Arrifadah, Y., & Suliani, M. (2026). Mathematical Communication in Mathematics Education: Productivity, Impact, and Emerging Themes from a Bibliometric Perspective. *Journal of Research in Science and Mathematics Education , 5*(1), 43-59.

Original literature review paper https://doi.org/10.56855/jrsme.v5i1.1981

Received: 28 February 2026.
Revised: 04 April 2026.
Accepted: 10 April 2026.

Mathematical Communication in Mathematics Education: Productivity, Impact, and Emerging Themes from a Bibliometric Perspective

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Abstract

Purpose: Mathematical communication is a key competence in mathematics education that supports students' reasoning, conceptual understanding, and problem solving. Despite the growing volume of empirical studies, a systematic overview of research trends and scholarly influence in this field remains limited. **Methodology:** This study aims to map the research landscape of mathematical communication in mathematics education through a bibliometric analysis. A total of 141 English-language journal articles published between 2015 and 2025 were retrieved from the Scopus database and selected following PRISMA guidelines. Bibliometric techniques—including publication and citation analysis, country and institutional performance analysis, and keyword co-occurrence analysis—were conducted using VOSviewer. **Findings:** The results show a steady increase in research output, particularly after 2019, with Indonesia emerging as the most productive country in terms of publication count. **Significance:** Research themes are predominantly centered on instructional strategies, student learning outcomes, problem solving, and mathematical literacy. These findings provide conceptual insights into the evolution of mathematical communication research and inform future theoretical and methodological developments in mathematics education.

Keywords: Mathematical communication; Mathematics education; Bibliometric analysis; Research trends; Citation analysis; Instructional strategies.

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Introduction

Communication plays a pivotal role in the learning process, including in the study of mathematics (Nguyen et al., 2025). In mathematics education, communication has been widely recognized as a central mediator of learning and creativity, as discursive practices enable students to articulate, negotiate, and refine their mathematical ideas (Mercer & Howe, 2012; Sfard, 2008). The National Council of Teachers of Mathematics (NCTM, 2000) explicitly underscores communication as a fundamental component of both mathematics and mathematics education, emphasizing its role in helping students formalize mathematical concepts and strategies (Pantaleon et al., 2023). Moreover, communication provides a crucial medium through which students express their reasoning and convey ideas, both orally and in written form.

Within this context, mathematical communication constitutes a core standard that must be systematically fostered in mathematics education. This standard highlights the importance of students consistently articulating their mathematical thinking in interactions with peers and teachers (Johar et al., 2025). Mathematical communication encompasses the ability to convey, discuss, and critically evaluate mathematical ideas in a clear and effective manner. It involves expressing reasoning, explaining concepts, and actively participating in mathematical discourse, thereby supporting the development of mathematical literacy and problem-solving skills (Ratnaningsih et al., 2024).

Mathematical communication skills refer to students' ability to explain reasoning, represent situations using mathematical models, and clearly express mathematical ideas (Hidayat & Aripin, 2023). The skill of Mathematical Communication is not simply as a means of learning in school, but to enable students as well to affirm, explain, ask questions, and in collaboration to possess a deepened mathematical comprehension. Students have some opportunities to collaborate within group to collect and to present data, to listen of others idea, to discuss together and then is up to a conclusion which becomes an opinion of the group (Rajagukguk et al., 2022). When students communicate their thoughts to others, it can enhance their conceptual understanding, improve problem-solving skills, and correct misconceptions about mathematical concepts (Lee, 2015; Martins & Martinho, 2021).

Mathematical communication is a core competence in mathematics learning, enabling students to articulate, interpret, and negotiate mathematical ideas through oral, written, and visual modes (Sugianto et al., 2025). It encompasses the ability to connect real-world contexts and representations to mathematical ideas; express mathematical relationships using verbal, symbolic, graphical, and algebraic forms; engage in listening, discussion, reading, and writing about mathematics; construct conjectures and arguments; formulate definitions and generalizations; and generate mathematically meaningful questions (Cartwright, 2020). These capacities rely on key sub-skills, including the appropriate use of mathematical language, the clear explanation of ideas, the evaluation of others' reasoning, and the use of logical and coherent discourse (Kaya & Aydın, 2016).

Research on the development of students' mathematical communication skills has grown substantially, with scholars frequently synthesizing journal-published empirical studies through systematic literature reviews, bibliometric and meta-analyses. For instance, Nguyen et al. (2025) conducted a systematic review of mathematical communication skills among high school students. In particular, Hanifah and Rahman (2024) conducted a scoping review of research on mathematical communication in Indonesia. Although mathematical communication has been widely studied in mathematics education, there is still limited bibliometric evidence that maps the intellectual structure, research productivity, and thematic development of this field. A systematic bibliometric analysis is therefore needed to identify dominant research themes, influential contributors, and emerging directions.

In this context, this study aims to conduct a bibliometric analysis of research on mathematical communication in mathematics education by systematically examining publication performance and thematic development within the field. Specifically, the analysis is structured to address the following research questions:

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1. Which journals, authors, and institutions demonstrate the highest levels of productivity and citation impact in research on mathematical communication in mathematics education?
2. What are the dominant research themes identified through title, abstract, and authors' keyword analyses, and how have these themes evolved over time?

