

STEM-Based Mathematics Learning in The Scopus Database: A Bibliometric Study and Thematic Analysis Using VOSviewer (2016–2025)

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ABSTRACT

STEM-based mathematics learning has become a widely discussed instructional approach globally, yet mathematics is often marginalized within integrated STEM practice, and bibliometric studies specifically and comprehensively focused on this topic in the Scopus database remain scarce. This study aims to analyze publication growth, publication types and author collaboration, and dominant thematic clusters in STEM-based mathematics learning research. A Systematic Literature Review combined with bibliometric analysis was conducted following the PRISMA 2021 guidelines, applied to 79 Scopus-indexed documents (39 articles and 40 conference papers) published between 2016 and 2025; co-keyword network mapping and thematic clustering were performed using VOSviewer version 1.6.20. Results show that publications increased steadily through the late 2010s, peaked in 2020, and stabilized at a high volume through 2021–2025, reflecting an established and actively maintained research field. Journal articles and conference papers were nearly evenly distributed, concentrated in a small number of physics- and engineering-adjacent venues, indicating regionally bounded rather than tightly networked international collaboration. The co-keyword network revealed technology-mediated curriculum integration as the dominant thematic core, surrounded by teacher preparation, problem-solving, achievement, and affective-factor clusters, while synthesis-level studies remained scarce. These findings offer a strategic reference for identifying under-explored research opportunities in global mathematics education.

Keywords: bibliometric analysis; mathematics education; STEM learning; thematic mapping; VOSviewer

INTRODUCTION

STEM-based mathematics learning (Science, Technology, Engineering, and Mathematics) has become one of the most widely discussed instructional approaches in global education today. Kelley & Knowles (2016) define an integrated STEM approach as the authentic application of STEM knowledge and practices in real-world situations, in which mathematics, science, technology, and engineering are interconnected like a pulley system working together. Within this framework, mathematics is not merely a supporting tool but the core that links the four disciplines. English (2023) emphasizes that mathematical thinking skills, including critical mathematical modeling, systems thinking, and design-based thinking, are indispensable components of STEM-based problem solving. Unfortunately, in practice,

the role of mathematics is often marginalized within integrated STEM activities in the classroom (English, 2023; Maass et al., 2019).

Attention to STEM-based mathematics learning has increased significantly over the past two decades. Various studies show that integrating STEM into mathematics learning can enhance students' critical thinking, learning motivation, and problem-solving skills (Kelley & Knowles, 2016). Meta-analytic studies conducted by various researchers have also demonstrated that STEM education has a moderate to significant effect on student learning outcomes across educational levels (Bong & Chen, 2024). The growth of this body of literature reflects how the international research community views the STEM approach as one response to the challenges of 21st-century mathematics education, including students' low interest in mathematics and the limited relevance of content to real life.

The Scopus database is a highly relevant data source for mapping this research trend on a global scale. As one of the world's largest scientific databases, covering more than 25,000 journals from hundreds of countries, Scopus enables analyses that are international and cross-disciplinary in scope (Donthu et al., 2021). Several previous bibliometric studies have examined related topics, such as mapping STEM education in general (Aboudahr et al., 2024), trend analysis of mathematics education and technology (Aurora Navarro-Ibarra et al., 2025), and studies of STEM and STEAM within the context of mathematics (Chehlarova et al., 2025). However, no bibliometric study has yet focused specifically and comprehensively on STEM-based mathematics learning in the Scopus database in an up-to-date manner.

Several related bibliometric studies have been conducted, but with different scopes and foci. (Maqruf et al., 2025) carried out a bibliometric analysis of mathematics within STEM education studies broadly, using 1,296 documents from Scopus, but did not specifically focus on the learning aspect within the context of mathematics. Aboudahr et al. (2024) mapped the global landscape of STEM education using Scopus, but their study covered all STEM disciplines without an in-depth focus on mathematics. Meanwhile, the study by Portillo-Blanco et al. (2024) focused systematically on interdisciplinary mathematics education, but did not employ a Scopus-based bibliometric approach. This gap indicates the need for a more focused and comprehensive study of research trends in STEM-based mathematics learning from a global bibliometric perspective.

The novelty of this study lies in its specific focus on the evolution of research on STEM-based mathematics learning in the Scopus database over the past decade (2016–2025), as well as its use of VOSViewer to identify dominant thematic clusters within international collaboration networks. The objectives of this study are to: (1) analyze the development of the number of publications on STEM-based mathematics learning in the Scopus database; (2) identify the types of publications and author collaborations in this field; and (3) identify the dominant thematic clusters in this body of research using VOSViewer-based co-keyword analysis. The results of this study are expected to serve as a strategic reference for mathematics education researchers, particularly in identifying research opportunities that remain open at the global level.

RESEARCH METHODS

This study uses a Systematic Literature Review (SLR) approach combined with bibliometric analysis. The guideline used for the literature selection process is the latest version of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), developed by Page et al. (2021). The PRISMA approach was chosen because it provides a systematic, transparent, and replicable reporting

standard, so that the literature selection and analysis process can be scientifically accounted for. For network mapping and thematic clustering, the analysis was carried out using VOSViewer version 1.6.20, which enables interactive visualization of co-keyword networks.

