Co-occurrence, Overlay, and Density Visualization

This subsection addresses RQ4 and RQ5 by identifying the thematic clusters that emerged from keyword co-occurrence analysis and by interpreting topics that appear to be emerging or relatively under-researched based on overlay and density visualizations. Keyword co-occurrence analysis revealed three thematic clusters. The first cluster was centered on mathematics education and learning processes, including keywords such as mathematics education, e-learning, students, teaching, and technology. This cluster represents studies that focus on how digital resources and online environments are used to support mathematics learning, student engagement, teacher practice, and instructional design. The prominence of students and teaching suggests that digital technology research is not limited to the technical availability of tools, but also concerns learner participation and pedagogical use. This interpretation is consistent with research showing that the pedagogical value of digital technology depends on the joint design of tools, mathematical tasks, classroom activity, and teacher orchestration (Drijvers, 2015).

The second cluster was oriented toward broader STEM and technology integration. It included terms such as science technologies, engineering education, STEM, education computing, engineering and mathematics, and curricula. This cluster indicates that digital technology in mathematics education often intersects with wider STEM agendas. Mathematics learning is increasingly connected to engineering design, computational thinking, digital fabrication, simulation, robotics, and curriculum reform. This direction is also supported by research showing that programming and computational approaches can contribute to mathematical motivation, reasoning, collaboration, and problem solving when they are pedagogically structured (Forsström & Kaufmann, 2018; Kaufmann & Stenseth, 2021).

The third cluster was related to digital learning systems, mathematical software, and accessibility-oriented e-learning. This cluster includes studies that discuss online platforms, web-based learning environments, GeoGebra-supported learning, and assistive e-learning systems. The emergence of this cluster indicates that digital technology in mathematics education is not only associated with general online learning and STEM integration, but also with specific tools and inclusive learning systems that support visualization, accessibility, and learner diversity. In this respect, mathematical software such as GeoGebra illustrates how modelling, visualization, and programming can be synthesized to support STEM-related mathematics learning (Ziatdinov & Valles, 2022).

Overlay visualization suggested that some topics appeared more recent in the dataset, especially students, mathematics education, teaching, and curricula. These topics indicate a recent emphasis on student-centered learning, teacher practice, and curriculum adaptation. Earlier or more established topics included technology, education computing, and digital storage. Density visualization showed that students, science technologies, and engineering education had relatively high density, indicating greater concentration of research around these terms. Conversely, topics such as curricula, technology, and digital storage showed lower density, suggesting opportunities for further investigation. The emergence of these topics also reflects growing attention to formative assessment, feedback, and classroom interaction in technology-supported mathematics learning (Aldon & Panero, 2020).

Overall, the keyword analysis shows that the research field has three interconnected directions. One direction examines digital technology as part of mathematics teaching and learning. The second connects mathematics education to broader STEM and technological ecosystems. The third focuses on specific digital tools, online learning systems, mathematical software, and inclusive e-learning environments. The most promising future research may lie at the intersection of these directions: designing technology-enhanced mathematics learning that is pedagogically meaningful, empirically tested, accessible, and connected to interdisciplinary STEM practices without losing attention to mathematical understanding.

