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Mapping the Global Research Landscape of Misconceptions in Mathematics Learning: A Bibliometric Study

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ABSTRACT

This study maps the global research landscape of misconceptions in mathematics learning using bibliometric analysis of Scopus-indexed publications from 2016 to 2026. The study addresses the need to understand how research has evolved from identifying students' conceptual errors toward assessment, intervention, teacher competence, and technology-supported learning. Data were retrieved from Scopus using the keyword "misconceptions in mathematics learning." From 596 initially identified records, 151 English-language open-access articles and conference papers met the selection criteria. Bibliometrix/Biblioshiny and VOSviewer were used to analyze publication trends, citation patterns, conceptual structures, thematic evolution, and collaboration networks. The findings show a substantial increase in research output, rising from 3 publications in 2016 to a peak of 31 in 2024, with 1,469 total citations. The intellectual core of the field remains centered on misconceptions, conceptual understanding, and error analysis, while educational computing and computer-aided instruction function as emerging motor themes. Assessment and feedback are gaining prominence, whereas teacher education, teacher knowledge, and lesson study remain weakly integrated. The findings further reveal a persistent gap between diagnosing misconceptions and developing and validating instructional interventions, alongside fragmented author and country collaboration. Based on these patterns, the study proposes an integrated research direction linking diagnosis, diagnostic assessment, conceptual-change-oriented intervention, teacher competence, and pedagogically grounded artificial intelligence. The study provides a global evidence base for strengthening research collaboration and developing more adaptive, evidence-based approaches to reducing mathematical misconceptions.

Keywords: Misconceptions; Mathematics Learning; Mathematics Education; Bibliometric Analysis; Artificial Intelligence; Learning Analytics.

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INTRODUCTION

Modern mathematics education emphasizes the development of conceptual understanding, reasoning, and problem-solving through technology-based approaches and diagnostic assessment practices (Weigand et al., 2024). Nonetheless, the success of mathematics learning is determined not only by procedural mastery but also by the quality of students' conceptual understanding and their ability to establish meaningful connections among mathematical concepts (Kazemi et al., 2022). In this context, misconceptions represent a fundamental issue because they can hinder the construction of accurate knowledge structures, reduce the quality of reasoning, and affect students' ability to integrate mathematical concepts comprehensively (Ekasari et al., 2025).

The issue of misconceptions has become increasingly relevant as modern mathematics education is expected not only to produce correct answers but also to foster deep understanding, knowledge transfer, and the ability to apply concepts across various contexts. In practice, student are capable of solving problems procedurally yet fail to understand the conceptual meaning underlying the steps they perform (Al-Mutawah et al., 2019). Consequently, misconceptions often remain hidden behind seemingly adequate academic performance.

Over the past few decades, research on misconceptions in mathematics learning has expanded in various directions, ranging from the identification of conceptual errors and error analysis to remediation strategies and the integration of educational technology (Mathaba et al., 2024). In Indonesia, studies on misconceptions have also shown significant growth. Runnalls and Hong (2020) demonstrated how teachers need to pedagogically respond to students' misconceptions regarding area concepts, while Suparman et al. (2021) reported an increase in mathematics education publications focusing on problem-based learning after 2016. Nevertheless, these studies tend to be fragmented and have not yet been systematically mapped within the global scientific landscape.

The growing number of publications on misconceptions in mathematics learning indicates a substantial increase in scholarly interest in this field. This trend highlights the need for a bibliometric approach to understand research development trajectories, intellectual structures, dominant themes, and patterns of scientific collaboration. Bibliometric analysis serves not only as a descriptive statistical tool but also as a strategic approach for identifying the maturity of a field, research gaps, and opportunities for future research development (Donthu et al., 2022).

Although research on mathematical misconceptions has developed significantly, most studies still focus on identifying students' conceptual errors within specific topics and have not provided a comprehensive global mapping of the intellectual evolution of this field. Previous bibliometric studies have generally concentrated on publication productivity and have paid limited attention to thematic evolution, conceptual structures, the integration of artificial intelligence, and international collaboration networks (Hwang & Tu, 2021; Ouyang et al., 2023).

To date, bibliometric study on mathematical misconceptions remain relatively limited, particularly those that specifically map thematic evolution, conceptual structures, and the integration of artificial intelligence within a multidimensional analytical framework (Hwang & Tu, 2021).

Table 1. Research Gap

Researcher	Research Focus	Method	Limitations	Contribution of This Study
Hwang & Tu (2021)	Artificial intelligence in mathematics education	Bibliometric	Did not specifically address mathematics misconceptions	Focuses the study on misconceptions in mathematics learning and the thematic evolution related to them
Ouyang et al. (2023)	AI-driven learning analytics and collaborative problem solving	Learning analytics & AI-based educational analysis	Did not focus on mathematics misconceptions or global bibliometric mapping	Integrates artificial intelligence and learning analytics within the context of mathematics misconception research
Phan et al. (2022)	Realistic mathematics education	Bibliometric	Did not discuss the thematic evolution of mathematics misconceptions	Maps thematic evolution, conceptual structure, and research directions in

				misconception studies
Li et al. (2020)	Mathematics education publication productivity	Descriptive bibliometrics	Did not explore thematic evolution, conceptual structure, or collaboration networks in depth	Employs thematic mapping, co-occurrence networks, collaboration networks, and AI trend analysis

Based on these gaps, this study offers several key innovations. First, it maps the global research landscape on mathematics misconceptions specifically through a bibliometric approach, which remains relatively limited. Second, the study analyzes the thematic evolution of research, highlighting the shift in focus from misconception identification toward assessment, teacher education, and artificial intelligence integration. Third, the research identifies the emergence of AI-based technologies as a new trend in mathematics misconception studies. Fourth, the study maps global collaboration patterns and disparities in contributions among countries. Fifth, it offers a direction for more integrative research development by strengthening the relationships among diagnosis, assessment, intervention, and evaluation in mathematics learning.

The objectives of this study are: (1) to analyze publication trends on misconceptions in mathematics learning during 2016–2026; (2) to identify dominant themes and the conceptual structure of the field; (3) to analyze thematic evolution toward technology-based mathematics education; (4) to explore global collaboration patterns among authors and countries; and (5) to identify opportunities for future research.

