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# TECHNOLOGY-ENHANCED TECHNIQUES FOR LEARNING MATHEMATICS: A BIBLIOMETRIC PERSPECTIVE

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**Abstract:**

The rapid incorporation of digital tools and emerging technologies has transformed mathematics education, prompting scholars to investigate technology-enhanced techniques that can improve teaching and learning effectiveness. Nonetheless, despite the growing body of research, there exists a need to systematically examine publication trends, influential works, and collaborative patterns in this field to better understand its evolution and future direction. This research bridges this gap via a bibliometric analysis of research on technology-enhanced learning in mathematics. Data were collected using the Scopus advanced search with specific keywords ("teaching," "learning," "mathematics," "technology," and "digital"), resulting in 1,248 relevant documents. To ensure data accuracy and consistency, OpenRefine was applied for cleaning and harmonization. The Scopus Analyzer was then used to generate descriptive statistics and graphical representations of publication trends, while VOSviewer software was employed to visualize co-authorship networks, country collaborations, citation patterns, as well as keyword co-occurrence maps. The findings demonstrate a steady increment in publication output from 2015 to 2025, with notable peaks during the COVID-19 pandemic years, reflecting the urgent demand for digital and remote learning solutions. The United States, Indonesia, China, and Malaysia emerged as the most active contributors, while highly cited articles focused on themes of equity in STEM, digital learning innovations, and project-based learning approaches. Keyword mapping highlighted clusters around "mathematics education," "e-learning," "educational technology," and "STEM integration," underscoring the interdisciplinary nature of the field. This research contributes to the body of knowledge by providing a comprehensive overview of research trends and global collaborations, offering insights for educators, policymakers, and researchers seeking to advance technology-enhanced mathematics education.

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**Keywords:**

Teaching, Learning, Mathematics, Technology, Digital

## Introduction

The incorporation regarding technology in education has revolutionized the teaching and learning landscape, particularly in the field of mathematics. This shift has been driven by the need to enhance student engagement, improve learning outcomes, and address the diverse needs of students. Note that technology-enhanced learning techniques offer innovative ways to present mathematical concepts, facilitate interactive learning, and provide immediate feedback, which are crucial for developing a deeper understanding of mathematics. The COVID-19 pandemic further accelerated the adoption of these technologies, highlighting their potential to support remote and hybrid learning environments. This paper explores the various technology-enhanced techniques used in education to teach mathematics, examining their effectiveness, challenges, and the factors that influence their successful implementation.

The use of technology in mathematics education has been a growing trend even before the COVID-19 pandemic. Various studies have highlighted the benefits of technology-enhanced resources in supporting the development of mathematical understanding and skills. For instance, technology can provide formative assessments that help students identify gaps in their knowledge and take appropriate actions to address them (Shé et al., 2024). These resources have been shown to encourage student engagement by making learning more interactive and accessible. However, the effectiveness of these resources is not always clear, and there is a need for more research to understand how students engage with technology in mathematics education (Ní Shé et al., 2023).

Several types of technologies have been identified as beneficial in enhancing mathematics learning. Graphing calculators, computer-based tools such as presentation software, and web-based instruction are some examples that have been used to motivate students and make learning more engaging (Raines & Clark, 2011). Additionally, innovative techniques like project-based learning and the integration of technology have been recognized for encouraging students' engagement as well as academic achievement in mathematics (Janardhanan & Charles, 2024). These methods make learning more interactive, help reduce math anxiety, and increase self-efficacy among students.

Despite the potential benefits, there are challenges associated with the integration of technology in mathematics education. One major issue is the lack of a comprehensive framework that develops both the educational context and pedagogical aspects of technology incorporation in mathematics (Ní Shé et al., 2023). Moreover, there is a disparity between the types of technology interventions being researched and those that are recognized as optimizing the potential of technology to enhance mathematics education (Bray & Tangney, 2017). This gap highlights the need for more empirical studies to identify effective strategies and best practices for using technology in mathematics education.

The role of digital tools in mathematics education has also been explored extensively. For example, e-learning platforms like Moodle and dynamic geometry software such as GeoGebra have been used to create engaging and flexible learning environments (Alessio et al., 2019).

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These tools can help overcome logistical challenges, such as large class sizes and varying levels of student preparedness, by providing personalized learning experiences and immediate feedback. Additionally, assistive technologies like mobile learning, tablet learning, and gamification have been shown to improve student attitudes towards mathematics and enhance their learning experiences (Reddy et al., 2021).