Literature Review

A growing body of scholarship situates mathematical communication at the core of mathematical proficiency. Empirical evidence indicates that representation, explanation, argumentation, and presentation are integral dimensions of mathematical communication (Tong et al., 2021). In this regard, mathematical communication extends beyond the mere transmission of information; it entails the expression, interpretation, and critical examination of mathematical ideas through appropriate language, symbols, diagrams, and logically structured reasoning (Pasani & Amelia, 2025). It encompasses students' capacity to articulate ideas coherently in oral discourse, construct and interpret visual representations such as graphs and diagrams, and employ mathematical symbols effectively across spoken, written, and visual modalities to develop and convey meaning (Mujiasih et al., 2021; Epih, 2024).

The National Council of Teachers of Mathematics (NCTM, 2000) positions communication as a fundamental process standard, defining it as the ability to express mathematical ideas through written, verbal, and visual forms. Such competence is reflected in students' understanding of concepts and procedures, their ability to represent and connect ideas across topics, and their capacity to apply mathematics in everyday contexts (Chasanah et al., 2020). Instructionally, the development of mathematical communication is closely linked to teachers' practices, including attentive engagement with students' reasoning, strategic questioning, encouragement of oral and written responses, careful assessment of conceptual depth, and the explicit introduction of appropriate notation (Khadka, 2024). Further elaboration by the National Council of Teachers of Mathematics (NCTM, 2003) identifies key indicators of proficiency: clarity and logical coherence in expressing mathematical thinking, accurate use of mathematical language, systematic organization of ideas, and the capacity to analyze and respond to others' reasoning. Collectively, these perspectives underscore communication as both a medium for learning mathematics and a defining feature of mathematical understanding itself.

Method

This study adopts a bibliometric analysis approach to systematically examine the body of literature on mathematical communication in mathematics education. Bibliometric analysis enables the structured mapping of the publication landscape and the identification of research patterns and gaps that can inform future scholarly inquiry (Chigbu et al., 2023; Li & Hale, 2016). As a quantitative research method, bibliometric analysis applies statistical techniques to published academic records in order to generate meaningful insights into the development and structure of a research field (Yıldız & Körpeoğlu, 2025). By analyzing metadata extracted from scientific publication databases, bibliometric methods facilitate a comprehensive understanding of research trends and scholarly influence (Uğraş, 2025).

In this study, citation analysis, co-occurrence analysis, and co-citation analysis are employed to evaluate research on mathematical communication within mathematics education. Citation analysis is used to identify the most influential publications, authors, and institutions in the field. Co-occurrence analysis examines the dominant research themes and their interrelationships, while co-citation analysis uncovers the intellectual foundations and knowledge structure underpinning mathematical communication research in mathematics education.

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The Process for Selecting Articles

The data for this study were retrieved from the Scopus database, which was selected due to its extensive coverage of high-quality, peer-reviewed academic literature and its widespread use in bibliometric research (Parlina et al., 2020). Scopus also provides comprehensive citation metadata, enabling systematic analyses of citation patterns and collaboration networks across countries and institutions.

Data collection was conducted through an institutional Scopus account. The Scopus search query used the keywords ("mathematical communication" OR "mathematics communication" OR "math communication") in titles, abstracts, and keywords. This initial search yielded 549 documents. To ensure the relevance and quality of the dataset, explicit inclusion and exclusion criteria were applied. The analysis was restricted to publications from the last ten years (2015–2025) and further refined by limiting the results to journal articles, English-language publications, and journal source types. Following this filtering process, 168 documents remained for further screening. A summary of the publication selection criteria is presented in Table 1.

Table 1

Summary of The Criteria for Selecting Publications

Criteria	Value
Data source	Scopus
Search terms	("mathematical communication" OR "mathematics communication" OR "math communication")
Publication periods	2015 to 2025
Source type	Journal
Document type	Article
Language	English
Query strings	TITLE-ABS-KEY ("mathematical communication" OR “mathematics communication” OR “math communication”) AND PUBYEAR > 2014 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English"))
Result	A total of 549 journal articles related to mathematical communication in general, were retrieved.

In addition, a manual screening process was conducted by reviewing the titles and abstracts of the 168 remaining articles to ensure explicit relevance to mathematical communication. Only studies that explicitly included the term *“mathematical communication”* in both the title and abstract were retained. To enhance the credibility and reliability of the selection process, the screening procedure was performed three times on different dates (January 21, 22, and 26, 2026).

As a result of this screening, 27 articles were excluded, comprising six articles not empirical research, ten articles that did not focus on mathematical communication, four studies addressing mathematical communication theory within philosophical contexts, one article on mathematical communication in applied mathematics, one study related to communication system theory in radio engineering, two articles on mathematical communication models in computer systems, one article discussing the Shannon–Weaver theory of mathematical communication in music, one study applying Shannon’s mathematical communication theory in digital imaging and optical sensors, and one article published in a language other than English. Consequently, a total of 141 articles were included in the final dataset.