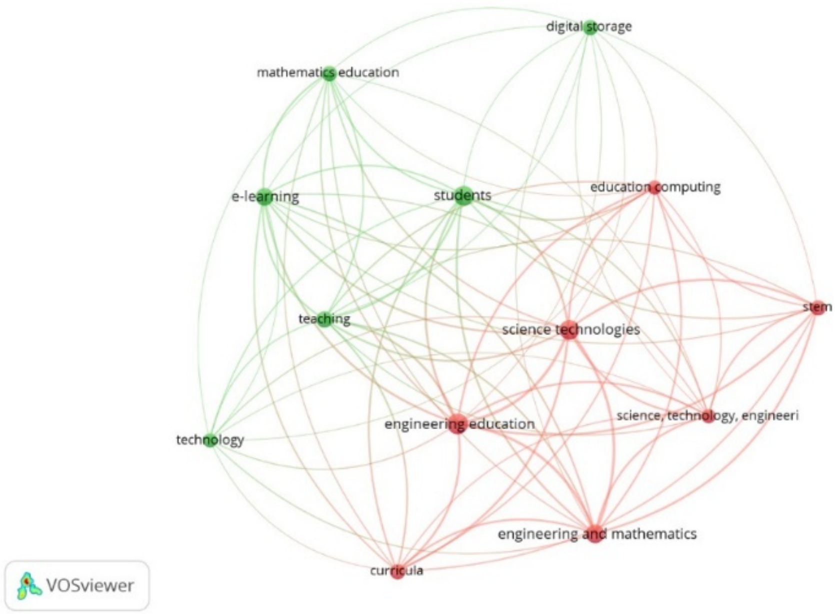

Figure 6. Keyword co-occurrence network visualization.

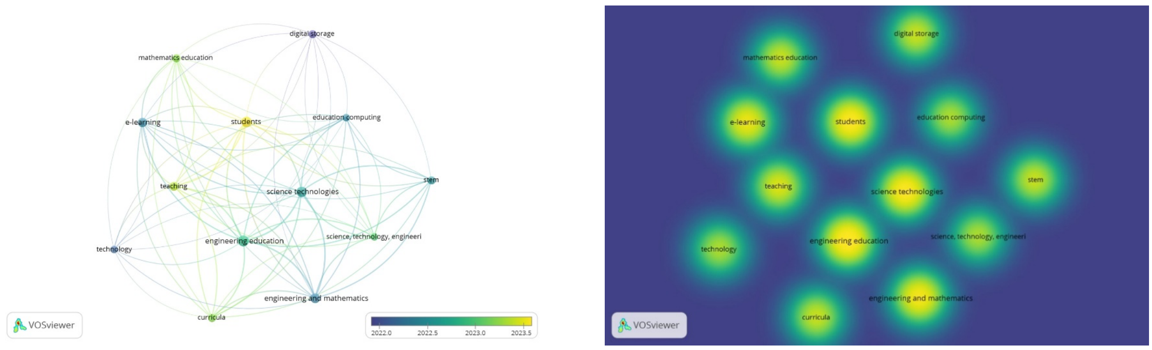

Figure 7. Overlay visualization (left) and density visualization (right) of keyword co-occurrence.

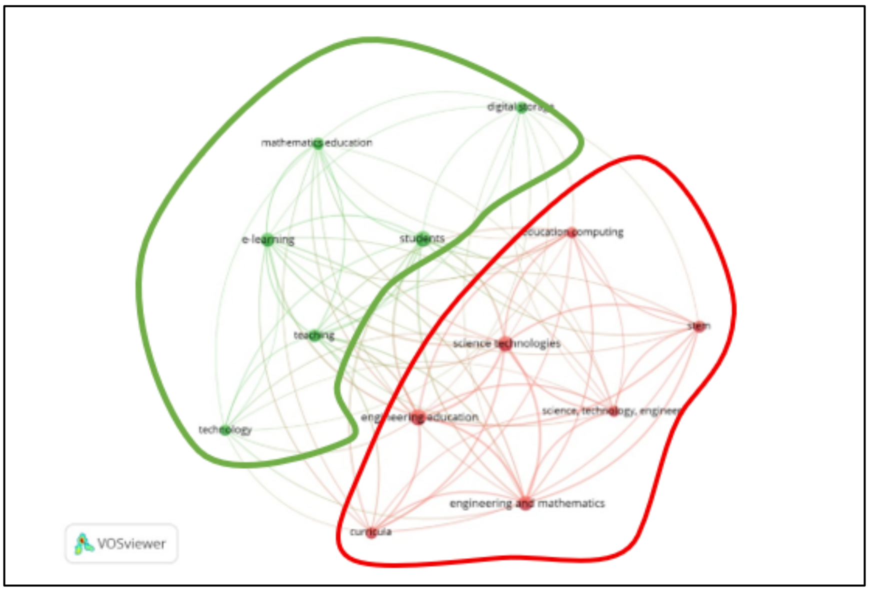

Figure 8. Cluster division in the keyword co-occurrence network.