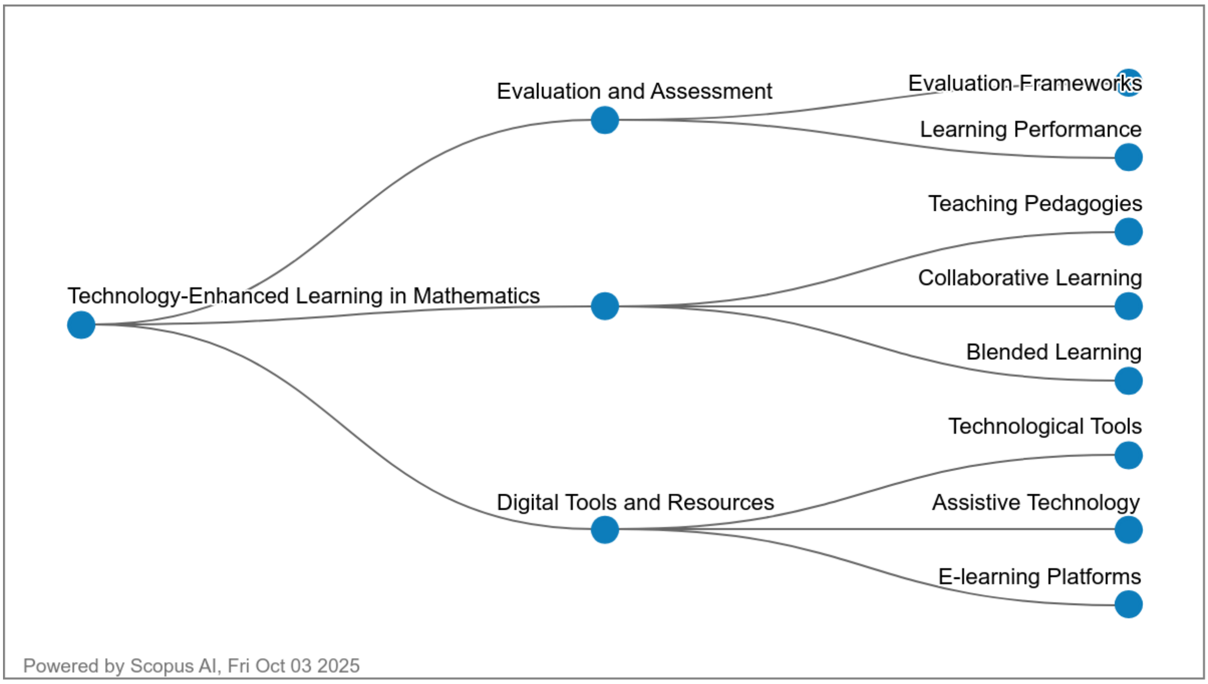


**Figure 1: Concept Map Technology-Enhanced Techniques In Learning Mathematics**
Source: (Scopus AI, Fri Oct 03 2025)

Figure 1 illustrates three main areas: Evaluation and Assessment, Pedagogical Approaches, and Digital Tools and Resources. Under evaluation, the focus lies on evaluation frameworks and learning performance, emphasizing structured methods to measure student outcomes. Pedagogical approaches encompass teaching pedagogies, collaborative learning, and blended learning, which highlight how technology supports diverse instructional strategies and fosters interactive, flexible learning environments. On the digital tools side, emphasis is placed on technological tools, assistive technology, and e-learning platforms, all of which provide critical resources to support accessibility, inclusivity, and adaptability in mathematical learning. Overall, the concept map suggests that effective integration of technology in mathematics education relies on the interplay between assessment strategies, innovative pedagogies, and the provision of digital tools that enhance both teaching and learning experiences. This multidimensional approach improves student engagement and collaboration, ensuring equitable access, performance monitoring, and sustainable learning practices.

To conclude, the incorporation of technology in mathematics education allows numerous benefits, which include increased student engagement, enhanced learning outcomes, as well as the ability to provide personalized learning experiences. Nevertheless, there are also challenges that need to be addressed, such as the lack of a comprehensive framework for technology integration and the need for more empirical research to identify effective strategies. By addressing these challenges and leveraging the potential of digital tools, educators can create more engaging and effective learning environments for students.

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**Research Question**
RQ1: What are the longitudinal publication trends in technology-enhanced mathematics education research across the years of study?
RQ2: Which articles represent the top 10 most highly cited contributions within this research domain?
RQ3: Which countries are the leading contributors in terms of the top 10 publication outputs?
RQ4: What are the most frequently occurring author keywords that reflect the thematic focus of this field?
RQ5: How are patterns of international collaboration reflected through co-authorship networks among countries?