The selected articles were downloaded from Scopus in CSV format and subsequently converted into a TAB-delimited file, which was uploaded to VOSviewer for bibliometric analysis. Each Scopus record contains comprehensive metadata, including citation information (e.g., authors, document title, publication

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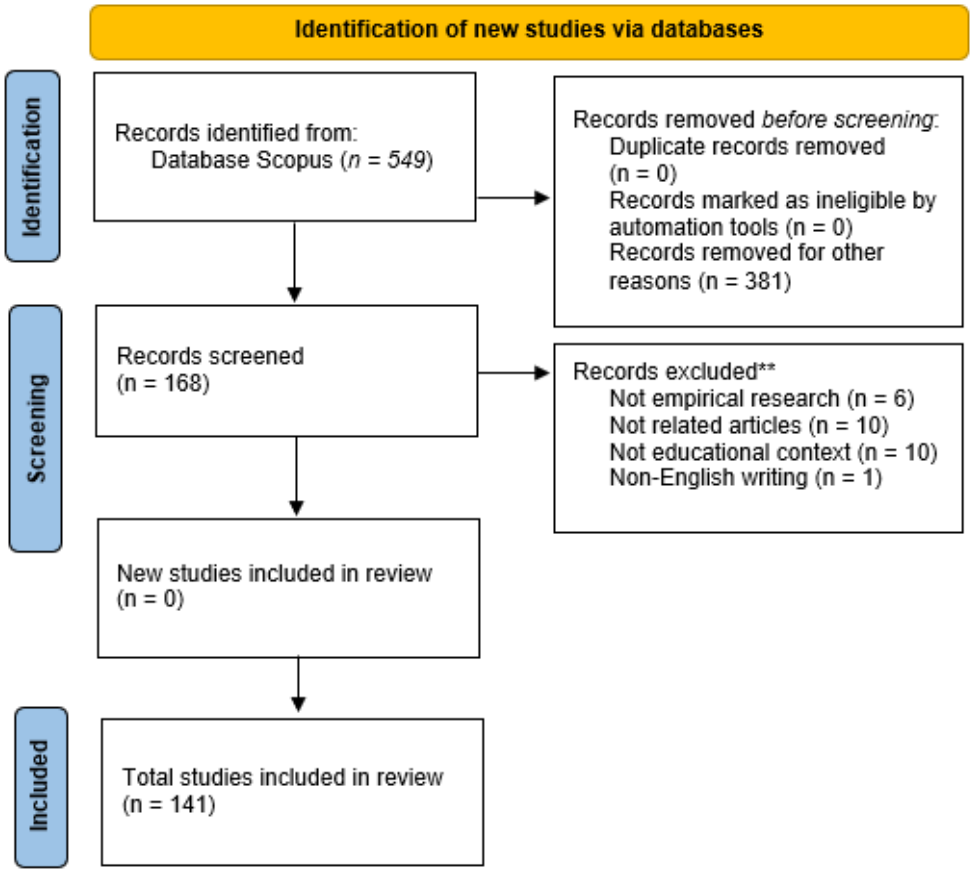
year, source title, and citation counts), bibliographic details (e.g., author affiliations, publisher, and language), abstracts and keywords, funding information, and reference lists. This metadata enabled a systematic and in-depth bibliometric analysis of research on mathematical communication in mathematics education.

Figure 1

Flowchart of Publication Selection Process



The data selection process adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, as illustrated in Figure 1. This systematic approach ensures transparency and rigor in the identification, screening, and inclusion of studies. The initial database search yielded 549 publications, which were subsequently screened and filtered to exclude non-relevant records. Following this process, a total of 141 publications were retained for inclusion in the final bibliometric analysis.

Coding and Analysis of Data

The study employed several bibliometric analyses, each designed to examine distinct dimensions of research trends in mathematical communication in mathematics education. First, publication and citation trend analyses were conducted to examine annual growth patterns in publications and citations, thereby capturing the overall development and momentum of the research field and identifying periods of heightened scholarly interest. Second, country- and institution-level analyses were performed to assess the geographical distribution of research output and citation impact, enabling the identification of the most productive countries and leading institutions contributing to this area of study. Third, keyword and topic analyses were carried out to examine the most frequently used keywords, allowing for the identification

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of dominant themes, emerging topics, and evolving research foci within mathematical communication in mathematics education.

To ensure analytical accuracy and efficiency, the bibliometric data were collected, analyzed, and visualized using VOSviewer in conjunction with the Bibliometrix package, based on data exported in CSV format. VOSviewer applies the Visualization of Similarities (VOS) methodology to generate two-dimensional network maps that display relationships among bibliographic elements through clustered visualizations (van Eck & Waltman, 2010). In these maps, the spatial distance between elements represents the strength of their relationships, while clusters are distinguished by different colors (van Eck et al., 2010; Waltman et al., 2010). The size of each node reflects its frequency of occurrence, with larger nodes indicating greater prominence (Rizzi et al., 2014). The axes of the visualizations do not carry explicit numerical values, as their function is to represent relational proximity rather than absolute measurements (Khalil & Crawford, 2015). Therefore, the bibliometric analyses provide quantitative insights into the evolution, structure, and thematic orientation of research on mathematical communication in mathematics education, highlighting both established strengths and areas for future investigation.