3.5 PAGER Synthesis of Representative Studies

This subsection addresses RQ6 by interpreting the selected representative studies through the PAGER framework, focusing on patterns, advances, gaps, evidence for practice, and research recommendations. The PAGER synthesis deepened the bibliometric findings by examining representative studies from the major clusters. In the first cluster, studies on internet-based mathematics learning showed a pattern of classroom transformation. Engelbrecht et al. (2020) described how the internet has shifted mathematics classrooms from teacher-centered spaces toward more flexible, collaborative, and digitally mediated environments. Raza & Reddy (2021) emphasized that effective online mathematics courses require intentional design, interaction, and assessment rather than passive content delivery. Dilling & Vogler (2023) showed that pre-service teachers' attitudes toward online platforms can be developed through training and reflection.

The advance in this cluster is the recognition that online platforms, learning management systems, MOOCs, discussion forums, video resources, and blended learning models can become part of mathematics instructional design. The evidence for practice suggests that teachers should use technology to support interaction, feedback, exploration, and conceptual understanding. However, gaps remain regarding the effectiveness of online and blended learning across grade levels, the quality of digital resources, the design of meaningful online mathematical tasks, and the relationship between teacher digital competence and student learning outcomes. Research on blended mathematics learning similarly suggests that digital environments require careful planning of interaction, student support, and classroom roles (Attard & Holmes, 2022).

In the second cluster, studies connected digital technology to STEM-oriented learning and Education 4.0. Boltsi et al. (2024) mapped digital tools such as IoT, 5G, artificial intelligence, robotics, remote laboratories, AR/VR, and smart campus technologies in STEM-oriented educational frameworks. Zhou et al. (2023) demonstrated how a solution-based design process can support integrated STEM program development through digital fabrication, Arduino, Tinkercad Circuits, CAD software, and prototyping. Ferro et al. (2021) developed a serious game for STEM learning that combined game-based learning, collaboration, role playing, quizzes, and interactive experimentation.

The advance in this cluster is the move from isolated technology use toward integrated design environments that combine mathematics, engineering, computation, and problem solving. Evidence for practice suggests that digital technology can support active, authentic, and collaborative STEM learning. Yet important gaps remain. Many studies still focus on the technical features of tools rather than on how those tools support mathematical reasoning. Implementation may also be limited by infrastructure, cost, teacher preparation, curriculum alignment, language, software stability, and access. Future studies should examine whether these technologies improve mathematical understanding and how teachers can adapt them to local contexts.

The third cluster focused on mathematical software, e-learning, and accessibility. Žilinskienė and Demirbilek (2015) showed that GeoGebra can support visualization, exploration, and modeling in primary mathematics education, but also identified teacher readiness as a key factor. Samonte et al. (2023) discussed an assistive web-based e-learning system, highlighting the importance of accessibility features such as text-to-speech, closed captions, and online laboratories. Although Samonte et al. (2023) focused on cybersecurity rather than mathematics, the study was relevant to the broader theme of inclusive digital learning systems because it shows how e-learning platforms can be designed to support learners with different needs.

Across the PAGER categories, a consistent pattern emerges: digital technology is most promising when it is embedded in purposeful pedagogy. Advances include more interactive learning environments, blended and online learning models, dynamic mathematical visualization, STEM integration, serious games, and inclusive web-based learning systems. Gaps include limited longitudinal evidence, insufficient attention to teacher professional development, uneven access to technology, underdeveloped curriculum integration, and a need for stronger assessment of mathematical outcomes. Evidence for practice suggests that teachers should select technology based on learning goals, provide guidance for digital resource use, create opportunities for collaboration and exploration, and consider accessibility from the beginning of instructional design. This interpretation aligns with prior work emphasizing that teacher expertise, professional learning, task design, and assessment practices are central to effective technology integration in mathematics education (Aldon & Panero, 2020; Bozkurt & Ruthven, 2017; Thurm & Barzel, 2020).

The research recommendations are therefore directed toward three priorities. First, future studies should produce stronger empirical evidence about the relationship between digital technology and mathematics learning outcomes, including conceptual understanding, problem solving, reasoning, motivation, and persistence. Second, future research should examine teacher preparation and professional development because teachers mediate the relationship between digital tools and students' mathematical experiences. Third, research should address equity, accessibility, and contextual variation so that digital innovation does not widen existing inequalities in mathematics education.