**Methodology**
Bibliometrics is a systematic method that entails the collection, organization, as well as critical analysis of bibliographic data derived from scientific publications (Alves et al., 2021; Assyakur & Rosa, 2022; Verbeek et al., 2002). Beyond descriptive statistics such as examining leading journals, publication trends, and prolific authors (Wu & Wu, 2017), bibliometric studies employ advanced techniques, including document co-citation and network analyses, to uncover the intellectual structure and thematic evolution of a field. A rigorous literature review necessitates an iterative process of keyword selection, database searching, and in-depth analytical synthesis to ensure both comprehensiveness and reliability (Fahimnia et al., 2015). In line with this, the present study emphasizes high-impact publications, as they offer deeper insights into the conceptual frameworks and theoretical foundations underpinning the discipline. To guarantee the robustness and accuracy of the dataset, Scopus was employed as the principal source for data collection (Al-Khoury et al., 2022; di Stefano et al., 2010; Khiste & Paithankar, 2017). To preserve academic rigor, the study was restricted to peer-reviewed journal articles, intentionally omitting books, conference proceedings, and lecture notes (Gu et al., 2019). Note that publications spanning the period from 2015 through September 2025 were systematically retrieved from Elsevier's Scopus, recognized for its extensive coverage and reliability, to serve as the foundation for subsequent bibliometric analysis.

**Data Search Strategy**
The data for this research were retrieved utilizing the Scopus advanced search function, applying a carefully structured query string: *TITLE ( ( teaching OR learning OR education ) AND ( mathematic OR mathematics OR maths ) AND ( technology OR digital OR mobile ) ) AND PUBYEAR > 2009 AND PUBYEAR < 2026 AND ( LIMIT-TO ( LANGUAGE , "English") )*. This search strategy was designed to obtain relevant publications that explicitly addressed the integration of technology, digital tools, or mobile applications in the teaching and learning of mathematics. The search was performed in October 2025 to ensure accuracy and currency of the dataset (Refer to Table 1). The publication period was limited to 2015–2025 in order to reflect contemporary developments over a 10-year span. A systematic screening process was then applied as shown in Table 2, with English-language publications forming the inclusion criterion, while non-English works were excluded. Similarly, articles published before 2010 were omitted to maintain focus on modern research contexts. The screening procedure ensured that the dataset was aligned with the study's objectives and comprised only relevant and accessible academic works. Following this process, a total of 1,248 publications were identified as the final dataset. This comprehensive collection provides a robust foundation for bibliometric analysis, enabling the identification of thematic research trends, collaboration networks, and intellectual structures. The transparent and replicable search strategy strengthens

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the reliability of the findings and supports future research extensions in the field of technology-enhanced mathematics education.

**Table 1: The Search String**

| | |
|---|---|
| Scopus | TITLE ( ( teaching OR learning OR education ) AND ( mathematic OR mathematics OR maths ) AND ( technology OR digital OR mobile ) ) AND PUBYEAR > 2009 AND PUBYEAR < 2026 AND ( LIMIT-TO ( LANGUAGE , “English”) ) |
| | Access date: October 2025 |

**Table 2: The Selection Criterion Is Searching**

| Criterion | Inclusion | Exclusion |
|---|---|---|
| **Language** | English | Non-English |
| **Time line** | 2015 – 2025 | < 2010 |
| **Literature type** | Journal (Article) | Conference, Book, Review |
| **Publication Stage** | Final | In Press |

**Data Analysis**
VOSviewer refers to a widely recognized and user-friendly bibliometric software established by Nees Jan van Eck and Ludo Waltman at Leiden University, Netherlands (van Eck & Waltman, 2010, 2017). It has become an indispensable tool for visualizing and analyzing scientific literature, particularly through the generation of intuitive network visualizations, clustering of associated items, as well as creation of density maps. The software’s versatility enables the exploration of co-citation, co-authorship, and keyword co-occurrence networks, thereby offering researchers a comprehensive perspective on research landscapes. Its interactive interface, combined with ongoing updates, facilitates dynamic exploration of large bibliometric datasets. Additionally, its capacity to measure performance metrics, customize visualizations, and integrate with multiple bibliometric data sources further enhances its value for researchers investigating complex domains.

A defining strength of VOSviewer lies in its capability to transform intricate bibliometric datasets into clear, visually interpretable maps and charts. Having a primary emphasis on network visualization, the software excels in clustering, assessing keyword co-occurrence structures, and generating density maps, all of which are accessible through an interface designed to support both novice and expert users. Continuous development has ensured that VOSviewer remains at the forefront of bibliometric analysis, offering advanced yet accessible insights through customizable visualization and clustering functions.