Results and Discussions

The bibliometric analysis in this chapter includes the following five components; (1) some descriptive statistics on the dataset, such as the number of publications over time; (2) citation analyses, including citation patterns, including the most cited publications and authors; (3) authorship analysis, with an author productivity report and authorship indicators; (4) performance analysis of institutions, considering productivity in terms of publications and citations; (5) keyword analysis, tracking the most frequently used keywords and trends in the use of these words. Table 2 summarizes the descriptive statistics of this bibliometric dataset. 78 journals published 141 articles between 2015 and 2025. In the field of mathematical communication in mathematics education, 136 researchers worked; 11 of the researchers worked with a single author, and 497 keywords emerged in the published studies.

Table 2

Main Information About the Data Field of Mathematical Communication in Mathematics Education

Description	Results
Timespan	2015-December 2025
Sources (Journals)	78
Total publications	141
All keywords	497
Index keywords	60
Author's keywords	451
Number of contributing authors	136
Sole-authored publication	11
Co-authored publication	130
Number of active years of Publication	10
Productivity per active year of Publication	14.1

The bibliometric analysis identified 141 articles related to mathematical communication in mathematics education published between 2015 and 2025. The distribution of these publications, as shown in Figure 2, highlights trends, patterns, and potential gaps in the research landscape.

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Figure 2

The Total Number of Publications and Citations by Years

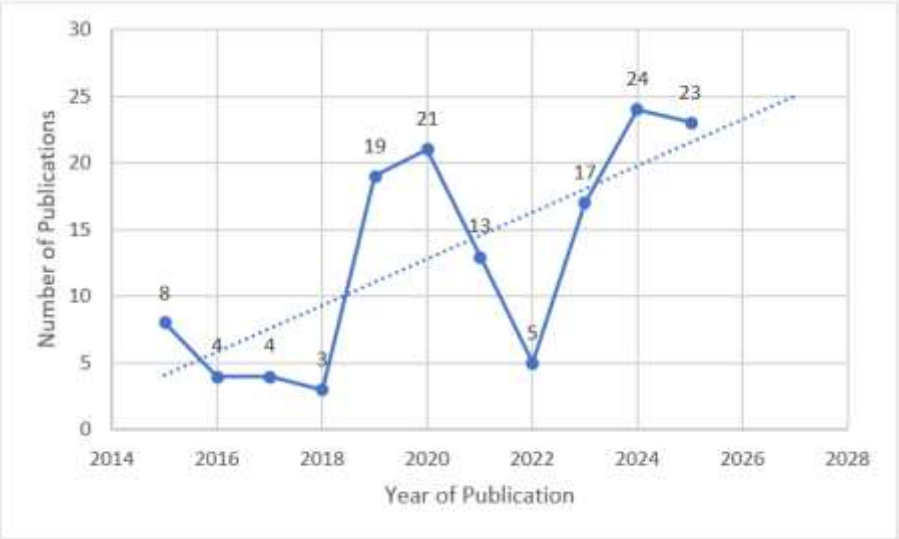

Figure 2 illustrates the annual publication trends in research on mathematical communication within mathematics education. Overall, the pattern demonstrates a clear upward trajectory, indicating a growing scholarly interest in this field over time, despite several short-term fluctuations. Between 2015 and 2018, the number of publications remained relatively low and stable, suggesting that research on mathematical communication had not yet emerged as a central focus within mathematics education research. A marked increase is observed beginning in 2019, with publication counts rising sharply through 2020, signaling a growing recognition of mathematical communication as a critical component of students' mathematical understanding and learning processes.

Although a temporary decline occurred around 2021–2022, this decrease did not alter the overall trend. From 2023 onward, the number of publications increased again and reached its highest levels in 2024–2025, reflecting renewed and sustained academic attention. The upward trend line further confirms the long-term growth of research output in this area. The observed trend suggests that research on mathematical communication has evolved from a relatively marginal topic into an increasingly established and influential area within mathematics education, with strong potential for continued theoretical and empirical development.

Citation Analysis with Countries

The Scopus database indicates that 37 countries were involved in the study. However, only countries with at least three publications were analyzed. Among the 37 countries, 12 meet the threshold.

Table 3

The Highest Publications 12 Countries

No.	Country	Documents	Citations
1.	Indonesia	71	538
2.	United States	12	74
3.	Turkey	10	45
4.	Vietnam	7	93
5.	Japan	7	75
6.	Portugal	5	34
7.	Australia	5	32

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No.	Country	Documents	Citations
8.	Malaysia	5	19
9.	Canada	3	34
10.	United Kingdom	3	30
11.	South Africa	3	8
12.	Saudi Arabia	3	7

Table 3 presents the countries contributing most to publications and citations in educational research on mathematical communication in mathematics education. The findings indicate that Indonesia is the most productive country, contributing 71 documents and accumulating 538 citations, which demonstrates both high research output and substantial scholarly impact. This dominant contribution suggests a strong and sustained national research focus on mathematical communication within the Indonesian mathematics education community.