METHOD

This study employs a bibliometric approach with a descriptive-quantitative design to map the global development of research on misconceptions in mathematics learning. The bibliometric approach was chosen because it can systematically and measurably identify patterns of scientific development, intellectual structure, thematic evolution, collaboration networks, and research trajectories (Pessin et al., 2022).

The data source for this study was the Scopus database, selected for its broad international publication coverage, relatively stable metadata quality, and frequent use in bibliometric studies in education and social sciences. Data retrieval was conducted in January 2026 through Scopus, using the search fields Title, Abstract, and Keywords (TITLE-ABS-KEY). The search syntax employed was as follows : TITLE-ABS-KEY ("misconceptions in mathematics learning") AND PUBYEAR > 2015 AND PUBYEAR < 2027 AND (LIMIT-TO (SUBJAREA, "SOCI") OR LIMIT-TO (SUBJAREA, "MATH") OR LIMIT-TO (SUBJAREA, "COMP") OR LIMIT-TO (SUBJAREA, "ARTS")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "cp")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (OA, "all"))

This syntax was used to retrieve publications covering the topic misconceptions in mathematics learning in the title, abstract, or keywords, with the publication period 2016–2026, subject areas Social Sciences, Mathematics, Computer Science, and Arts and Humanities, document types article and conference paper, written in English, and included in the Open Access category.

Table 2. Research Data Search Parameters

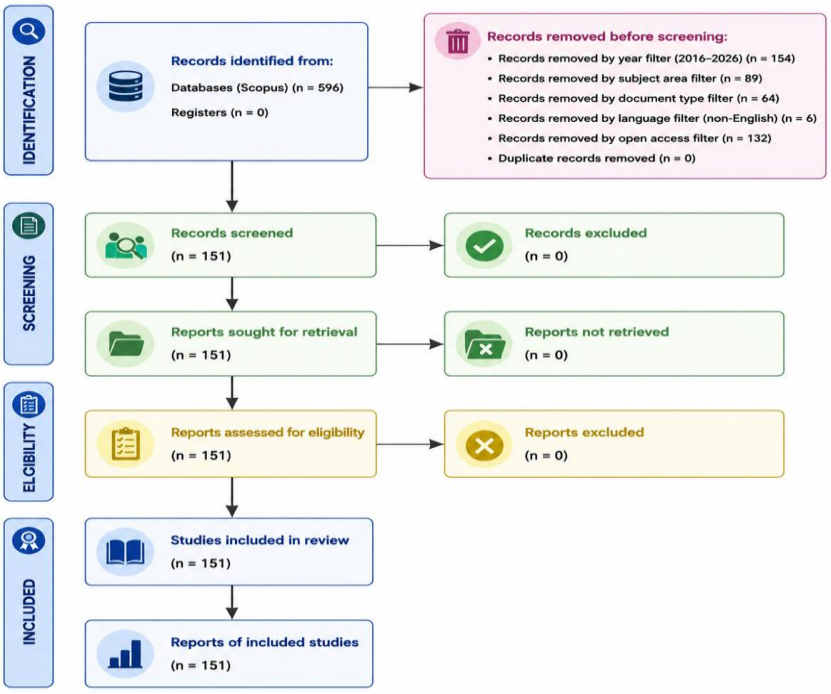
Parameter	Criteria
Database	Scopus
Keywords	"misconceptions in mathematics learning"
Search Fields	Title, Abstract, Keywords

Publication Year	2016–2026
Subject Area	Social Sciences, Mathematics, Computer Science, Arts and Humanities
Document Type	Article, Conference Paper
Language	English
Access	Open Access

The research data were obtained from the Scopus database using the keyword "misconceptions in mathematics learning" for the publication period 2016–2026. Publications from 2026 are considered partial because the Scopus indexing process was still ongoing at the time of data retrieval. The initial search yielded 596 documents. Subsequently, a selection process was conducted using an adapted PRISMA 2020 approach (Figure 1) (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) to ensure the relevance and quality of the research dataset.

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Figure 1. PRISMA 2020 Flow Diagram of Document Selection Process



The first stage involved limiting publications to the period 2016–2026, resulting in 442 documents. The second stage applied a filter based on subject areas relevant to the research focus, namely Social Sciences, Mathematics, Computer Science, and Arts and Humanities, leaving 353 documents. The next stage filtered by document type, selecting only articles and conference papers, which resulted in 289 documents. Subsequently, language filtering was applied, choosing only English-language documents to ensure consistency in international

bibliometric analysis, leaving 283 documents. The final stage applied an All Open Access filter, yielding 151 documents as the final research dataset. Metadata exported from Scopus included: author names, article title, publication year, affiliation, abstract, keywords, journal source, citations, and references.

The data were then exported in .csv and .ris formats for analysis using Bibliometrix/Biblioshiny in RStudio and VOSviewer version 1.6.20. Bibliometrix was used for bibliometric statistical analysis, visualization of publication productivity, three-field plots, thematic evolution, and thematic mapping. Meanwhile, VOSviewer was used to visualize keyword co-occurrence networks, co-authorship networks, and country collaboration maps.

Before analysis, the data underwent cleaning and metadata normalization to reduce redundancy in keywords, variations in author name spelling, and inconsistencies in terminology. Keywords with similar meanings were consolidated through thesaurus standardization, for example, "AI" and "artificial intelligence," as well as "mathematics education" and "math education."

In network analysis using VOSviewer, the full counting method was applied to measure connections between items. A minimum threshold of 5 occurrences was set for keywords to focus the network visualization on dominant themes. Association strength normalization was employed as the normalization method, as it is effective for mapping the strength of relationships between items in bibliometric networks.

The bibliometric indicators analyzed in this study included: Annual Scientific Production to examine yearly publication trends; Average Citations per Year to assess scientific impact; Word Frequency Analysis to identify dominant themes; Three-Field Plots to map relationships among references, authors, and keywords; Co-occurrence Networks to explore the conceptual structure of the field; Thematic Maps to analyze theme centrality and density; Collaboration Networks to map author collaboration patterns; and Country Collaboration Maps to examine the distribution and global collaboration network.

Although bibliometrics provides a comprehensive overview of research development, this study has limitations because it relies solely on the Scopus database and open-access documents. Therefore, the results do not fully represent all global publications on misconceptions in mathematics learning.