Table 1. Summary of the PAGER Synthesis of Representative Studies

No.	Authors	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
Red Cluster						
1	Engelbrecht et al. (2020)	Research shows a shift from traditional to internet-based mathematics learning, encompassing blended	The internet has expanded mathematics learning spaces through online platforms, social interaction, and the humans-with-media	Empirical evidence on the effectiveness of online and blended learning across mathematics levels remains limited, and challenges	Teachers should integrate blended learning, LMS, instructional videos, and online discussion forums to support active	Future studies should examine the effectiveness of online and blended learning on mathematical understanding, MOOCs development, and strategies to

No.	Authors	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
		learning, MOOCs, LMS, flipped classrooms, and student-centered digital environments.	concept, where technology shapes mathematical thinking.	persist in digital learning design and teacher readiness.	conceptual understanding rather than merely replicating traditional methods digitally.	address technology access gaps.
2	Ferro et al. (2021)	A 3D serious game integrating role-playing, quizzes, collaborative activities, and an AI-based virtual tutor was developed to support STEM learning.	Gea2 combines virtual learning environments, intelligent pedagogical agents, and collaborative tasks to enhance student engagement beyond the classroom.	The impact of game-based learning on actual learning outcomes remains inconsistent due to time constraints, language barriers, game bugs, and weak classroom integration.	Trial with approximately 100 high school students showed higher student interest compared to traditional learning, though improvements in learning outcomes still require stronger evaluation.	Future research should test serious games on STEM learning outcomes and develop more stable, linguistically appropriate, and curriculum-integrated game designs.
Blue Cluster						
3	Boltsi et al. (2024)	The article maps STEM-oriented Education 4.0 technologies — including IoT, 5G, AI, robotics, AR/VR, and remote labs — within inquiry-based and engineering design learning frameworks.	A systematic classification of digital tools and pedagogical approaches highlights that modern STEM learning requires digital experiments, simulations, and smart campus infrastructure.	Many studies address technical features of technologies without linking them to clear pedagogical approaches, and implementation remains limited by cost, infrastructure, and curriculum readiness.	Examples such as robotic arm projects using Arduino, 3D printing, and sensors demonstrate that STEM learning can be made active, practical, and problem-solving-oriented.	Future research should assess the effectiveness of Education 4.0 technologies on learning outcomes and examine university readiness in building smart campuses and technology-aligned curricula.
4	Zhou et al. (2023)	The Solution-Based Design Process (SBDP) guides integrated STEM learning through stages of solution selection, prototyping, and testing using Arduino,	SBDP offers a more structured design-based pedagogy that combines cross-disciplinary integration, authentic contexts, and digital fabrication beyond conventional engineering design cycles.	Existing design models are still insufficient in combining interdisciplinary integration, authentic contexts, and practical design-based problem solving simultaneously.	A parking sensor redesign project demonstrated how SBDP can be applied through circuit simulation, Arduino, and 3D printing to address real-world problems.	Future studies should test SBDP directly in classrooms and measure its impact on students' creativity, critical thinking, problem solving, and collaboration.