The United States ranks second in terms of publication volume (12 documents) with 74 citations, reflecting a moderate but influential contribution, likely characterized by high-quality and internationally visible studies. Turkey follows with 10 publications and 45 citations, indicating growing engagement with the topic in the context of mathematics education research.

Interestingly, some countries exhibit a disproportionately high citation impact relative to their publication count. For example, Vietnam (7 documents, 93 citations) and Japan (7 documents, 75 citations) show high average citations per document, suggesting strong international visibility and influence despite smaller publication volumes. Similarly, Canada and the United Kingdom, although contributing only three documents each, demonstrate relatively high citation counts, indicating impactful research outputs. The distribution reveals that research on mathematical communication is geographically diverse, with notable contributions from both developing and developed countries. The results suggest a shift toward broader global engagement in this research area, while also highlighting differences between research productivity and citation impact across countries.

Citation Analysis with Institutions

An analysis of the Scopus database identified 141 published papers affiliated with 192 different institutions. However, only institutions with a minimum of three publications were considered for the study. Among these, 12 institutions meet the inclusion criteria.

Table 4

The Most Productive Publishing 12 Institutions

No.	Institutions	Country	Documents	Citations
1.	Universitas Pendidikan Indonesia	Indonesia	8	130
2.	Universitas Ahmad Dahlan	Indonesia	6	73
3.	Universitas Negeri Semarang	Indonesia	6	11
4.	Can Tho University	Vietnam	5	50
5.	Universitas Negeri Padang	Indonesia	5	24
6.	Universitas Negeri Yogyakarta	Indonesia	4	43
7.	Simon Fraser University	Canada	3	34
8.	Universitas Khairun	Indonesia	3	22
9.	Eskişehir Osmangazi Üniversitesi	Turkey	3	11
10.	Universitas Negeri Malang	Indonesia	3	7
11.	Universitas Sriwijaya	Indonesia	3	5
12.	Universitas Muhammadiyah Surakarta	Indonesia	3	2

Table 4 highlights the institutions contributing most prominently to the publication of highly cited research on mathematical communication in mathematics education. The findings reveal a strong

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concentration of research productivity within Indonesian institutions, indicating that Indonesia serves as a central hub for scholarly work in this field. Universitas Pendidikan Indonesia emerges as the most productive and influential institution, with the highest number of documents (8) and citations (130), suggesting both sustained output and strong citation impact. This positions the institution as a leading contributor shaping the research agenda on mathematical communication.

Several other Indonesian universities—including Universitas Ahmad Dahlan, Universitas Negeri Semarang, Universitas Negeri Padang, and Universitas Negeri Yogyakarta—also demonstrate notable productivity. However, citation counts vary considerably across institutions, indicating differences in research visibility and impact. This pattern suggests that while research production is widespread nationally, citation influence remains concentrated within a smaller number of institutions. Beyond Indonesia, Can Tho University (Vietnam) and Simon Fraser University (Canada) stand out for their relatively high citation counts compared to their publication volume. This indicates that institutions from Vietnam and Canada contribute fewer studies but produce research with strong international resonance, reflecting higher citation efficiency and broader scholarly influence.

Figure 3
International Cooperation Network

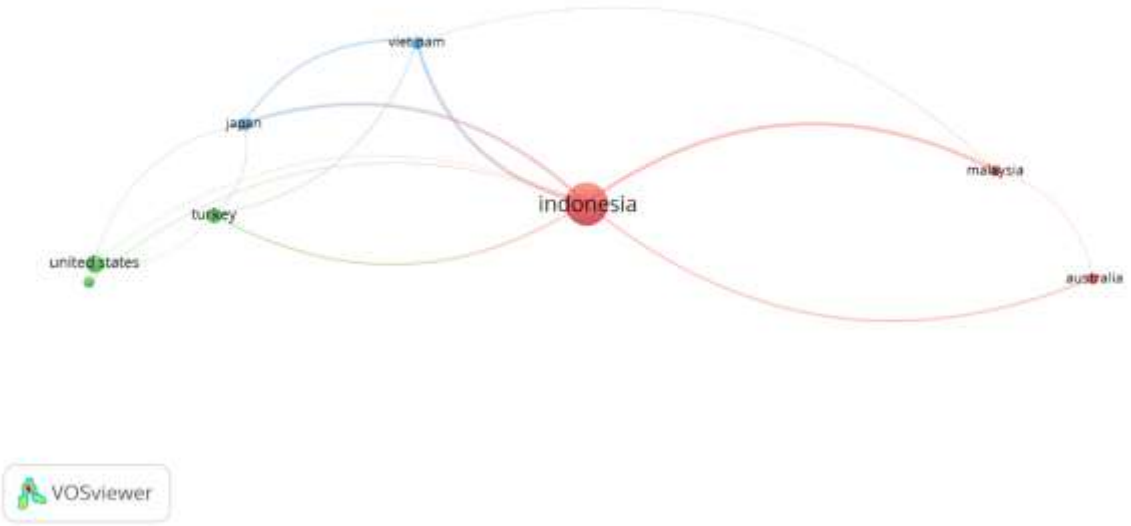

Figure 3 further illustrates the international cooperation network, showing that collaboration across countries remains limited but emerging. Indonesian institutions appear predominantly connected within national clusters, while cross-national collaborations are fewer and more selective. Institutions from Vietnam, Canada, and Turkey tend to function as bridging nodes, linking regional research clusters to the wider international network. This suggests that although the field is currently driven largely by nationally grounded research efforts, international collaboration plays a strategic role in enhancing citation impact and global visibility. The pattern of contribution and collaboration indicates that research on mathematical communication is characterized by strong national productivity combined with selective international partnerships. These findings underscore the importance of expanding cross-institutional and cross-

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country collaborations to strengthen the global integration, methodological diversity, and international impact of future research in mathematics education.