The literature selection process followed the four main stages of PRISMA: identification, screening, eligibility, and inclusion. At the identification stage, the search was conducted in the Scopus database using the main keywords 'STEM' and 'mathematics learning' applied to the title and keyword fields. The search was limited to the 2016–2025 period in order to obtain a picture of the trend over the past decade, which is most relevant to the current state of global research. All initial records obtained were then recorded, including the identification of duplicates, with the assistance of Publish or Perish (Harzing, 2007) and Microsoft Excel.

At the screening stage, records deemed irrelevant based on title and abstract were filtered out and removed from the list. Documents unrelated to the topic of mathematics learning within a STEM context were considered irrelevant and excluded from further analysis. Subsequently, at the eligibility stage, documents were further verified based on their full text against the following inclusion criteria: (1) document type is article or conference paper; (2) included within the subject areas of Social Sciences and Mathematics; and (3) containing key phrases related to STEM-based mathematics learning in the title or keywords. Documents that did not meet one or more of these criteria were excluded at this stage.

At the inclusion stage, documents that passed all inclusion criteria were entered into the final analysis. The document selection flow is visualized through the PRISMA flow diagram, following the recommendations of Page et al. (2021), as shown in Figure 1. Based on the initial search of the Scopus database using the keywords 'STEM' and 'mathematics learning' in the title and keyword fields for the 2016–2025 period, 104 documents were obtained. After filtering the documents by document type, retaining only articles and conference papers, and aligning them with the subject area criteria of Social Sciences and Mathematics, 79 documents were obtained that met the requirements for further analysis.

The bibliometric data from the 79 selected documents were then exported from Scopus in .csv format for further analysis using VOSViewer. Three main types of analysis were carried out: (1) analysis of the development of the number of publications per year; (2) analysis of author collaboration and country of origin distribution; and (3) identification of dominant thematic clusters based on the co-keyword network. The results of this analysis were then interpreted descriptively to depict the global research landscape of STEM-based mathematics learning.

RESULT AND DISCUSSION

Publication Growth and Citation Trends

The bibliometric dataset compiled from the Scopus database encompasses a total of 79 documents (comprising 39 journal articles and 40 conference papers) published between 2016 and 2025 on the subject of STEM-based mathematics learning. This corpus, although selective by virtue of the eligibility criteria applied during the document screening process, constitutes a representative and analytically tractable sample of the indexed scholarly output on this topic within the defined period. The annual distribution of these publications, presented in Table 1, reveals a trajectory that is neither linear nor arbitrary: it reflects the developmental arc of an emerging interdisciplinary field as it transitions from nascent interest to institutionalised scholarly attention.

Publication output was minimal at the outset of the observation window, with only one document indexed in 2016. This figure should not be interpreted as evidence that scholarly engagement with STEM-based mathematics learning was absent prior to this point; rather, it reflects the specificity of the search terms employed ('STEM' AND 'Mathematics Learning' in title and keyword fields) and the natural indexing lag that characterises early-stage research domains before they acquire dedicated terminological conventions in the academic literature. By 2017, output had grown to five documents, including two of the corpus's most highly cited contributions (Chalmers et al., 2017; Sahin et al., 2017), each of which achieved more than 80 total citations, suggesting that the conceptual groundwork for the field was being established by a small cohort of theoretically ambitious scholars working largely independently across different national contexts.

The period from 2019 to 2023 represents the field's most productive phase, with annual document counts ranging from 7 to 13. The most notable single-year surge occurred in 2020, which produced 13 documents and the highest annual citation aggregate in the corpus (232 citations). This convergence of high production and immediate scholarly impact in 2020 is analytically significant and is most plausibly explained by two concurrent forces: first, the organic momentum of a maturing research domain that had, by 2019, accumulated a sufficient critical mass of scholars, dedicated journal spaces, and conference venues to sustain elevated output; and second, the exogenous stimulus provided by the COVID-19 pandemic, which from early 2020 compelled educators and researchers globally to explore technology-mediated, project-based, and integrated learning models with renewed urgency (OECD, 2020). STEM-based approaches, intrinsically oriented toward applied, collaborative, and contextualised learning, aligned closely with the pedagogical demands of emergency remote instruction, likely accelerating both the production of new scholarship and its immediate uptake by practitioners seeking evidence-based alternatives to conventional classroom delivery.

Following the 2020 peak, publication output stabilised rather than declined, averaging 10.7 documents per year across 2021–2025. This stabilisation pattern is a bibliometrically significant indicator: fields characterised by transient scholarly enthusiasm typically display sharp post-peak contractions in output, while fields that have achieved structural embedding, through the establishment of dedicated journal sections, recurring conference tracks, funded research programmes, and graduate curricula, sustain high production over time. The consistent output across the most recent quinquennium (2021–2025, $n = 50$ documents, 63.3% of the total corpus), therefore, provides affirmative evidence that STEM-based mathematics learning has crossed the threshold from emergent focus to established subfield, with a self-reproducing community of practice capable of generating sustained scholarly output independently of any single catalytic event.