For this study, datasets comprising publication year, title, author, journal, citation, and keywords in PlainText format were retrieved from the Scopus database, covering the period from 2015 to September 2025. These datasets were analyzed using VOSviewer software version 1.6.20. By applying VOS clustering and mapping techniques, the software allowed the construction of detailed bibliometric maps. In contrast to traditional Multidimensional Scaling

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(MDS), VOSviewer situates items within low-dimensional spaces such that the distance between items reflects the strength of their relatedness, while still sharing conceptual similarities with the MDS approach (van Eck & Waltman, 2010; Appio et al., 2014). Contradictory to MDS, which primarily engages in the computation of similarity metrics like Jaccard and cosine indices, VOS employs a more fitting method for normalizing co-occurrence frequencies, such as the Association Strength ($AS_{ij}$), which is measured as:

$$AS_{ij} = \frac{C_{ij}}{w_i w_j},$$

which is "proportional to the ratio between the observed number of co-occurrences of $i$ and $j$. On the other hand, the expected number of co-occurrences of $i$ and $j$ under the assumption that co-occurrences of $i$ and $j$ are statistically independent" (Van Eck & Waltman, 2007).

## Findings

### *RQ1: What Are The Longitudinal Publication Trends In Technology-Enhanced Mathematics Education Research Across The Years Of Study?*

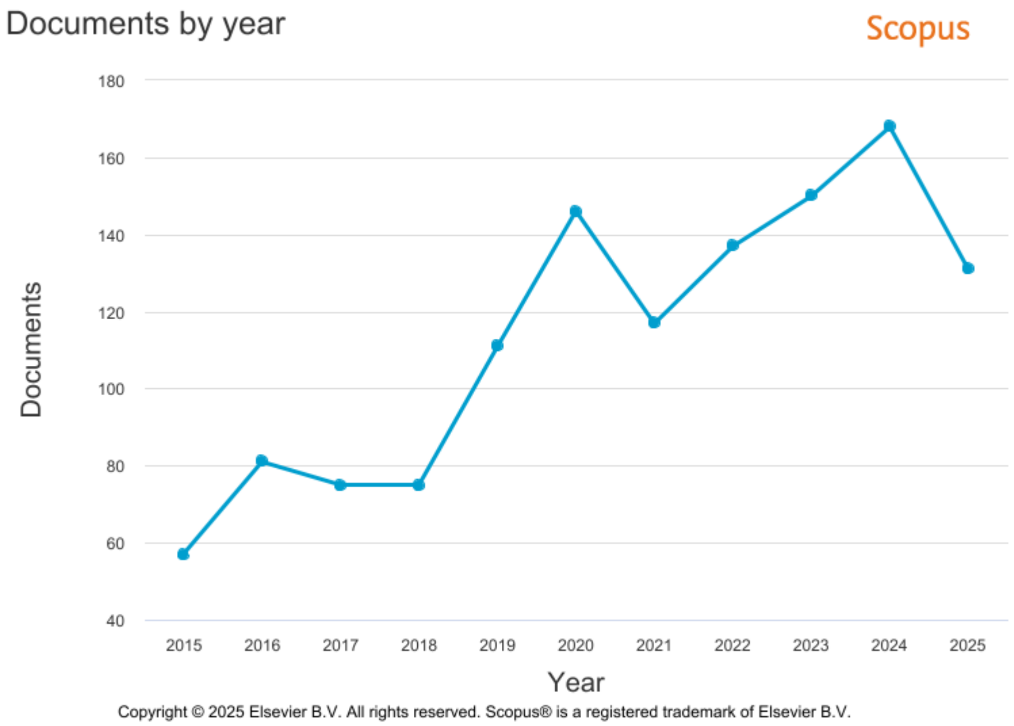


**Figure 2: Number Of Documents Based on Year of Publication.**

Source: (Scopus, Fri Oct 03 2025)

The trend of publications on technology-enhanced techniques for learning mathematics in education from 2015 to 2025 shows a clear overall growth, with fluctuations in some years. Starting at 57 publications in 2015, there was a gradual increase over the next few years, reaching 81 publications in 2016. The growth continued more steadily from 2017 to 2020, peaking at 146 in 2020, although there was a slight dip in 2019. After 2020, the number of publications remained relatively high, fluctuating between 117 and 168 documents per year, with the highest output recorded in 2024 (168 publications). This indicates that research interest

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in applying technological tools to enhance mathematics learning has been steadily increasing, reflecting growing recognition of digital and mobile learning solutions in education.

The fluctuations observed, such as the dip in 2021 and the slight decrease in 2023 and 2025 compared to 2024, could be attributed to various factors, including research funding cycles, global events like the COVID-19 pandemic, and shifting academic priorities. The sharp rise after 2017 may be linked to the wider adoption of online and hybrid learning platforms, which accelerated during the pandemic period when institutions prioritized technology-enhanced learning. The overall upward trend demonstrates the increasing academic and practical relevance of integrating technology into mathematics education, as educators and researchers respond to the need for more engaging, accessible, and effective learning methods.