RESULT AND DISCUSSION

Dataset Selection and Characteristics

Based on the search results from the Scopus database, 596 documents were retrieved at the initial identification stage. After a stepwise selection process using a PRISMA-adapted database filtering approach, the final dataset consisted of 151 English-language open-access documents published between 2016 and 2026. The dataset comprised 141 journal articles (93.4%) and 10 conference papers (6.6%), all in English. These publications cover the fields of Social Sciences, Mathematics, Computer Science, and Arts and Humanities, with a total of 1,469 citations and an average of 9.73 citations per document. The most cited article was by Wardat et al. (2023) on ChatGPT in mathematics learning, receiving 324 citations. The restriction to open-access documents was applied to ensure accessibility and traceability of sources, although it also represents a limitation of this study.

Table 3. Dataset Characteristics: Top 10 Journals, Most Productive Authors, and Leading Contributor Countriese

No.	Top 10 Journals	n	No.	Productive Authors	n	No.	Contributing Countries	n
1	Eurasia Journal of Mathematics, Science and Technology Education	9	1	Shahrill M.	3	1	United States	23
2	Infinity Journal	8	2	Mukuka A.	2	2	Indonesia	22
3	Education Sciences	6	3	Veith J.M.	2	3	South Africa	16
4	Journal on Mathematics	6	4	Bitzenbauer	2	4	Turkey	11

	Education			P.				
5	European Journal of Educational Research	5	5	Foster C.	2	5	United Kingdom	11
6	Mathematics	4	6	Carrisi M.C.	2	6	Germany	9
7	School Science and Mathematics	3	7	Wardat Y.	2	7	Malaysia	8
8	International Journal of Emerging Technologies in Learning	3	8	Li C.	2	8	Australia	6
9	CBE Life Sciences Education	3	9	Woodhead S.	2	9	Spain	6
10	ZDM – Mathematics Education	3	10	Nguyen D.T.	2	10	Philippines	4

Publication Productivity and Scientific Impact

The results of the Annual Scientific Production analysis (Figure 2) indicate that scientific publications related to misconceptions in mathematics learning have shown a generally increasing trend over time, although the growth has not been linear. This finding is consistent with development patterns reported in bibliometric studies within the broader field of mathematics education. For example, Wang and Abdullah (2024) also identified an acceleration in publications on mathematics education topics indexed in Scopus after 2020.

Figure 2. Annual Scientific Production (2016–2026)

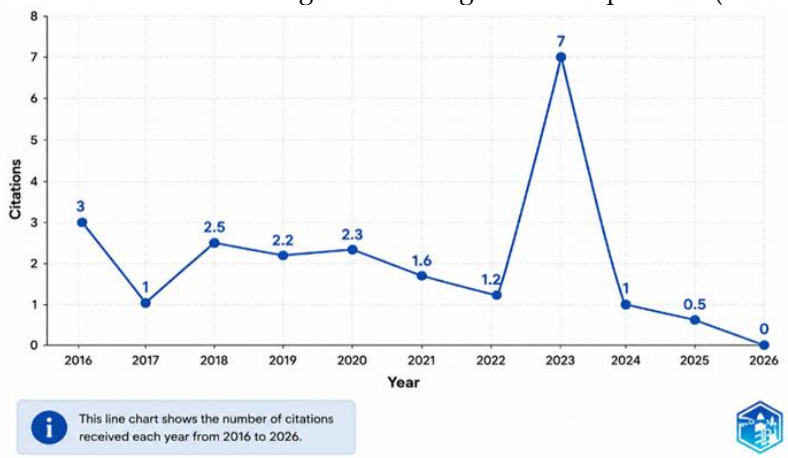


In the early period of 2016–2019, the number of publications remained relatively low and fluctuated, with 3 documents in 2016, 7 in 2017, 6 in 2018, and 4 in 2019. Entering the 2020–2022 period, a clearer upward trend emerged, increasing from 12 documents in 2020 to 18 in 2021, and reaching 21 in 2022. The peak of the development occurred in 2024, when the number of publications reached 31 documents—the highest across the entire study period—indicating that research on misconceptions in mathematics learning had entered a phase of scientific acceleration. In 2025, 27 documents were recorded, while the figure of 7 documents in 2026 should be interpreted with caution, as it is likely influenced by the ongoing status of the year and delays in Scopus indexing.

From the perspective of Average Citations per Year (Figure 3), the citation impact of this topic shows a fluctuating pattern, with an overall average of 9.73 citations per document from a total of 1,469 citations. The highest average citation rates occurred in 2016 (29.67 citations/year) and 2023 (28.33 citations/year), indicating the emergence of highly influential articles during these two periods. This finding is consistent with the study by Widodo et al. (2023) in a

bibliometric analysis of ethnomathematics, which reported that citation surges do not always increase linearly with publication output. After 2023, the average citations declined; however, this should not be directly interpreted as a decrease in research quality, as newly published articles have not yet had sufficient time to accumulate citations (Tahamtan et al., 2016)

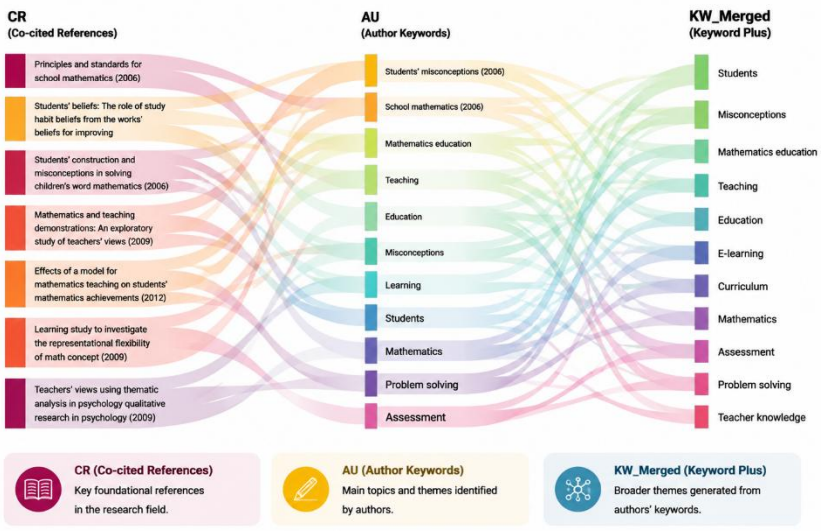
Figure 3. Average Citations per Year (2016–2026)