The cumulative citation count for the 79-document corpus stands at 979, yielding an overall average of 12.4 citations per document. This average, however, masks pronounced distributional skewness: the ten most highly cited articles collectively account for 622 citations (63.5% of the total), while the lower half of the citation distribution (40 documents) contributes a combined total of only 64 citations (6.5% of the total). Such concentration is consistent with the Lotka–Matthew distribution that characterises citation patterns in most academic fields (Merton, 1968), wherein a small number of foundational or theoretically generative contributions attract disproportionate citational recognition. For the purposes of this analysis, the observed distribution further justifies the analytical primacy accorded to the ten most-cited

articles in Next Section. Importantly, the markedly lower average citations per document recorded for 2024 (1.9) and 2025 (1.6) should not be read as evidence of declining scholarly quality or impact; rather, these values reflect the fundamental recency bias of citation-based impact metrics, wherein publications require a minimum temporal window, typically three to five years, to accumulate a citation record commensurate with their eventual scholarly influence (Hirsch, 2005).

Table 1 Annual distribution of publications and total citations on STEM-based mathematics learning (2016–2025)

Year	Documents (n)	Total Citations	Avg. Cites per Doc	Cumulative Documents	Cumulative Citations
2016	1	64	64.0	1	64
2017	5	215	43.0	6	279
2018	3	16	5.3	9	295
2019	7	91	13.0	16	386
2020	13	232	17.8	29	618
2021	12	139	11.6	41	757
2022	9	57	6.3	50	814
2023	12	136	11.3	62	950
2024	8	15	1.9	70	965
2025	9	14	1.6	79	979
Total	79	979	12.4	—	—

The Ten Most-Cited Articles

The ten most-cited articles in Table 2 show the main ideas that have shaped research on STEM-based mathematics learning. These studies are important because later researchers have used them as theoretical, methodological, or empirical references. Their topics, methods, and citation patterns also show the major research interests in this field since 2016.

The most-cited article is Chalmers et al. (2017), with 99 citations and an annual citation rate of 11.0 over nine years. The study introduces the concept of “big ideas” as a framework for integrating STEM teaching and learning. It addresses an important challenge: how to integrate different STEM disciplines without allowing one discipline to dominate the others. The high number of citations shows that this issue remains important. Later studies have used the article as a reference for theoretical frameworks, curriculum development, and policy discussions. This continued use suggests that the article has become an important foundation for research on STEM integration.

Apkarian et al. (2021) has the highest annual citation rate, with 17.8 citations per year and 89 total citations in five years. The study examines factors that influence university instructors' use of active learning in chemistry, mathematics, and physics. Its main finding is that institutional culture, peer influence, and administrative support are stronger predictors of active learning adoption than individual teaching beliefs alone. The high citation rate indicates that the findings are useful for researchers and

policymakers seeking to implement STEM teaching reforms. Its position as the second most-cited article also shows the growing interest in higher education and in the practical implementation of teaching innovations.

Another important group of highly cited studies focuses on the affective and psychological aspects of STEM mathematics learning. Rozgonjuk et al. (2020) received 88 citations, with an annual rate of 14.67. The study examines mathematics anxiety, self-efficacy, and learning approaches among university students in STEM and social science. The main finding is that students' learning approaches influence the relationship between mathematics anxiety and self-efficacy. Students who use deeper learning approaches show stronger self-efficacy that can help buffer mathematics anxiety. This finding suggests that STEM mathematics instruction should encourage deeper learning rather than only surface-level task completion.

Sahin et al. (2017), with 82 citations, examines STEM mathematics experiences during high school and their relationship with students' self-efficacy in college. The longitudinal findings show that the quality of earlier STEM mathematics experiences predicts later self-efficacy. This supports the view that students' early experiences with STEM mathematics can influence their later STEM identity and educational or career choices.

The third major theme concerns pedagogical strategies, particularly project-based learning. Han et al. (2016) is the only article from the first year of the observation period. It provides early evidence that STEM project-based learning can significantly improve student achievement across four mathematics topics. This finding has been used by later researchers to support the design of STEM project-based learning interventions.

Chai et al. (2020) received 70 citations and focuses on teacher preparation. The study examines Indonesian preservice teachers' design-based learning experiences through a STEM-TPACK framework. Its contribution is the connection between teacher education and technology integration. The study has therefore provided a useful foundation for research on STEM teacher preparation.

Gil-Doménech and Berbegal-Mirabent (2019) received 46 citations and focuses on students in non-STEM programmes who are still required to study mathematics. The study finds that game-based learning can improve students' engagement and performance. This finding challenges the assumption that STEM-integrated mathematics approaches are only useful for students in STEM programmes. It also has implications for mathematics curriculum design for non-STEM students.

The presence of Tytler et al. (2023) and Ting et al. (2023) in the top ten is also important because both were published near the end of the observation period. Tytler et al. has an annual citation rate of 9.33, while Ting et al. has a rate of 8.33. These rates are relatively high compared with many older studies, suggesting that both studies address current research needs.

Tytler et al. (2023) examines the opportunities and challenges of integrated STEM for mathematics learning. Compared with earlier studies that often emphasized the benefits of STEM integration, this study takes a more critical perspective. Ting et al. (2023) provides a meta-analysis of active learning effects among Asian students in STEM contexts. Together, these studies suggest that research in this field is becoming more mature. Researchers are increasingly moving beyond the question of whether STEM integration works and examining for whom it works, under what conditions, and in which cultural and institutional contexts.