Citation analysis with sources

As presented in Table 2, a total of 141 papers has been published across 78 different sources. However, for this study, only sources with a minimum of four publications were considered. Out of the 78 sources, ten meet this criterion. Table 5 highlights the top ten journals that have contributed the most to research on mathematical communication in mathematics education.

Table 5

The Most Published Sources

No.	Source	Documents	Citations
1.	Infinity Journal	10	59
2.	International Journal of Scientific and Technology Research	10	39
3.	Educational Studies in Mathematics	5	75
4.	Journal on Mathematics Education	5	50
5.	International Journal of Instruction	4	78
6.	Journal for the education of Gifted Young Scientists	4	73
7.	International Journal of Evaluation and Research in Education	4	66
8.	International Journal of Mathematical Education in Science and Technology	4	20
9.	Journal of Educational Research	4	18
10.	TEM Journal	4	0

Table 5 summarizes the journals that published the most-cited educational research on mathematical communication in mathematics education, revealing a clear distinction between publication volume and citation impact. Several journals demonstrate high productivity, while others exhibit stronger scholarly influence despite fewer published articles. Infinity Journal and the International Journal of Scientific and Technology Research rank highest in terms of publication output, each contributing ten documents. However, their citation counts are comparatively moderate, indicating that high publication volume does not necessarily correspond to high citation impact. These journals appear to function primarily as dissemination outlets, supporting the broad circulation of research within the field.

In contrast, journals such as Educational Studies in Mathematics, International Journal of Instruction, and the Journal for the Education of Gifted Young Scientists show substantially higher citation counts relative to their publication numbers. This pattern suggests that these journals publish fewer but more influential studies, reflecting stronger international visibility, higher selectivity, and greater theoretical or methodological contribution to the field.

Field-specific journals, including the Journal on Mathematics Education and the International Journal of Mathematical Education in Science and Technology, demonstrate a balance between productivity and impact, indicating their role as core disciplinary venues for advancing research on mathematical communication within mathematics education.

Notably, TEM Journal shows no recorded citations despite publishing multiple documents, highlighting variability in journal influence and suggesting differences in indexing coverage, readership, or scholarly reach. The publication characteristics indicate that research on mathematical communication is disseminated through a diverse range of journals, spanning specialized mathematics education outlets and broader educational research journals. The findings underscore that citation impact is more strongly associated with journal reputation and scholarly focus than with publication volume, emphasizing the importance of journal selection for enhancing research visibility and influence.

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Citation analysis with authors

Citation analysis was carried out to identify the most productive and effective authors in the field of mathematical communication research in mathematics education. In VOSviewer, the minimum number of documents and citations by authors was chosen as at least two. Of the 136 authors, four meet the threshold. Table 6 shows the four most prominent authors sorted by total number of citations.

Table 6

The Most Prominent 4 Authors

No.	Author	Country	Documents	Citations
1.	Sumaji, S.; Sa'dijah, C.; Susiswo, S.; Sisworo	Indonesia	2	19
2.	Arani, M.R.S.	Japan	2	17
3.	Baran, A.; Kabael, T.	Turkey	2	11
4.	Miranda, P.; Mamede, E.	Portugal	2	5

Table 6 presents the most prominent authors contributing to the publication of highly cited educational research on mathematical communication in mathematics education. The results indicate that authorship in this field is characterized by small, stable collaborative groups, rather than dominance by single highly prolific individuals. The most highly cited contribution originates from a four-author collaborative team based in Indonesia (Sumaji, S.; Sa'dijah, C.; Susiswo, S.; Sisworo), which produced two publications that together accumulated 19 citations. Both articles were published in the same year (2020). The first study examines junior secondary students' mathematical communication processes in problem solving through the lens of the APOS theoretical framework (Sumaji et al., 2020a). The second investigates levels of junior secondary students' mathematical communication abilities in solving open-ended problems (Sumaji et al., 2020b). This pattern underscores the significance of collaborative, team-based research, particularly within national research networks, in advancing scholarship on mathematical communication.

A similar trend is observed in the works of Arani (2015; 2016) from Japan, as well as the author pairs Baran and Kabael (2021; 2023) from Turkey and Miranda and Mamede (2022; 2023) from Portugal, each of whom contributed two publications. Although their citation counts are lower than those of the Indonesian research group, they nevertheless demonstrate notable scholarly influence given their relatively limited publication output. Collectively, these findings suggest that citation impact is not determined solely by publication productivity, but is also shaped by the quality, thematic focus, and international relevance of the research.