Intellectual Foundations and Research Directions

The Three-Field Plot analysis (Figure 4) illustrates that research on misconceptions in mathematics learning is shaped by the interconnected relationships among the most frequently cited references, active authors, and dominant keywords. From the perspective of references, this field continues to be grounded in seminal works on mathematics education and teacher knowledge, particularly those of Ernest et al. (2016) and Zazkis and Koichu (2017). This pattern indicates that the development of the field remains firmly rooted in discussions concerning how mathematical concepts are taught, understood, and subject to conceptual errors during the learning process (Stylianides et al., 2017; Runnalls & Hong, 2020)

Figure 4. Three-Field Plot (References | Authors | Keywords)



Compared with similar bibliometric studies in science education, such as the work of Kurtuş and Tatar (2021) on science misconceptions, the intellectual foundation of mathematics misconception research is more strongly dominated by pedagogical theories rather than purely cognitive theories. This finding suggests that mathematics education has integrated pedagogical dimensions more extensively in examining misconceptions.

Dominant Research Themes

The Word Cloud visualization (Figure 5) and TreeMap analysis (Figure 6) reveal that the most dominant keywords are misconceptions (32 occurrences, including the variants "misconceptions" and "misconception"), mathematics education (12), mathematics (12), teacher education (7), assessment (6), and error analysis (5). The prominence of these keywords confirms that the central focus of research remains on students' conceptual errors within the context of mathematics education, while teacher education and assessment have emerged as increasingly important supporting themes.

Figure 5. Word Cloud of Dominant Keywords

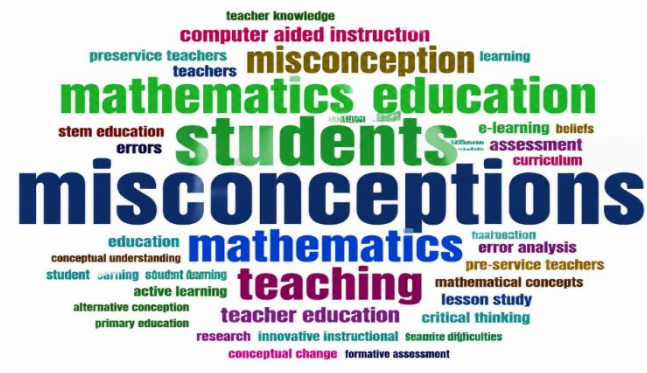
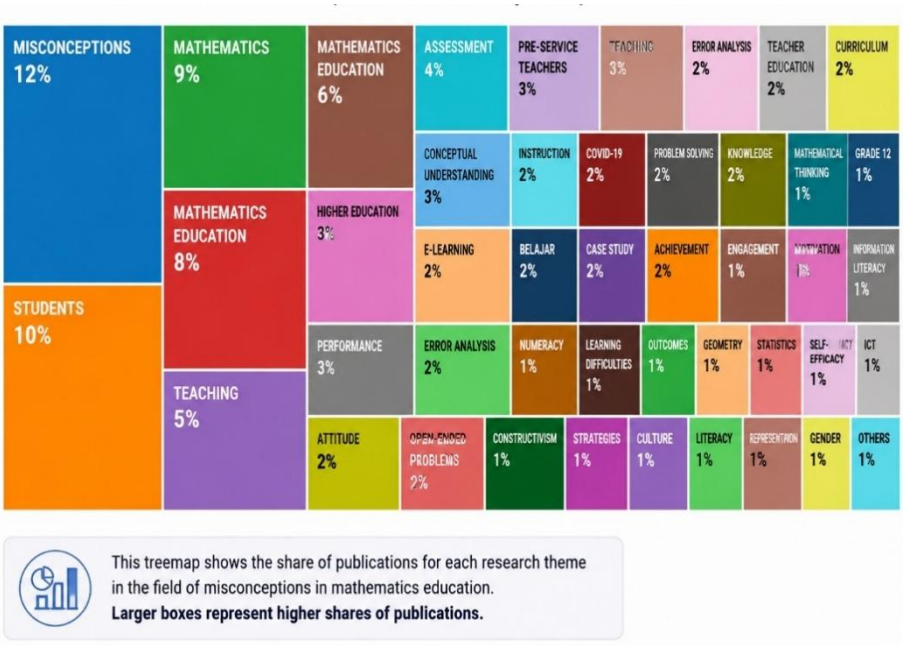


Figure 6. TreeMap of Keyword Frequencies



These findings are consistent with the literature review conducted by Putri et al. (2025), which demonstrated that student misconceptions continue to be a primary focus of research in mathematics education. However, when compared with bibliometric studies on adjacent topics such as mathematical thinking (M. Wang et al., 2025), which have increasingly explored curricular dimensions, the field of mathematics misconceptions appears to lag behind in integrating curriculum and assessment perspectives.

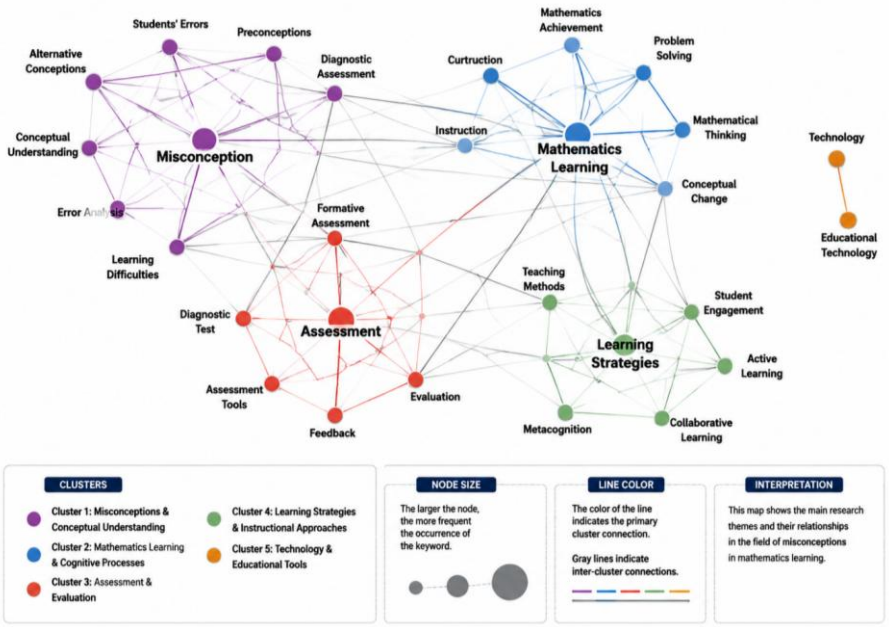
Beyond the core themes, several supporting keywords emerged, including assessment, feedback, curricula, computer-aided instruction, e-learning, and artificial intelligence. The presence of these terms indicates that the field of misconceptions in mathematics learning is evolving toward a more multidimensional direction, driven by the increasing integration of