Table 2 Ten most-cited articles on STEM-based mathematics learning indexed in Scopus (2016–2025)

Rank	Author(s)	Title	Year	Source	Cites	CPY
1	Chalmers et al.	Implementing "Big Ideas" to Advance the Teaching and Learning of Science, Technology, Engineering, and Mathematics (STEM)	2017	Int. J. Science and Mathematics Education	99	11.00
2	Apkarian et al.	What really impacts the use of active learning in undergraduate STEM education? Results from a national survey of chemistry, mathematics, and physics instructors	2021	PLOS ONE	89	17.80
3	Rozgonjuk et al.	Mathematics anxiety among STEM and social sciences students: the roles of mathematics self-efficacy, and deep and surface approach to learning	2020	Int. J. STEM Education	88	14.67
4	Sahin et al.	The relationships among high school STEM learning experiences, expectations, and mathematics and science efficacy and the likelihood of majoring in STEM in college	2017	Int. J. Science Education	82	9.11
5	Chai et al.	Indonesian science, mathematics, and engineering preservice teachers' experiences in STEM-TPACK design-based learning	2020	Sustainability Switzerland	70	11.67
6	Han et al.	The effect of Science, Technology, Engineering and Mathematics (STEM) project-based learning (PBL) on students' achievement in four mathematics topics	2016	J. Turkish Science Education	64	6.40
7	Gil-Doménech & Berbegal-Mirabent	Stimulating students' engagement in mathematics courses in non-STEM academic programmes: A game-based learning approach	2019	Innovations in Education and Teaching Int.	46	6.57
8	Fajrina et al..	Science, technology, engineering, and mathematics (STEM) as a learning approach to improve 21st century skills: A review	2020	Int. J. Online and Biomedical Engineering	31	5.17
9	Tytler et al.	Exploring a framework for integrated STEM: challenges and benefits for promoting engagement in learning mathematics	2023	ZDM Mathematics Education	28	9.33
10	Ting et al.	A meta-analysis of studies on the effects of active learning on Asian students' performance in Science, Technology, Engineering and Mathematics (STEM) subjects	2023	Asia Pacific Education Researcher	25	8.33

Research Topic Distribution

Beyond the ten most-cited articles, the 79 documents were examined to identify the main research themes. Table 3 groups the documents into ten topic clusters based on keyword analysis of article titles and the full bibliometric record. These clusters are not mutually exclusive. One article can belong to more than one theme. For example,

an article may examine problem-solving through project-based learning. Therefore, the percentages show the proportion of documents addressing each theme, not separate groups of documents.

The largest topic cluster is Technology and Digital Integration, with 42 documents (53.2%). This result shows the strong role of technology in STEM-based mathematics learning. Technology is used not only as a teaching aid but also as a way to connect mathematics with science and engineering. The studies cover a wide range of topics, including TPACK for STEM teacher preparation, GeoGebra in secondary mathematics, computational thinking, and digital simulations for mathematical modelling. The large number of technology-focused studies may also be related to the high number of conference papers in the corpus. Technology research is often presented at conferences to obtain early feedback on new implementations.

The next major clusters are Curriculum and Integration Framework, with 20 documents (25.3%), and Teacher Education and Preparation, with 19 documents (24.1%). Their similar proportions show that researchers pay attention to both curriculum development and teacher preparation. This suggests that successful STEM integration requires both appropriate curriculum design and teachers who are prepared to implement it. The relatively high proportion of teacher education studies also reflects the importance of teacher knowledge, pedagogical skills, and readiness in implementing STEM curricula (Remillard, 2005).

Problem-Solving and Thinking Skills includes 16 documents (20.3%), while Student Achievement and Performance includes 11 documents (13.9%). Together, these themes represent an important empirical focus of the corpus because they examine measurable student outcomes. However, achievement-focused research accounts for only 13.9% of the documents, compared with 53.2% for technology and digital integration. This difference suggests that the field has more research on technology and instructional design than on rigorous measurement of learning outcomes. This gap may limit the available evidence for evaluating the effectiveness of STEM integration.

The Affective Factors cluster includes 10 documents (12.7%). This theme focuses on psychological and emotional aspects of STEM mathematics learning, such as mathematics anxiety and self-efficacy. It extends the focus found in studies such as Rozgonjuk et al. (2020). The 21st Century Skills cluster includes 11 documents (13.9%) and connects STEM mathematics learning with skills such as critical thinking, collaboration, communication, and other competencies emphasized in contemporary education.

The smaller clusters are Active and Game-Based Learning, with 5 documents (6.3%), and Meta-Analysis and Systematic Review, with 3 documents (3.8%). The small number of systematic reviews is particularly important. Only three documents provide this type of evidence, indicating that the field still has limited research that combines findings across studies, contexts, and methods.

Ting et al. (2023) is an important contribution to this area because it provides a meta-analysis of active learning in Asian STEM contexts. However, the limited number of systematic reviews suggests that the field may not yet have enough comparable primary studies for broader quantitative synthesis. This finding indicates that the field is still developing and that future research should place greater emphasis on systematic reviews, meta-analyses, and stronger evidence of learning outcomes.