***RQ2: Which Articles Represent The Top 10 Most Highly Cited Contributions Within This Research Domain?***

**Table 3: Most Cited Author**

| No. | Authors | Title | Year | Source title | Cited by |
|---|---|---|---|---|---|
| 1 | Theobald et al.(2020) | Active Learning Narrows Achievement Gaps For Underrepresented Students In Undergraduate Science, Technology, Engineering, And Math | 2020 | Proceedings of the National Academy of Sciences of the United States of America | 926 |
| 2 | Stoet & Geary (2018) | The Gender-Equality Paradox in Science, Technology, Engineering, and Mathematics Education | 2018 | Psychological Science | 702 |
| 3 | Han et al. (2015) | How Science, Technology, Engineering, And Mathematics (STEM) Project-Based Learning (PBL) Affects High, Middle, And Low Achievers Differently: The Impact Of Student Factors On Achievement | 2015 | International Journal of Science and Mathematics Education | 334 |
| 4 | Hillmayr et al. (2020) | The Potential Of Digital Tools To Enhance Mathematics And Science Learning In Secondary Schools: A Context-Specific Meta-Analysis | 2020 | Computers and Education | 274 |

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| | | | | | |
|---|---|---|---|---|---|
| 5 | Bano et al. (2018) | Mobile Learning For Science And Mathematics School Education: A Systematic Review Of Empirical Evidence | 2018 | Computers and Education | 201 |
| 6 | Mulenga & Marbán (2020) | Is COVID-19 The Gateway For Digital Learning In Mathematics Education? | 2020 | Contemporary Educational Technology | 191 |
| 7 | Borba et al. (2016) | Blended Learning, e-Learning and Mobile Learning in Mathematics Education | 2016 | ZDM - International Journal on Mathematics Education | 189 |
| 8 | Bray & Tangney (2017) | Technology Usage In Mathematics Education Research – A Systematic Review Of Recent Trends | 2017 | Computers and Education | 181 |
| 9 | Eddy & Brownell (2016) | Beneath The Numbers: A Review Of Gender Disparities In Undergraduate Education Across Science, Technology, Engineering, And Math Disciplines | 2016 | Physical Review Physics Education Research | 175 |
| 10 | Lee et al. (2020) | Computational Thinking from a Disciplinary Perspective: Integrating Computational Thinking in K-12 Science, Technology, Engineering, and Mathematics Education | 2020 | Journal of Science Education and Technology | 165 |

Source: (Scopus, Fri Oct 03 2025)

The citation pattern of the top 10 articles shows that the most influential works extend beyond mathematics education alone and engage with broader STEM and equity-related issues. Theobald et al. (2020), with 926 citations, and Stoet & Geary (2018), with 702 citations, dominate the list as they tackle urgent themes of inclusivity, equity, and gender gaps in STEM education—topics that resonate widely across disciplines and policymaking spheres. Similarly, Han et al. (2015), with 334 citations, emphasized project-based learning and its differential impact on diverse student groups, further highlighting the importance of pedagogical innovations that address educational inequality. These high citation counts suggested that articles that bridge mathematics education with pressing social, structural, and interdisciplinary concerns tend to have broader academic appeal, resulting in greater impact across the global research community.

In contrast, articles focusing more narrowly on technology in mathematics teaching, such as Hillmayr et al. (2020) (274 citations), Borba et al. (2016) (189 citations), and Bray & Tangney (2017) (181 citations), while still influential, received fewer citations compared to equity-focused STEM studies. Their relevance is more specific to the educational technology and

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mathematics education domains, making their impact somewhat narrower but still significant. Notably, Mulenga & Marbán (2020) reflected the role of global events like COVID-19 in accelerating digital learning research, while Bano et al. (2018) underscored the importance of systematic reviews as evidence-based references for scholars and practitioners. Overall, the data suggested that while technology-enhanced mathematics learning is an important research area, the highest academic influence is achieved when such studies are framed within global challenges, interdisciplinary integration, and issues of access, equity, and inclusion.