artificial intelligence and learning analytics into modern mathematics education (Hwang & Tu, 2021; Ouyang et al., 2023).

Conceptual Structure and Thematic Mapping

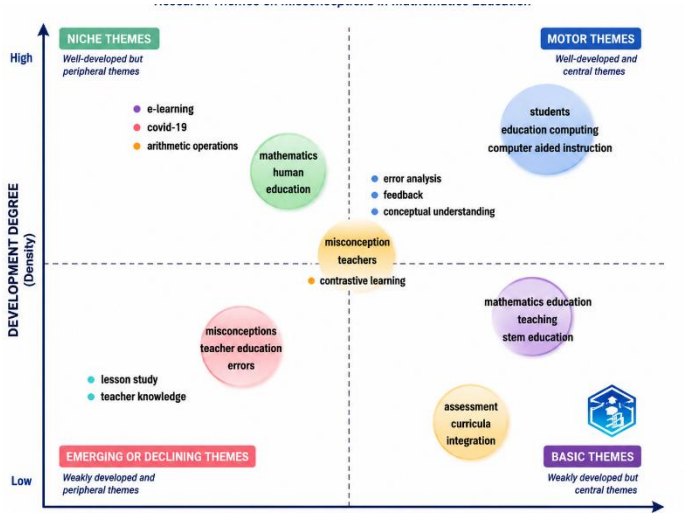
The co-occurrence network analysis (Figure 7) reveals that research on misconceptions in mathematics learning is organized into several interconnected thematic clusters. Based on the VOSviewer analysis with a minimum threshold of five occurrences, four major clusters were identified. The first cluster (red) represents the core cluster, encompassing the keywords misconceptions, mathematics education, conceptual understanding, and error analysis, which serve as the conceptual backbone of the field. The second cluster (green) groups technology-oriented themes such as computer-aided instruction, educational computing, and artificial intelligence, reflecting a growing research orientation toward technology-enhanced learning. The third cluster (blue) encompasses pedagogical themes, including teacher education, teacher knowledge, and lesson study, highlighting the increasing emphasis on teacher competence in addressing students' misconceptions. The fourth cluster (yellow) comprises assessment and evaluation themes, including assessment, formative assessment, and feedback. The numerous links connecting the clusters indicate a relatively strong level of interconnectivity, particularly between the core cluster and the technology-oriented cluster.

Figure 7. Keyword Co-occurrence Network



The Thematic Map (Figure 8) illustrates the intellectual structure of the field based on two key dimensions: centrality and density.

Figure 8. Thematic Map (Centrality × Density)



The core themes located in the central themes quadrant (high centrality, high density) include misconception, conceptual understanding, and error analysis, indicating that these topics are both intellectually mature and central to the field. In the motor themes quadrant (high centrality, low density), themes such as students, educational computing, and computer-aided instruction are particularly prominent. These themes actively drive the development of the field, although they have not yet become fully consolidated. The basic themes quadrant (low centrality, high density) is occupied by topics such as mathematics education, teaching, STEM education, assessment, and curricula.

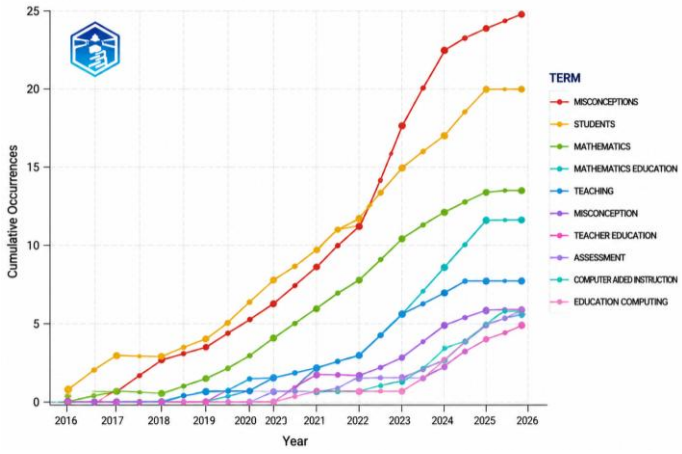
This positioning indicates that these themes play an important role as foundational elements of the research field; however, their connections with other themes remain relatively limited. Meanwhile, the emerging or declining themes quadrant, characterized by low centrality and low density, includes teacher education, teacher knowledge, and lesson study. This placement does not imply that these themes are less important; rather, it suggests that their development and integration within the mathematics misconceptions research landscape remain insufficient.

In fact, these three themes are highly significant for supporting the systematic prevention and remediation of misconceptions through the enhancement of teacher competence and the promotion of reflective teaching practices (Akinsola, 2015; da Ponte, 2017). This finding is consistent with Li and Li (2024), who emphasized that the integration of technology has become one of the key driving themes in the advancement of contemporary mathematics education research.

Evolution of Themes over Time

The Words' Frequency over Time analysis (Figure 9) illustrates the cumulative development of keywords from 2016 to 2026. The term misconceptions emerged as the most dominant theme, showing the sharpest increase, particularly during the 2022–2024 period. This acceleration pattern is consistent with bibliometric findings in science education, which also reported a strengthening of misconception-related research themes in the post-pandemic era (Uyanik, 2025).