Table 3 Ten most-cited articles on STEM-based mathematics learning indexed in Scopus (2016–2025)

Research Topic Cluster	Documents (n)	Percentage (%)	Representative Titles / Scope
Technology & Digital Integration	42	53.2	STEM-TPACK, GeoGebra, computational thinking, digital tools in mathematics instruction
Curriculum & Integration Framework	20	25.3	Integrated STEM curriculum design, Big Ideas framework, cross-disciplinary scope and sequence
Teacher Education & Preparation	19	24.1	Preservice and in-service teacher development, pedagogical content knowledge in STEM
Problem-Solving & Thinking Skills	16	20.3	Analytical thinking, critical reasoning, mathematical problem-solving within STEM contexts
Student Achievement & Performance	11	13.9	Test scores, mathematics outcomes, academic achievement under STEM interventions
21st Century Skills & Literacy	11	13.9	STEM literacy, scientific reasoning, communication, collaboration, creativity
Project-Based Learning (PBL)	10	12.7	STEM-PBL design and implementation, interdisciplinary project outcomes
Affective Factors (Anxiety, Self-Efficacy)	10	12.7	Mathematics anxiety, self-efficacy beliefs, motivation, engagement under STEM approaches
Active & Game-Based Learning	5	6.3	Game-based mathematics, inquiry-based STEM, active learning strategies
Meta-Analysis & Systematic Review	3	3.8	Systematic evidence synthesis of STEM mathematics intervention effects

Country of Origin Distribution and the Global Knowledge Landscape

The geographic analysis in Table 4 shows a strong concentration of research in Indonesia. Indonesia contributes 36 of the 79 documents (45.6%), making it the largest contributor in the corpus. This result can be explained by three factors: Indonesia's academic publication system, the country's strong policy interest in STEM education, and the search criteria used in this study.

One important factor is the SINTA (Science and Technology Index) system in Indonesia. Scopus-indexed conference papers are recognised alongside journal articles for academic promotion and institutional ranking. This creates a strong incentive for Indonesian researchers to publish in conference proceedings. The concentration is particularly clear because 23 of Indonesia's 36 documents (63.9%) were published in the *Journal of Physics Conference Series*. Therefore, the high number of Indonesian publications is partly related to the country's academic publication system.

However, the high number of Indonesian publications should not be interpreted as only a result of publication incentives. STEM mathematics learning is also an important educational issue in Indonesia. The country has approximately 50 million students in more than 250,000 schools, while Indonesian mathematics achievement

has remained below the OECD average in several PISA cycles (OECD, 2023). In addition, the Merdeka Belajar curriculum reform promotes STEM-based and project-oriented learning. These conditions have increased the importance of STEM mathematics research in Indonesia. Indonesian contributions therefore reflect both national educational needs and institutional publication incentives.

The United States is the second-largest contributor, with 9 documents (11.4%). American studies cover several topics, including active learning in higher education, mathematical identity and equity, informal STEM learning, game-based learning, and computational mathematics. Although the United States contributes fewer documents than Indonesia, its studies have a higher average citation impact. The mean citation count is approximately 18.7 for U.S. contributions compared with 5.3 for Indonesian contributions. This suggests that Indonesia has a larger publication volume, while U.S. research has greater citation influence.

Malaysia contributes 6 documents (7.6%), while the Philippines contributes 4 documents (5.1%). Together with Indonesia, Thailand, and Vietnam, these countries account for 49 documents (62.0%) of the corpus. Malaysian studies mainly focus on teacher preparation and technology-based mathematics instruction. Philippine studies mainly examine STEM project-based learning at the senior high school level. These patterns are consistent with the STEM education priorities in both countries.

The remaining 18 countries contribute between one and two documents each, with a total of 27 documents (34.2%). These countries represent regions including Europe, East Asia, Africa, the Middle East, and Oceania. Countries such as Estonia, Jordan, Vietnam, Pakistan, and the United Arab Emirates show that STEM-based mathematics learning is studied in different parts of the world.

However, research outside Southeast Asia and North America remains limited. Europe, Latin America, sub-Saharan Africa, and South Asia are particularly underrepresented in the corpus. This geographic imbalance means that the existing literature may not fully represent the different educational conditions found around the world. Differences in teacher training, class size, resources, curriculum autonomy, and cultural views of mathematics may influence how STEM-based mathematics learning is implemented.

Overall, the geographic findings show that Southeast Asia, especially Indonesia, dominates the corpus in publication volume, while the United States has a stronger average citation impact. The limited representation of many other regions indicates a need for more research from underrepresented countries. Greater international collaboration could also help produce evidence that is more applicable across different educational contexts.

Table 4 Research topic cluster distribution across the STEM-based mathematics learning corpus (2016–2025)

Country	Documents (n)	Percentage (%)	Thematic Orientation and Publication Context
Indonesia	36	45.6	Largest contributor; predominantly conference papers (J. Physics Conf. Series, AIP); themes: STEM-PBL, mathematical reasoning, local context integration
United States	9	11.4	Diverse themes: active learning, identity, equity, informal STEM environments, undergraduate mathematics
Malaysia	6	7.6	Teacher preparation, TPACK integration, GeoGebra-assisted and technology-mediated mathematics learning