***RQ3: Which Countries Are The Leading Contributors In Terms Of The Top 10 Publication Outputs?***

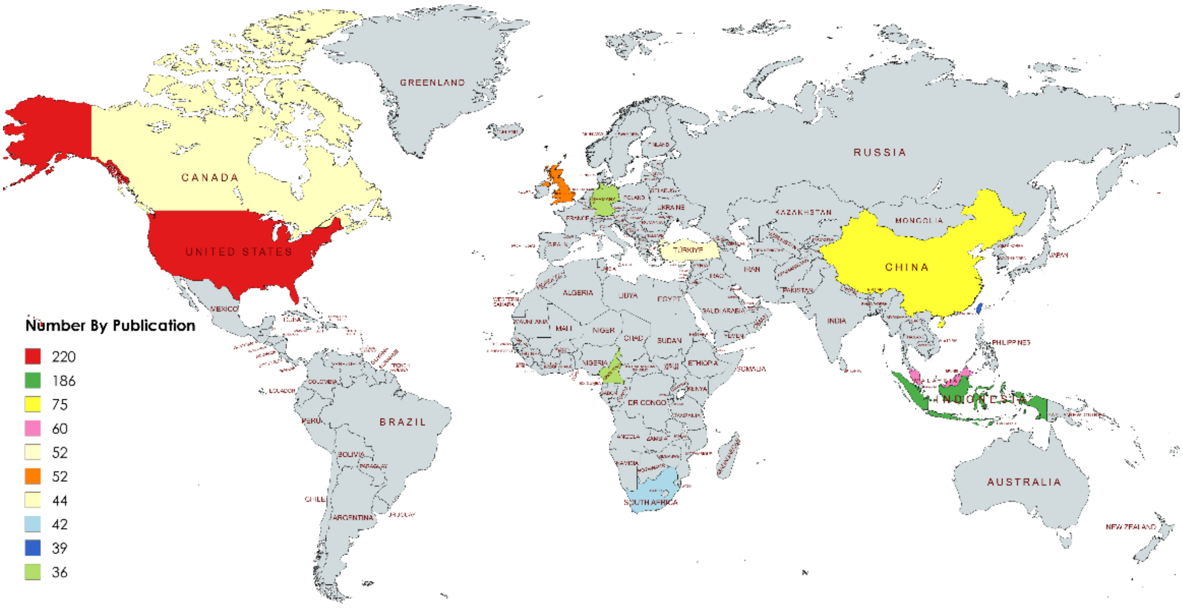


**Figure 3: Country Mapping Based On the Number Of Publications**
Source: (Scopus, Fri Oct 03 2025)

The publication distribution by country highlights the United States (220) and Indonesia (186) as the leading contributors to research on technology-enhanced techniques for learning mathematics, far surpassing other countries. This dominance may be attributed to the United States' strong research infrastructure, large education system, and significant investments in educational technology. Indonesia's high contribution reflects its recent emphasis on digital transformation in education and the government's strong push to integrate technology into teaching and learning, particularly in response to the rapid expansion of education institutions. Other Asian countries, such as China (75), Malaysia (60), and Taiwan (39), also appear prominently, showcasing the region's growing interest in leveraging technology to improve mathematics learning outcomes and address large student populations.

Meanwhile, contributions from Turkey (52), the United Kingdom (52), Canada (44), South Africa (42), and Germany (36) indicate more balanced yet steady engagement with the field. These countries often emphasize pedagogical innovation and policy-driven adoption of educational technologies in education, but their smaller outputs compared to the United States and Indonesia may be due to differences in funding priorities and national education agendas. The presence of both developed and developing nations in the top contributors list suggests

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that the push toward technology-enhanced mathematics education is a global phenomenon. Countries are adopting it either to strengthen competitiveness in knowledge economies (developed nations) or to expand access and improve the quality of education (developing nations).