The pattern of author contribution demonstrates a decentralized authorship structure, with influence distributed across multiple small research teams from different countries. The absence of highly dominant individual authors indicates that the field is still emerging and collaborative in nature, relying on localized research groups rather than global thought leaders. Strengthening cross-country co-authorship may therefore be a key strategy for increasing international visibility and citation impact in future research on mathematical communication in mathematics education.

Citation analysis with articles

To identify the most influential articles on higher-order thinking in mathematics education, we set a threshold for minimum number of citations of a document of 25 in VOSviewer. Out of 141 documents, 10 meet this criterion as shown in Table 7.

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Table 7

The Most Influential Research

No.	Authors	Title	Citations
1.	Sundayana (2017)	Using ASSURE learning design to develop students' mathematical communication ability	51
2.	Hartinah (2019)	Probing-prompting based on ethnomathematics learning model: The effect on mathematical communication skills	43
3.	Kusumah (2020)	The effect of Geogebra in three-dimensional geometry learning on students' mathematical communication ability	39
4.	Yang (2016)	Improving pupils' mathematical communication abilities through computer supported reciprocal peer tutoring	39
5.	Tong (2021)	The improvement of 10th students' mathematical communication skills through learning ellipse topics	35
6.	Kaya (2016)	Elementary mathematics teachers' perceptions and lived experiences on mathematical communication	29
7.	Vale (2023)	Active learning strategies for an effective mathematics teaching and learning	27
8.	Setiyani (2020)	Designing a digital teaching module based on mathematical communication in relation and function	27
9.	Ingram (2019)	When students offer explanations without the teacher explicitly asking them to	27
10.	Aguilar (2021)	What mathematical competencies does a citizen needs to interpret Mexico's official information about the COVID-19 pandemic?	26

Table 7 presents the most influential educational research publications on mathematical communication in mathematics education, as indicated by citation counts. The results show that citation impact is concentrated in a relatively small set of studies, suggesting a core literature that has shaped scholarly discourse in this field.

The most highly cited publication is Sundayana (2017), which focuses on the use of the ASSURE instructional design model to develop students' mathematical communication abilities. Its high citation count indicates strong scholarly interest in instructional frameworks and design-based interventions that explicitly target communication skills. Similarly, other highly cited studies—such as Hartinah (2019) and Kusumah (2020)—emphasize pedagogical approaches and technological tools, including ethnomathematics-based instruction and GeoGebra-supported learning, highlighting the centrality of instructional innovation in this research area.

Several influential publications, including Yang (2016) and Ingram (2019), address interactive and dialogic learning processes, such as peer tutoring and spontaneous student explanations. These studies suggest that research emphasizing classroom discourse, interaction, and student agency tends to attract sustained scholarly attention. In addition, works such as Kaya (2016) extend the focus beyond students by examining teachers' perceptions and experiences, indicating the relevance of teacher-related factors in understanding mathematical communication.

More recent highly cited studies, including Aguilar (2021) and Vale (2023), reflect an expansion of the field toward societal relevance and active learning, connecting mathematical communication to real-world contexts and citizenship. This trend suggests a broadening of research interest from classroom-based skill development to the role of mathematical communication in addressing contemporary social challenges.

The citation pattern reveals that the most influential publications predominantly focus on instructional strategies, technological integration, and interactive learning environments. The distribution of citations across studies published between 2016 and 2023 also indicates that both foundational and recent works contribute significantly to the field, reflecting a balanced and evolving citation landscape in research on mathematical communication in mathematics education.

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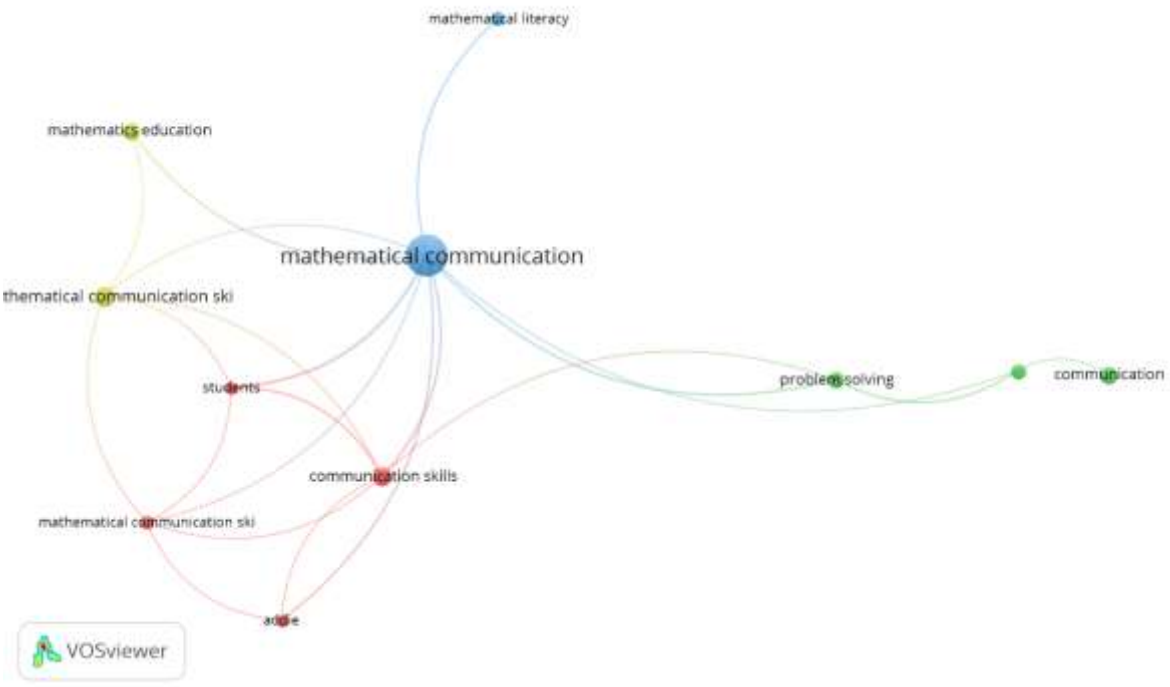
Keywords and terms analysis