Country	Documents (n)	Percentage (%)	Thematic Orientation and Publication Context
Philippines	4	5.1	STEM-PBL frameworks, mathematics achievement, senior high school curriculum implementation
Australia	2	2.5	Integrated STEM curriculum frameworks, informal STEM learning environments, curriculum coherence
Singapore	2	2.5	Computational thinking, design-based learning, mathematical reasoning in technology contexts
South Korea	2	2.5	STEM motivation, student achievement, project-based learning outcomes
Turkey	2	2.5	STEM learning environments, pre-service teacher education, STEM dispositions
Germany	2	2.5	Project-based learning integration, course design outcomes, higher education contexts
South Africa	2	2.5	Interdisciplinary mathematics teaching, secondary school performance, teacher development
Estonia	1	1.3	Mathematics anxiety and self-efficacy in STEM learning contexts
Spain	1	1.3	Game-based learning approaches in non-STEM academic programmes
United Kingdom	1	1.3	STEM learning environments and informal educational settings
Croatia	1	1.3	Interdisciplinary STEM integration and teacher collaboration
China	1	1.3	Active learning strategies and STEM mathematics performance outcomes
Canada	1	1.3	Curriculum frameworks for integrated STEM mathematics education
Egypt	1	1.3	STEM-based mathematics instruction in secondary school contexts
Thailand	1	1.3	Analytical thinking development through STEM-integrated science and mathematics
Pakistan	1	1.3	STEM learning and mathematics engagement in higher education
Vietnam	1	1.3	STEM approaches to mathematics problem-solving and student outcomes
Jordan	1	1.3	Technology-integrated mathematics learning in secondary school contexts
United Arab Emirates	1	1.3	STEM education in multicultural and multilingual classroom contexts
Total	79	100.0	22 countries across 5 continents; Southeast/East Asia = 52 docs (65.8%)

Bibliometric Network Analysis with VOSviewer

To complement the citation- and topic-based analysis in all sections, a co-occurrence network of author keywords/title terms was generated in VOSviewer from the finalized bibliographic dataset (N = 79 documents: 39 articles, 49.4%, and 40 conference papers, 50.6%), matching exactly the corpus reported in Section Publication Growth and Citation Trends. Three complementary visualizations were produced: a network map (Figure 1), a temporal overlay map (Figure 2), and a density map (Figure 3).

Network Structure

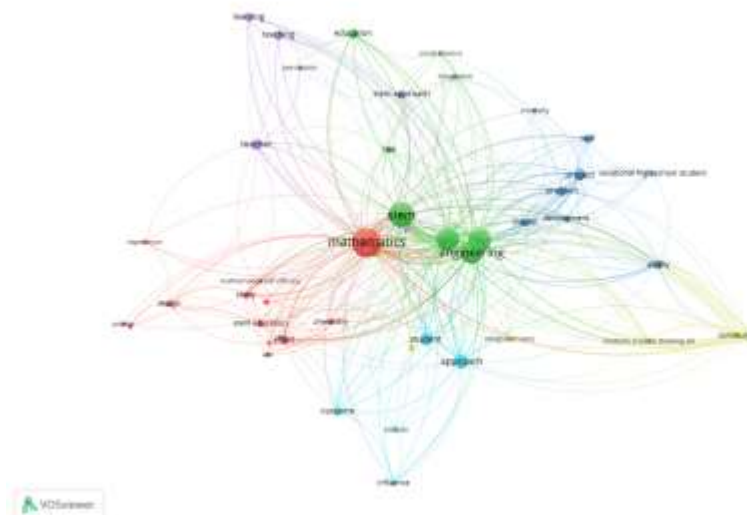


Figure 1 Network visualization of co-occurring keywords (cluster colour = thematic group; node size = occurrence frequency)

Three dominant, large nodes anchor the network: “mathematics”, “stem”, and “engineering”, confirming numerically what Table 3 already shows, that Technology and Digital Integration (53.2%) and Curriculum/Integration Framework (25.3%) are the field’s structural core. These three terms sit at the convergence point of the red, green, and blue clusters, indicating that almost no sub-theme in the corpus is discussed independently of disciplinary integration itself. Five clusters emerge: (1) a red cluster (mathematics, mathematics self-efficacy, design, activity, STEM education, effect) reflecting the achievement/affective research strand identified around Rozgonjuk et al. (2020) and Sahin et al. (2017); (2) a green cluster (STEM, engineering, role, STEM approach, education) corresponding to the curriculum-integration literature exemplified Chalmers et al. (2017); (3) a blue cluster (skill, project, problem, model, development, vocational high school student, ability, community) mapping onto the Problem-Solving/21st-Century-Skills clusters in Table 3; (4) a purple cluster (learning, teaching, perception, teacher) aligning with Teacher Education and Preparation (24.1%); and (5) a cyan cluster (student, approach, outcome, attitude, influence, integrated STEM) corresponding to Student Achievement and Performance and Affective Factors. The thin, peripheral placement of “meta-analysis”-adjacent terms (absent altogether as a labelled node) is consistent with the very small Meta-Analysis/Systematic Review cluster (3.8%) reported in Section Research Topic Distribution.

Temporal Evolution

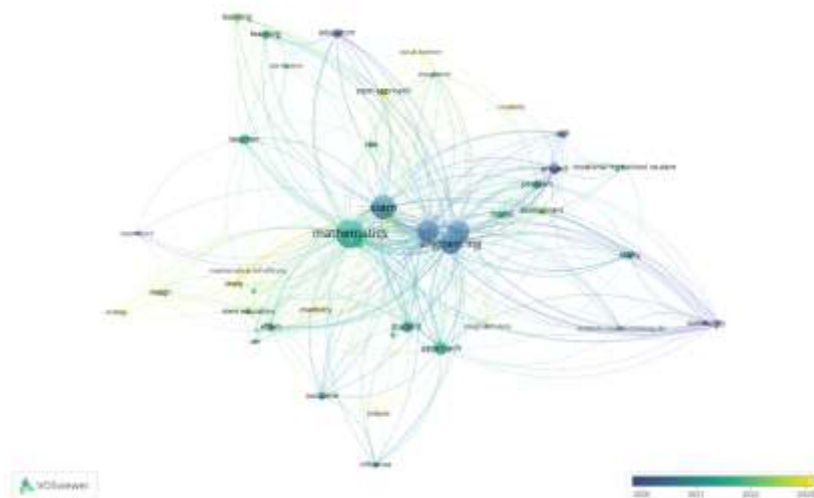


Figure 2 Overlay visualization showing the average publication year per term (blue = earlier, c. 2020; yellow = later, c. 2023)