***RQ4: What Are The Most Frequently Occurring Author Keywords That Reflect The Thematic Focus Of This Field?***

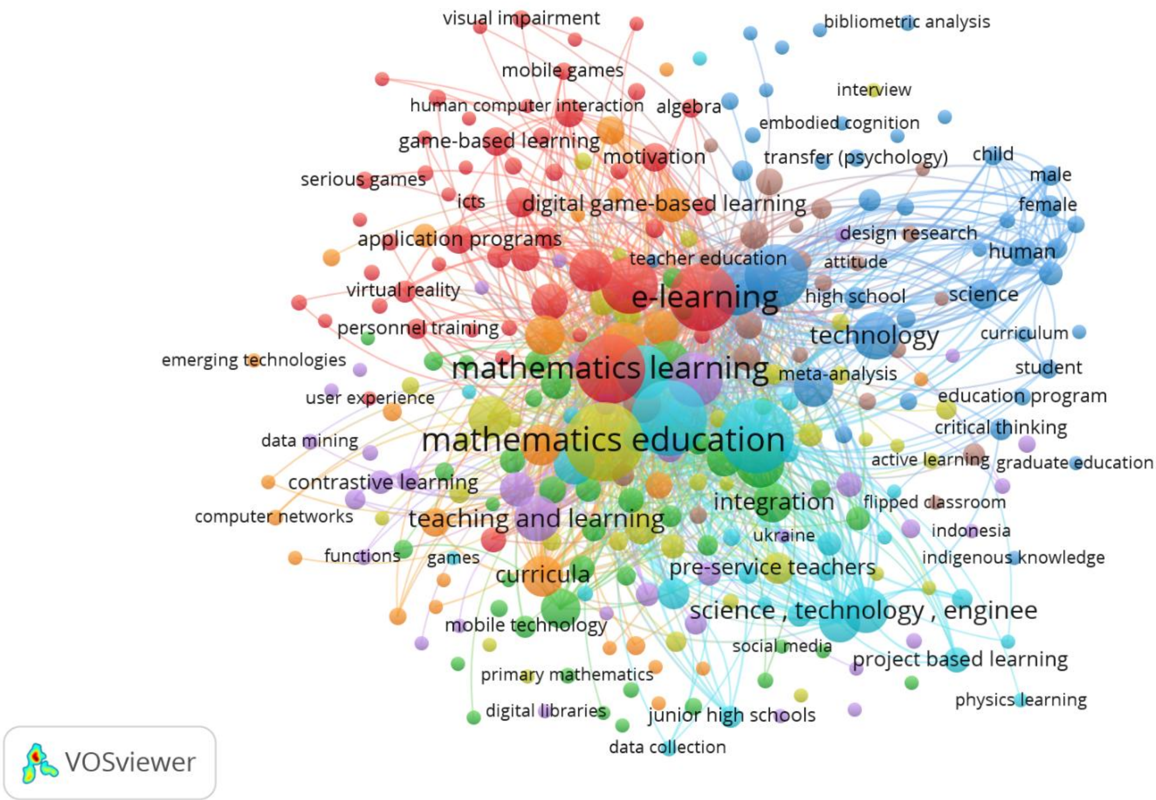


**Figure 4: Network Visualization Map Of Keywords' Co-Occurrence**
Source: (Scopus, Fri Oct 03 2025)

Co-occurrence analysis of author keywords in VOSviewer identifies how often specific terms appear together across publications, revealing thematic linkages and research trends within a field. In this case, the *full counting method* was implemented, meaning each co-occurrence of keywords was counted equally, regardless of the number of times they appeared in one paper. A minimum threshold of five occurrences was set, reducing the dataset from 2,305 to 287 significant keywords. To ensure meaningful grouping, a minimum cluster size of five was chosen, resulting in eight clusters. This clustering process groups related keywords based on their Total Link Strength (TLS), where stronger connections indicate more frequent co-occurrence and closer thematic association within the literature.

The findings highlight core research foci such as *mathematics education* (251 occurrences), *students* (222), *engineering education* (213), *e-learning* (175), and *mathematics learning* (182), which serve as central nodes in the network. High link strengths (e.g., 1924 for "students") reflected their central role in connecting diverse research themes such as *educational technology*, *STEM*, *mobile learning*, *teaching practices*, and *digital tools*. The generation of

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eight clusters demonstrates the multidimensional nature of the field, covering pedagogical approaches, digital and mobile technologies, STEM integration, and learner-centered outcomes such as motivation and problem-solving. These findings contribute to the body of knowledge by mapping the intellectual structure of technology-enhanced mathematics education, identifying dominant areas of focus, and showing how global trends such as *COVID-19, gamification, digital literacy,* and *AI* are integrated into this evolving research landscape.