No.	Authors	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
		CAD, and 3D printing.				
Green Cluster						
5	Raza & Reddy (2021)	Effective online mathematics courses rely on intentional design including weekly quizzes, discussion forums, LMS, and active online assessment to promote student engagement.	The study demonstrates that interactive and structured online mathematics learning — rather than passive content delivery — can improve student participation and success rates.	Online mathematics courses are still often dominated by conventional passive approaches, resulting in lower student success rates compared to other disciplines.	Data from the University of the South Pacific confirm that active assessment strategies and discussion forums meaningfully increase student engagement in online mathematics learning.	Future research should explore interactive online strategies including gamification, learning analytics, and collaborative activities to improve mathematics learning success.
6	Samonte et al. (2023)	CyLearn integrates assistive features — text-to-speech, closed captions, virtual machines, and online labs — into a web-based e-learning system to support diverse learners.	The system supports students with hearing and visual impairments alongside mainstream users, illustrating how inclusive e-learning design can broaden access to digital learning.	Few e-learning systems address accessibility for students with special needs, and security vulnerabilities in web-based platforms remain a persistent challenge.	Students using CyLearn achieved higher scores than those using conventional materials such as PDFs and PowerPoint, supporting the value of interactive and accessible e-learning design.	Future development should extend assistive e-learning to other subject areas, expand accessibility features, and strengthen the security of web-based learning systems.
7	Žilinskienė & Demirbilek (2015)	GeoGebra is used in primary mathematics education to support visualization, concept exploration, modeling, and interactive learning, with teacher readiness as a key mediating factor.	GeoGebra enables students to understand mathematical concepts through dynamic visual representation and interactive exploration across algebra, geometry, and measurement topics.	Optimal use of GeoGebra is constrained by teachers' limited knowledge, technological readiness, and uncertainty about software suitability for primary-level learning objectives.	Expert opinion confirms GeoGebra's suitability for primary mathematics, particularly for algebra, simple geometry, tables, graphs, and concept visualization.	Future research should include classroom-based studies, develop structured teacher training programs, and assess GeoGebra's impact on primary students' conceptual understanding and motivation.
8	Dilling & Vogler (2023)	The study examines pre-service	Online training can positively shift pre-service	Research on how teacher attitudes	Reflective activities involving 14	Future studies should involve larger participant

No.	Authors	Patterns	Advances	Gaps	Evidence for Practice	Research Recommendations
		teachers' attitudes toward online learning platforms — including Moodle and blended learning tools — before and after university-based online training.	teachers' perspectives on using digital platforms for mathematics instruction, supporting materials, communication, and assessment.	toward online platforms change through training remains limited, particularly regarding the link between attitude change and actual classroom practice.	pre-service teachers showed measurable shifts in attitudes toward online platform use, supporting reflection-based approaches in teacher education.	samples, test platform use in real classrooms, and examine the relationship between teacher attitudes, digital skills, and student learning outcomes.

3.6 Synthesis of PAGER Findings from the Reviewed Articles

This subsection further synthesizes RQ6 by summarizing the main findings across the five PAGER components from the eight reviewed articles.

3.6.1 Patterns

Based on the Patterns component, the eight articles show that the use of digital technology in mathematics and STEM education is increasingly directed toward more interactive, flexible, collaborative, and student-centered learning. The reviewed articles no longer position technology merely as a supporting tool, but as an integral part of instructional design. The patterns identified include internet-based learning, blended learning, flipped classrooms, learning management systems, massive open online courses, serious games, web-based e-learning, GeoGebra-supported learning, online learning platforms, and the integration of digital technology within the Education 4.0 framework. Several articles also emphasize project-based and design-based learning through the use of Arduino, 3D printing, sensors, virtual laboratories, and integrated STEM approaches. Overall, the main pattern emerging from the eight articles is the shift from traditional classroom instruction toward digital learning environments that are more active, visual, adaptive, and capable of increasing student engagement.

3.6.2 Advances

Based on the Advances component, the eight articles demonstrate important developments in the use of digital technology to support mathematics and STEM learning. These developments are reflected in various innovations, such as online learning, blended learning, the use of the internet to support social interaction and knowledge construction, three-dimensional serious games, Education 4.0 technologies, smart campuses, the Internet of Things, 5G, artificial intelligence, robotics, remote laboratories, and more inclusive web-based learning platforms. The article on GeoGebra shows advances in the visualization and exploration of mathematical concepts, while the article on online learning platforms indicates that online training can influence pre-service teachers’ attitudes toward the use of technology in mathematics instruction. In general, the advances discussed in the eight articles indicate that digital technology can expand learning spaces, improve access to learning resources, strengthen conceptual visualization, and support more independent, collaborative, and problem-solving-oriented learning.

3.6.3 Gaps

Based on the Gaps component, the eight articles reveal that although digital technology has developed rapidly, several research and practice gaps remain. One of the main gaps is the limited empirical evidence regarding the effectiveness of online learning, blended learning, massive open online courses, serious games, and digital platforms in improving students' mathematics learning outcomes. Several articles also indicate that technology use is still often focused on technical aspects, such as devices, systems, or platforms, without being sufficiently connected to appropriate pedagogical approaches. In addition, challenges remain in relation to teacher readiness, students' digital competence, infrastructure, cost, language, accessibility, system security, and the integration of technology into classroom instruction. In the use of GeoGebra and online learning platforms, the gaps are also evident in the limited availability of teacher training and the lack of classroom-based studies that directly examine the impact of technology on students' conceptual understanding in mathematics.