The overlay map shows “community”, “integrated stem”, and “students’ creative thinking skills” shading toward yellow (2022–2023), while “mathematics”, “stem”, and “engineering” remain a darker blue-green (c. 2020–2021), reflecting their role as persistent, foundational terms rather than emerging ones. This pattern is fully consistent with the publication-growth narrative in Section The Ten Most-Cited Articles: the 2020 production/citation peak ($n = 13$, 232 citations) is dominated by core integration vocabulary, while the post-2021 stabilisation phase ($n = 50$ documents, 63.3% of the corpus) is where more specific, applied terms (creative thinking, community-based and integrated STEM approaches) gain prominence. This mirrors the shift documented for Tytler et al. (2023) and Ting et al. (2023) in Section The Ten Most-Cited Articles, whose work moved the field from “whether STEM integration works” toward “for whom and under what conditions.”

Density concentration

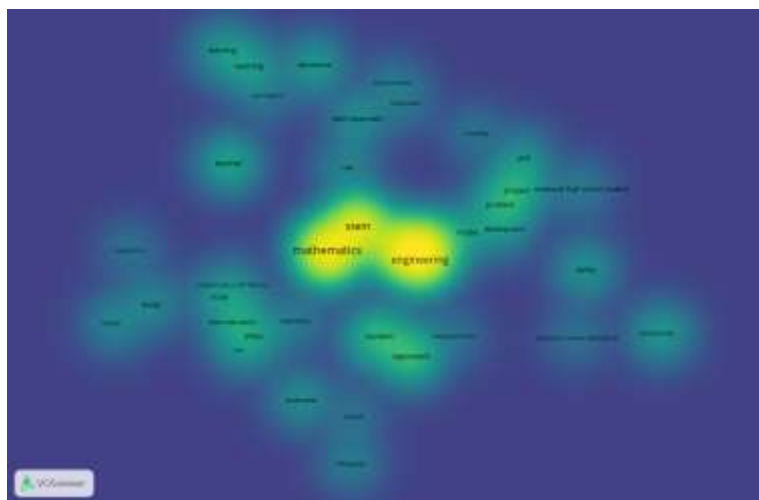


Figure 3 Density visualization of keyword concentration (yellow = highest density)

The density map shows a single dominant yellow zone centred on “mathematics–STEM–engineering,” with all other terms (teacher, student, community, approach, outcome) appearing as smaller, isolated green islands against a low-density blue background. This visual pattern numerically reproduces the source-concentration finding in Section Country of Origin Distribution and the Global Knowledge Landscape: three conference-affiliated venues (Journal of Physics Conference Series, AIP Conference Proceedings, and the 2025 ISTEM-Ed proceedings) account for 43.0% of the corpus, producing a narrow vocabulary band dominated by applied STEM-engineering-mathematics terminology typical of physics-education-adjacent conference publishing rather than a more dispersed, specialised mathematics-education lexicon. The sparse density elsewhere reinforces the conclusion that thematic diversification (e.g., affective, meta-analytic, cross-national strands) remains comparatively underdeveloped relative to the technology-integration core

Discussion

Synthesizing all 79 documents against the VOSviewer maps confirms a technology-anchored, integration-focused field with a thin empirical/synthesis core. Documents are grouped below by the same nine clusters as Table 3 (clusters overlap, so totals exceed 79).

Technology & Digital Integration (≈53%): largest cluster, matching the dominant mathematics–STEM–engineering hub in Figure 1: GeoGebra (MD-Ali & Kim, 2018), e-modules (Hadiyanti et al., 2021), AR (Li et al., 2025), IoT (Habib et al., 2021), programming/computational thinking (Namukasa et al., 2023; Ng et al., 2023; Park & Manley, 2024), plus a large Indonesian classroom-technology sub-group (E. Dewi et al., 2024; Firdaus et al., 2020; Guntur et al., 2025; Ilyas et al., 2022; Malik et al., 2024; Manis et al., 2021; Milaturrahmah et al., 2017b, 2017a; Mohamed Elsayed, 2022; Montana et al., 2025; Rohendi et al., 2023; Rohmah et al., 2023; Rudiansyah & Utama, 2024; Susanti et al., 2023; Utami & Nurlaela, 2021; Werdiningsih et al., 2019; Yuniar et al., 2020).

Curriculum & Integration Frameworks (≈23%) in theoretical backbone (Makonye & Moodley, 2023; Ng et al., 2023; Scholkmann et al., 2023; Tytler et al., 2023); applied studies (Adikayanti & Retnawati, 2022; Bao et al., 2019; Hussin et al., 2019; Purwaningsih et al., 2020; Saputri et al., 2022; Susilowati et al., 2020); newer framings (Belcher et al., 2025; Elliott et al., 2023; Erenia & Sarmiento, 2025; Forawi, 2018; Mohktar et al., 2025).