***RQ5: How Are Patterns Of International Collaboration Reflected Through Co-Authorship Networks Among Countries?***

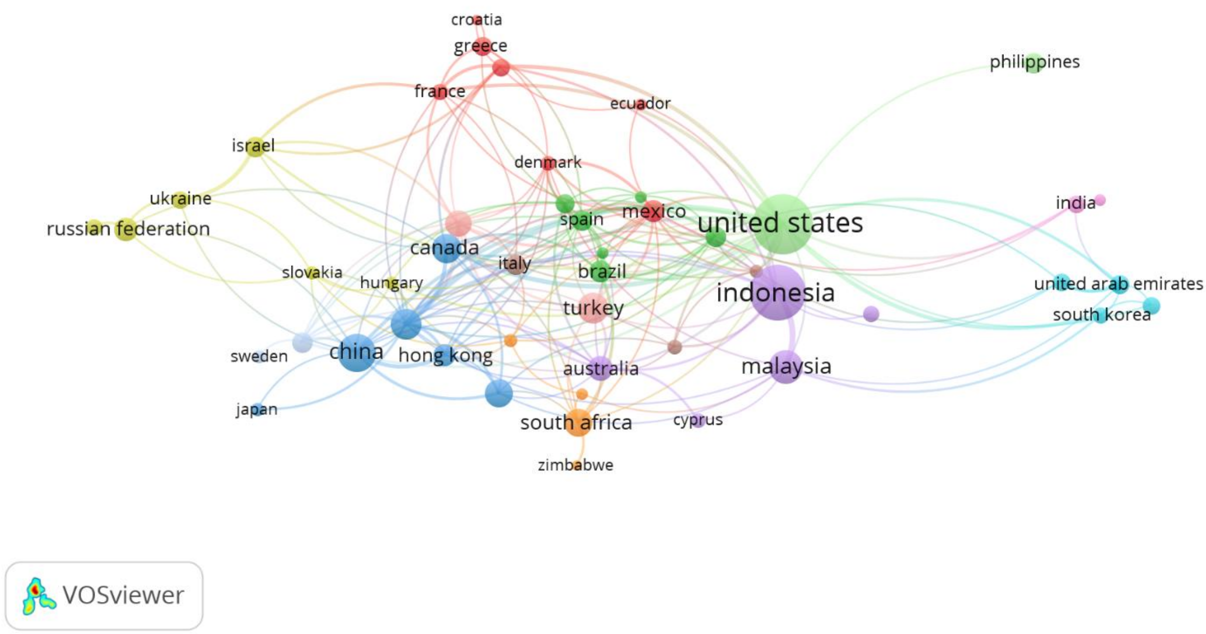


**Figure 5: Network Visualization Map Of Co-Authorship By Countries**
Source: (Scopus, Fri Oct 03 2025)

Co-authorship analysis in VOSviewer maps the collaboration patterns between countries by examining how often researchers from different nations publish together. Using the *full counting method*, each co-authorship link is given equal weight, regardless of how many times authors collaborate in a single paper. In this study, a minimum threshold of five documents was set, reducing the dataset from 102 to 55 active countries. A minimum cluster size of 12 was applied to generate meaningful clusters, resulting in eight clusters. The network visualization produced reveals the most productive countries and the strength of their research collaborations based on TLS.

The findings show that the United States leads both in publications (220 documents) and citations (5,059), highlighting its central role in advancing technology-enhanced mathematics education research and fostering strong international ties (TLS = 75). The United Kingdom, Indonesia, China, Canada, and Germany also emerge as key contributors, with notable collaboration networks. Interestingly, Indonesia ranks second in document output (186) but has lower citations compared to Western counterparts, reflecting its emerging but growing influence in the field. Meanwhile, countries such as Malaysia, Turkey, South Africa, and Taiwan strengthen the global south's representation, emphasizing the widening adoption of digital learning technologies in developing contexts. Overall, these collaboration clusters enrich the body of knowledge by illustrating how global partnerships are shaping research directions, balancing contributions between developed and developing nations, and highlighting the internationalization of technology-enhanced mathematics education.

## Conclusion

This bibliometric analysis set out to explore the evolution of technology-enhanced techniques for learning mathematics, especially in education, focusing on publication trends, influential works, global contributors, keyword themes, and international collaborations. The findings revealed a steady growth of publications between 2015 and 2025, with notable increases during the COVID-19 pandemic years, reflecting the urgent adoption of digital and online platforms. The analysis of citations showed that highly impactful articles often extend beyond mathematics education to address broader issues in STEM, inclusivity, and equity. This suggests that studies connecting technology with wider educational and social challenges attract stronger academic attention. The United States and Indonesia emerged as the most prolific contributors, while countries such as China, Malaysia, Turkey, and the United Kingdom also played central roles, highlighting both developed and developing nations as active participants in shaping this field. Keyword co-occurrence further underscored the interdisciplinary character of this research, with clusters forming around mathematics education, e-learning, STEM integration, and digital innovations.

The research contributes to the body of knowledge by mapping how research in this area has developed and where it is heading. It offers insights for academics, educators, and policymakers seeking to strengthen digital practices in mathematics education. The evidence points to the increasing importance of collaboration across regions, pedagogical adaptability, and the integration of emerging technologies such as mobile learning, gamification, and artificial intelligence. Nonetheless, limitations remain, including reliance on Scopus as a single data source and the exclusion of non-English publications, which may have left out valuable perspectives. Future research could expand the scope by incorporating multiple databases, conducting longitudinal case studies, or examining the practical impact of technological tools in specific higher education contexts. Overall, this study reaffirms the value of bibliometric analysis as a lens for understanding research dynamics, guiding innovation, and fostering global collaboration in the advancement of technology-enhanced mathematics education.

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