Figure 4 presents the trends in keywords used in research on higher-order thinking in mathematics education. The analysis includes only keywords that appear at least four times. Out of 497 keywords, 12 meet the threshold. Keywords that are closely related are categorized in similar colors, while the connections between them indicate their co-occurrence in publications. Additionally, the size of each keyword node reflects the frequency of its appearance in the analyzed publications.

Figure 4

Keywords that Appear Most Frequently in The Keyword of Publications



The keyword co-occurrence network shown in the figure 4 provides insight into the conceptual structure of the most-cited research on mathematical communication in mathematics education. The visualization reveals a clearly centralized structure, with mathematical communication occupying the most dominant and central position in the network. The size and central placement of this node indicate its high frequency of occurrence and its strong connectivity with other key concepts, confirming its role as the core theme of the research field.

Several thematic clusters can be identified around this central node. One prominent cluster links mathematical communication with students, communication skills, and mathematical communication skills. This cluster reflects a strong emphasis on student-centered learning outcomes, highlighting that most highly cited studies focus on developing students' abilities to express, explain, and represent mathematical ideas effectively.

Another cluster connects mathematical communication with problem solving and communication. This relationship suggests that mathematical communication is frequently conceptualized as an integral component of problem-solving processes, rather than as an isolated competence. The strength of these links indicates that researchers commonly investigate how communication supports reasoning, explanation, and solution strategies in mathematics learning.

A smaller but conceptually important cluster associate's mathematical communication with

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mathematics education and mathematical literacy. This cluster reflects a broader educational perspective, positioning mathematical communication within the goals of mathematics education and literacy development. The presence of mathematical literacy suggests an emerging orientation toward connecting classroom communication practices with wider competencies needed for understanding and applying mathematics in real-life contexts.

The network structure indicates that research on mathematical communication is thematically cohesive, with strong interconnections among instructional, cognitive, and educational dimensions. The dominance of student-related and skill-oriented keywords suggests that the field is primarily focused on instructional interventions and learning outcomes, while the relatively smaller presence of broader socio-cultural or policy-related keywords points to potential directions for future research expansion.

Conclusion

This bibliometric study maps the development of research on mathematical communication in mathematics education based on 141 Scopus-indexed journal articles published between 2015 and 2025. The findings reveal a clear and sustained growth trend, particularly since 2019, indicating that mathematical communication has evolved from a peripheral topic into an increasingly established area of mathematics education research. The concentration of publications and citations in recent years reflects rising scholarly recognition of the role of communication in supporting students' mathematical understanding and learning processes.

The results also show that research productivity is geographically uneven, with Indonesia emerging as the most dominant contributor, while several other countries demonstrate high citation impact despite lower publication volume. At the institutional and authorship levels, research is largely driven by national clusters and small collaborative teams, with limited but strategically important international cooperation. Furthermore, the analysis of journals and keywords indicates that the field is thematically cohesive and primarily focused on instructional approaches, student learning outcomes, and classroom-based practices, positioning mathematical communication as a core construct within mathematics education.

Despite its growth, the field exhibits several important research gaps. International collaboration remains limited, and research contributions are concentrated in a small number of countries and institutions. Future studies should therefore emphasize cross-national and cross-institutional collaboration to strengthen global integration and enhance the international visibility of research on mathematical communication. In addition, existing studies predominantly focus on instructional interventions and student outcomes, leaving areas such as assessment of mathematical communication, teachers' instructional decision-making, curriculum design, and policy perspectives relatively underexplored.

Moreover, there is a need for methodological diversification, including longitudinal, mixed-methods, and design-based research, to better capture the development of mathematical communication over time. Expanding research toward socio-cultural, affective, and equity-oriented perspectives—including language diversity, inclusion, and students' mathematical identities—would further enrich the field. Addressing these gaps will be essential for advancing mathematical communication as a theoretically robust and socially relevant component of mathematics education.

Declaration of Conflicting Interests

The authors report no conflicts of interest related to the research, authorship, and/or publication of this article.

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