Teacher Education & Preparation (≈16%): (Alsalhi et al., 2022; Chai et al., 2020; E. Dewi et al., 2024; Nurkanti et al., 2021; Poonpaiboonpipat, 2021).

Problem-Solving & Thinking Skills (≈15%): (Adikayanti & Retnawati, 2022; Guntur et al., 2025; İnal & Ergen, 2025; Insani et al., 2021; Ng et al., 2023; Ningrum et al., 2020; Pasaribu & Suyanto, 2020; Purwaningsih et al., 2020; Saputri et al., 2022; Yuniar et al., 2020).

Student Achievement & Performance (≈19%): Han et al. (2016) and Von Solms & Nel (2017) as early evidence; extended by Hadiyanti et al. (2021), N. R. Dewi & Maulida (2023), Mohamed Elsayed (2022), Ilyas et al. (2022), Han et al. (2016), Han et al. (2016), and Ting et al. (2023) meta-analytic synthesis, plus Utami & Nurlaela (2021), Manis et al. (2021), Insani et al. (2021), Andriani et al. (2021).

Affective & Psychological Factors (≈11%): (Hall et al., 2022; Hallarte et al., 2024; Han et al., 2016; İnal & Ergen, 2025; Li et al., 2025; Manis et al., 2021; Mohktar et al., 2025; Morton & Smith-Mutegi, 2022; Rozgonjuk et al., 2020)

21st-Century Skills ($\approx 9\%$) & Active/Game-Based Learning ($\approx 15\%$): (N. R. Dewi & Maulida, 2023; Fajrina et al., 2020; Ghani et al., 2021; Hadiyanti et al., 2021; Hussin et al., 2019; Milaturrehman et al., 2017b; Rohmah et al., 2023); active-learning anchors Apkarian et al. (2021) and Gil-Doménech & Berbegal-Mirabent (2019), with PBL across (Adikayanti & Retnawati, 2022; Han et al., 2016; Hussin et al., 2019; Purwaningsih et al., 2020; Rudiansyah & Sutarna, 2024; Saputri et al., 2022; Von Solms & Nel, 2017; Widiyanti et al., 2020).

Meta-Analysis/Systematic Review ($\approx 5\%$, smallest (Fajrina et al., 2020; Rahmatika et al., 2024; Ting et al., 2023; Wahyuni et al., 2024), a direct methodological precedent for this study, mirroring the near-absent “meta-analysis” node in Figure 1.

Other/Cross-cutting: Chalmers et al. (2017) and Sahin et al. (2017), the field's two most historically influential papers; informal/family learning (Sobel, 2023); teacher perception (Mustam & Adnan, 2019); lesson design (Husna et al., 2020; Winangun & Fauziah, 2019); manipulatives (Hendri et al., 2020; Susanti et al., 2023); teacher criticality (Darmadi, 2022).

Synthesis: Technology, Curriculum, and Teacher Education together account for roughly 90% of the corpus, while rigorous achievement/affective outcome research and synthesis-level scholarship (Rahmatika et al., 2024; Ting et al., 2023; Wahyuni et al., 2024) remain comparatively thin, the field's clearest priority for future consolidation. Secara garis besar, simpulkan isi dalam artikel dengan jelas. Kesimpulan merupakan ringkasan padat atas paragraf-paragraf sebelumnya dengan tidak membangun ide baru di luar paragraf isi.

CONCLUSION

This study mapped STEM-based mathematics learning research through three lenses, each answered by the evidence above. Publication growth shows emergence followed by consolidation: steady rise through the late 2010s, a peak in 2020, and stabilization at a high but no-longer-accelerating volume through 2021–2025, indicating an established, actively maintained field rather than a passing trend. Publication types and collaboration patterns reveal a near-even article/conference-paper split concentrated in a small number of physics- and engineering-adjacent venues, suggesting knowledge production driven more by parallel, regionally bounded efforts than by a tight international network which explains the field's comparatively narrow thematic vocabulary despite its size. Dominant thematic clusters converge unambiguously on technology-mediated curriculum integration as the structural core, with teacher preparation, problem-solving, achievement, affective factors, and active-learning clusters orbiting it; this core has been stable since the field's earliest years, while synthesis-level work (meta-analyses, systematic reviews) remains the smallest, most peripheral cluster.

Theoretically, the field remains organized around demonstrating that STEM-mathematics integration is feasible and beneficial, rather than explaining the mechanisms or conditions that make it effective. Practically, this implies more guidance currently exists on how to design STEM-mathematics activities than on which design choices reliably improve outcomes. For researchers, the results point to under-served opportunities in cross-national collaboration, mathematics-specific reasoning constructs distinct from general STEM literacy, and systematic or meta-analytic synthesis to consolidate the field's large but fragmented evidence base.

This study is limited by its reliance on title-level co-keyword analysis rather than full-text or abstract-based coding, since abstract data were unavailable, which may understate thematic richness or occasionally misclassify documents. The corpus was

also drawn from a single database within a defined 2016–2025 window, and citation-based indicators inherently favor older publications, potentially understating the eventual influence of the most recent (2023–2025) contributions. Future work would benefit from full-text thematic coding, multi-database triangulation, and periodic replication as the field's synthesis-level scholarship matures.

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