Figure 9. Words' Frequency over Time (Cumulative 2016–2026)

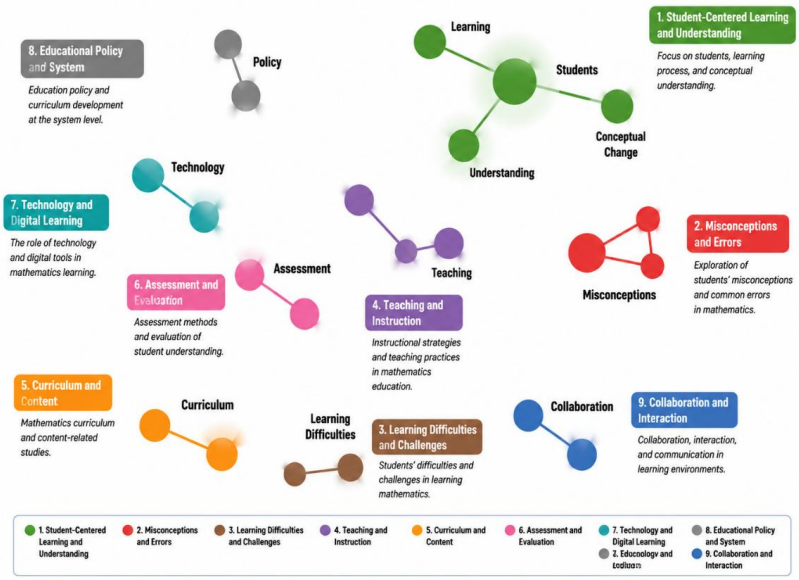


The terms teacher education, assessment, computer-aided instruction, and educational computing have also shown increasing prominence, although their growth remains less pronounced than that of the core themes. This pattern suggests that the research landscape is gradually moving toward a more integrative orientation, linking the diagnosis of misconceptions with teacher education, assessment practices, and educational technology (Brown et al., 2024).

Scientific Collaboration Network

The collaboration network analysis (Figure 10) reveals that patterns of author collaboration in research on misconceptions in mathematics learning remain relatively fragmented. The network is composed of several small clusters with strong internal connections, while the links between clusters are comparatively weak (Emmons et al., 2016). This high level of fragmentation indicates that mathematics misconception research is still developing within relatively isolated research groups that are not yet extensively connected. Such a condition may limit the exchange of methodological perspectives and research approaches across regions and scholarly communities (Ha et al., 2020; Phan et al., 2022; Barrot, 2023).

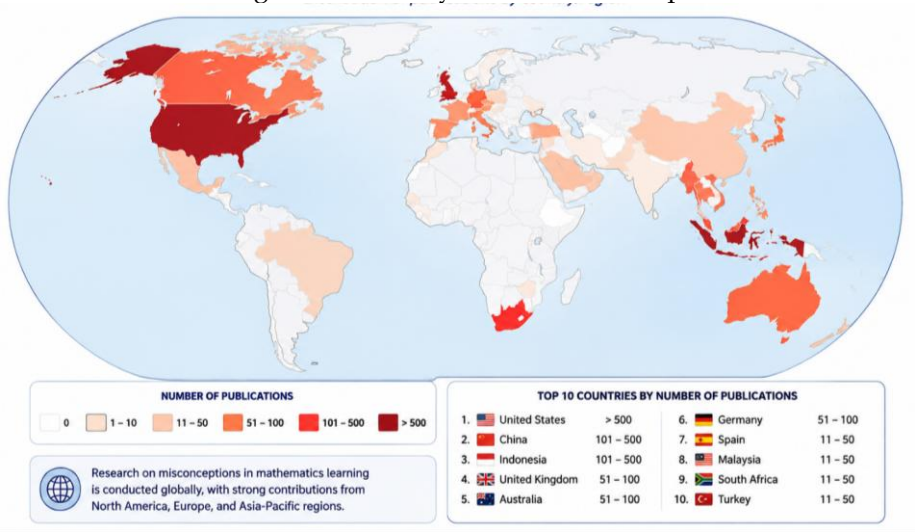
Figure 10. Author Collaboration Network



At the country level, the country collaboration map (Figure 11) further supports the view that research on misconceptions in mathematics learning has expanded internationally, although contributions remain unevenly distributed. The United States emerges as one of the most influential contributors, followed by several European countries, including the United Kingdom, Germany, Spain, Italy, and Turkey, as well as countries in the Asia-Pacific region such as Indonesia, Australia, Japan, and Malaysia. South Africa also appears as a significant contributor within the African region.

Indonesia's presence on this collaboration map is a positive indicator, highlighting the country's growing involvement in the field while also demonstrating substantial opportunities to strengthen international research collaborations in the future (Donthu et al., 2021; Kumar et al., 2025).

Figure 11. Country Collaboration Map



The emergence of themes such as artificial intelligence, educational computing, and learning analytics reflects a significant shift in the direction of global mathematics education research. This development indicates that the diagnosis of misconceptions is no longer viewed merely as a conventional evaluative activity; rather, it has evolved into a component of intelligent, data-driven learning systems capable of detecting conceptual errors in real time (Lu et al., 2020).

Trends, Theoretical Foundations, and Future Research Directions

The bibliometric findings of this study indicate that research on misconceptions in mathematics learning has evolved into a field with a strong scientific foundation and an increasingly broad range of research perspectives. The steady growth in publications over time suggests that misconceptions continue to be regarded as a fundamental issue in contemporary mathematics education. This trend aligns with the principles of cognitive constructivism proposed by Jean Piaget, who argued that learners construct knowledge through the processes of assimilation and accommodation.

The bibliometric findings, which reveal the dominance of the themes "misconception," "mathematics education," and "conceptual understanding," indicate that the primary focus of research continues to revolve around the identification and classification of students' conceptual errors. This finding is consistent with the Conceptual Change Theory developed by George J. Posner and his colleagues, which argues that misconceptions can only be corrected when learners experience cognitive conflict that prompts the restructuring of their existing understanding.