3.6.4 Evidence For Practice

Based on the Evidence for Practice component, the eight articles provide practical evidence that digital technology can be implemented meaningfully in learning when it is carefully designed and aligned with learners' needs. The practical evidence includes the use of blended learning, flipped classrooms, learning management systems, online discussion forums, instructional videos, massive open online courses, serious games, virtual laboratories, simulations, Arduino, Raspberry Pi, robotics, sensors, GeoGebra, and web-based e-learning platforms. Several articles show that technology can increase students' interest and engagement, particularly through serious games and project-based learning. Other articles indicate that weekly quizzes, discussion forums, and active assessment can improve student participation in online mathematics learning. Furthermore, GeoGebra is shown to have potential for supporting mathematical concept visualization, while accessible e-learning systems can support students with special needs. Therefore, the practical evidence from the eight articles confirms that digital technology can strengthen learning when it is used as part of a pedagogical strategy rather than merely as an additional medium.

3.6.5 Research Recommendations

Based on the Research Recommendations component, the eight articles emphasize the need for further studies that are more empirical, practice-based, and situated in authentic classroom contexts. Future research should examine the effectiveness of online learning, blended learning, serious games, GeoGebra, learning management systems, massive open online courses, and digital platforms on students' learning outcomes, conceptual understanding, motivation, creativity, collaboration, and problem-solving skills. In addition, future studies need to develop evidence-based digital learning designs, investigate teacher and institutional readiness, and evaluate the alignment between technology, curriculum, and learners' needs. Several articles also recommend involving larger numbers of participants, testing digital technologies directly in real classrooms, and linking technology use with appropriate pedagogical approaches. Overall, the research recommendations across the eight articles point toward the development of mathematics and STEM learning that is more effective, inclusive, interactive, and capable of using digital technology in a meaningful way.

4. CONCLUSION

This review mapped research on digital technology in mathematics education indexed in Scopus from 2011 to 2025 through a combination of bibliometric analysis and PAGER-based scoping synthesis. The bibliometric analysis revealed a fluctuating but generally increasing publication trend, with growth becoming more evident after 2017 and reaching its highest point in 2025 within the included dataset. Author and institutional productivity were relatively dispersed, whereas country-level contributions were more concentrated, particularly in China, the United States, and Spain. Keyword analysis identified three thematic clusters: one centered on mathematics education, e-learning, students, teaching, and technology; another centered on broader STEM-oriented digital integration, including science technologies, engineering education, education computing, and curricula; and a third centered on digital learning systems, mathematical software, and accessibility-oriented e-learning.

The PAGER synthesis indicated that research on digital technology in mathematics education is moving beyond the adoption of digital tools toward more integrated instructional design. The major patterns identified included online and blended learning, learning management systems, serious games, STEM-oriented digital tools, GeoGebra, web-based e-learning systems, and teacher training for online platforms. The advances reflected the development of more interactive, flexible, collaborative, and inclusive learning environments. However, several gaps remain, particularly in empirical evidence, teacher preparation, curriculum integration, accessibility, technology infrastructure, and contextual representation. Evidence for practice suggests that digital technology is most beneficial when it is aligned with mathematical learning goals, embedded in meaningful pedagogy, and supported by teacher guidance.

This review contributes a combined quantitative and qualitative map of the field. Nevertheless, the findings should be interpreted within the limitations of the single-database Scopus dataset, the specific search string used, and the selective PAGER analysis of eight representative studies. Future research should broaden database coverage, refine search strategies, pre-register review protocols, and conduct more rigorous empirical studies on the impact of digital technology on mathematical understanding, problem solving, reasoning, motivation, collaboration, and equity. As digital technology continues to evolve, mathematics education research should ensure that innovation is guided by evidence, pedagogy, accessibility, and meaningful mathematical learning.

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