Nevertheless, the results of the analysis reinforce the assumption that most studies remain concentrated on the diagnosis of misconceptions and have not substantially progressed

toward the development of comprehensive instructional interventions. This gap between diagnosis and intervention represents a significant finding, indicating that the research community has been successful in extensively identifying and mapping conceptual problems, yet has not produced sufficiently empirically validated solutions to address them. This situation contrasts with the field of science misconceptions, where intervention strategies such as refutation text and predict-observe-explain have been widely examined and validated through experimental studies. According to the theory of Pedagogical Content Knowledge (PCK) (Purwianingsih et al., 2010), teachers are expected not only to possess a strong understanding of subject matter content but also to understand how students' misconceptions emerge and to apply the most effective strategies for conceptual change and correction.

The strengthening of the assessment theme in the bibliometric findings indicates a growing recognition that assessment plays a crucial role in identifying students' misconceptions. This trend is particularly noteworthy because it differs from the trajectory observed in science misconception research, where diagnostic assessment was integrated at an earlier stage. Such a pattern suggests that mathematics education is only now collectively entering this phase of development. Andersson and Palm (2017) demonstrated that changes in formative assessment practices significantly improve students' mathematics achievement, as they provide teachers with deeper insights into students' conceptual difficulties and enable more responsive instructional adjustments. In mathematics learning, diagnostic assessment approaches such as the Certainty of Response Index (CRI), two-tier tests, and clinical interviews have proven effective in identifying forms of misconceptions that are often undetectable through conventional testing methods. The emergence of this theme within the bibliometric map confirms that the field is gradually shifting from merely documenting misconceptions toward measuring them more precisely through evidence-based assessment practices.

On the other hand, the emergence of the themes teacher education and teacher knowledge indicates a growing concern for strengthening teachers' professional competencies. According to Lev Vygotsky's theory of social constructivism, learning occurs through social interaction and scaffolding provided by more knowledgeable individuals. When teachers possess limited conceptual understanding or employ inappropriate instructional approaches, students' misconceptions may become further reinforced rather than corrected. Therefore, teacher education programs should focus on enhancing conceptual teaching, reflective teaching, and teachers' ability to diagnose students' misconceptions and patterns of erroneous reasoning. Strengthening these competencies is essential to enable teachers not only to identify conceptual difficulties but also to design effective learning experiences that promote meaningful conceptual change.

The bibliometric findings also reveal a gradual strengthening of the themes of artificial intelligence and educational technology, which is consistent with George Siemens' theory of connectivism. From this perspective, artificial intelligence has significant potential to support the identification of students' misconception patterns through automated analysis, provide adaptive feedback, and personalize learning experiences according to each student's conceptual needs. The growing prominence of these themes suggests that mathematics education research is increasingly exploring technology-driven approaches to address misconceptions more effectively and efficiently. Such developments reflect a broader shift toward data-informed and adaptive learning environments that can support deeper conceptual understanding and improve learning outcomes.

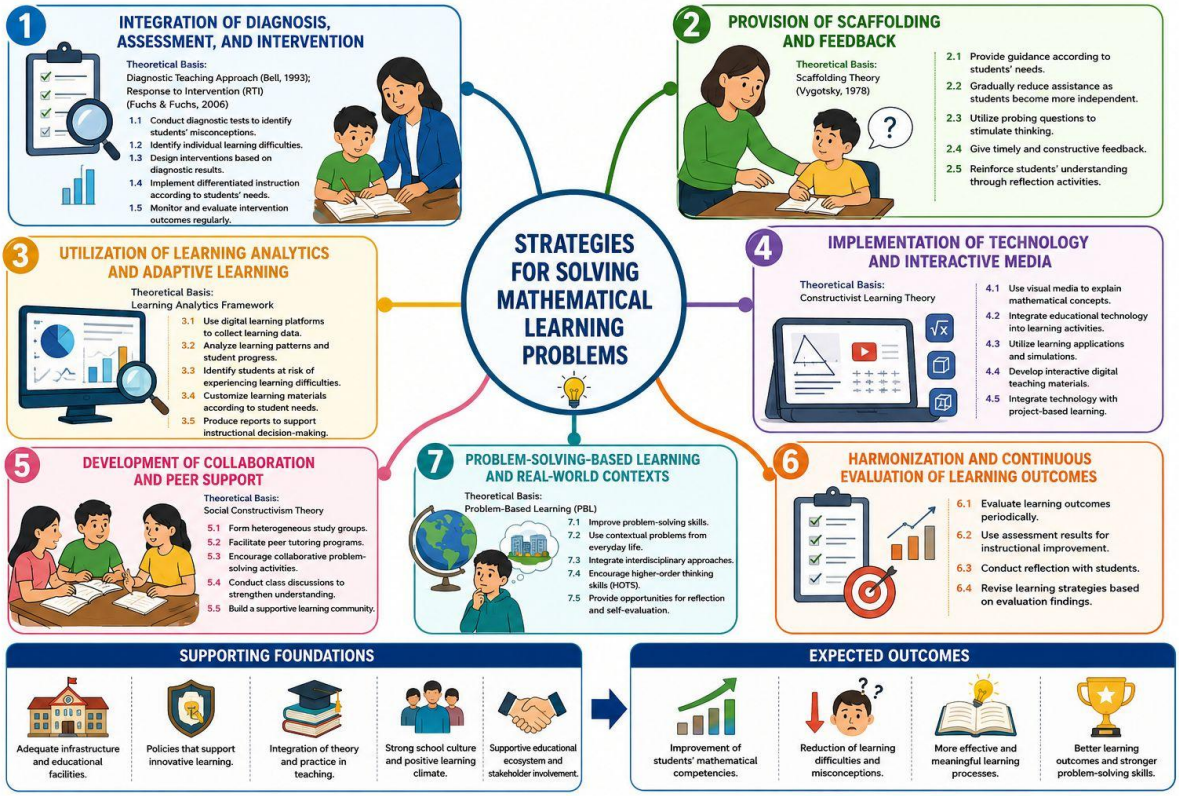
From the perspective of scientific collaboration, the findings indicate that this field continues to experience fragmentation at both the author level and in terms of unequal contributions across countries. This condition is more than a mere statistical phenomenon; collaborative fragmentation reflects structural limitations in which researchers studying mathematical misconceptions tend to work within isolated epistemic communities, thereby hindering the development of shared theoretical frameworks and the cross-cultural replication of research findings (Ha et al., 2020). The dominance of contributions from the United States and Europe further suggests that perspectives from educational contexts in the Global South, including Indonesia, remain underrepresented in shaping the global research agenda. The

emergence of Indonesia within the global collaboration network represents a positive development; however, its position still requires strengthening through active participation in international research consortia, publication in high-impact Scopus-indexed journals, and the establishment of more systematic and sustainable collaborative networks. Future research should integrate perspectives from cognitive psychology, educational technology, mathematics pedagogy, and learning assessment within a more comprehensive research framework. Such an approach would move beyond merely describing misconceptions toward experimentally testing the effectiveness of interventions across diverse educational and cultural contexts, thereby contributing to the development of more robust and globally relevant solutions.

Mind Map of Strategies for Addressing Misconceptions in Mathematics Education

(Figure 12) presents a conceptual framework for addressing misconceptions in mathematics learning, developed based on the findings of the bibliometric analysis and theoretical review. The framework illustrates that misconceptions cannot be effectively resolved solely through the identification of students' conceptual errors; rather, they require an integrated approach encompassing diagnosis, assessment, instructional intervention, teacher competency development, and the continuous utilization of educational technology. Furthermore, the diagram highlights the importance of interconnected pedagogical, evaluative, and technological dimensions in supporting more adaptive mathematics instruction that is oriented toward fostering students' conceptual understanding. This framework provides a holistic perspective for researchers, educators, and policymakers seeking to design evidence-based strategies for reducing misconceptions and enhancing the quality of mathematics learning.

Figure 12. Strategies for Overcoming Misconceptions in Mathematics Learning



Addressing misconceptions in mathematics learning requires an integrated, multidimensional, and sustainable approach. The remediation of misconceptions cannot rely solely on identifying students' conceptual errors; rather, it must involve interconnected

processes of diagnosis, assessment, instructional intervention, and evaluation. In this context, strengthening teachers' competencies through Pedagogical Content Knowledge (PCK), lesson study, and reflective teaching is essential for helping teachers understand, identify, and effectively address students' conceptual misunderstandings. These approaches enable teachers to recognize the underlying causes of misconceptions and implement appropriate instructional strategies to facilitate meaningful conceptual change.

The strengthening of diagnostic and formative assessment practices is also essential to enable the learning process to monitor students' conceptual understanding more accurately and continuously. At the same time, advancements in educational technology and artificial intelligence offer new opportunities for identifying patterns of misconceptions, developing adaptive learning systems, and personalizing mathematics instruction based on data-driven insights. Furthermore, strengthening research collaboration among scholars and across countries can support the development of innovative instructional approaches and enhance the overall quality of research in the field of mathematical misconceptions. Such collaborative efforts are crucial for fostering knowledge exchange, validating findings across diverse educational contexts, and advancing evidence-based solutions to address students' conceptual difficulties in mathematics.

Furthermore, the development of instructional models, learning resources, and conceptually oriented curricula should be directed toward fostering more meaningful learning through inquiry-based learning, problem-solving activities, and the use of multiple representations. These approaches can help students construct deeper conceptual understanding and reduce the likelihood of persistent misconceptions. In addition, research findings should be translated into educational practice through the development of assessment instruments, instructional modules, learning media, and teacher professional development programs. Such efforts are essential to ensure that research outcomes generate tangible and sustainable impacts on classroom practice and educational improvement in schools.

Thus, these strategies indicate that addressing misconceptions in mathematics learning requires synergy among teachers, researchers, technology, educational institutions, and educational policies. Through a systematic and collaborative approach, students' misconceptions can be minimized, thereby enhancing conceptual understanding, improving the effectiveness of mathematics instruction, and promoting the sustainable improvement of mathematics education quality.

DISCUSSION

The novelty of this study lies in its attempt to move beyond descriptive counting of publications and to read the bibliometric structure of misconception research through established learning theories. Earlier bibliometric work has examined artificial intelligence in mathematics education in general (Hwang & Tu, 2021), realistic mathematics education (Phan et al., 2022), AI-driven learning analytics in collaborative problem solving (Ouyang et al., 2023), and misconceptions in the science domain (Kurtuş & Tatar, 2021). To the best of our knowledge, none of these studies takes misconceptions in mathematics learning as the primary unit of analysis while simultaneously tracing publication growth, intellectual foundations, conceptual structure, thematic evolution, and collaboration networks within one analytical framework. In addition, this study converts the bibliometric evidence into an integrated conceptual framework (Figure 12) that connects diagnosis, assessment, instructional intervention, teacher competence, and technology. Such a synthesis has not been offered in previous mappings and is the main original element of the present work.

The principal findings can be summarized as follows. Based on 151 Scopus-indexed open-access documents published between 2016 and 2026, annual output rose from 3 documents in 2016 to a peak of 31 documents in 2024, accumulating 1,469 citations (9.73 citations per document). The conceptual core of the field remains anchored in misconceptions,

mathematics education, conceptual understanding, and error analysis. Educational computing and computer-aided instruction appear as motor themes, assessment and curricula as basic themes, and teacher education, teacher knowledge, and lesson study in the low-centrality, low-density quadrant. Author and country collaboration is fragmented, with the United States (23 documents), Indonesia (22), and South Africa (16) among the leading contributors. These results are significant because they show simultaneously where the field is intellectually mature (diagnosis of conceptual errors) and where it is weakly integrated (teacher knowledge, intervention, and cross-regional collaboration). This is precisely the information that researchers, teacher educators, and funders need in order to position future work.

Interpreting these findings theoretically, the dominance of the keywords misconceptions, conceptual understanding, and error analysis is consistent with the constructivist premise that learners actively build knowledge by assimilating new information into existing schemas and accommodating those schemas when they fail (Piaget, 1952). Under this view, misconceptions are not random mistakes but systematic products of prior knowledge structures, which explains why so many studies in the dataset concentrate on identifying and classifying them. The prominence of conceptual understanding also reflects the long-standing distinction between conceptual and procedural knowledge (Hiebert & Lefevre, 1986) and between relational and instrumental understanding (Skemp, 1976). Students who execute procedures correctly may still hold fragile or incorrect concepts, a pattern also noted by Al-Mutawah et al. (2019), so misconceptions often remain hidden behind adequate test performance. However, the concentration on error identification may also reveal a limitation. Smith et al. (1993) argued that student conceptions should be treated not only as obstacles but also as resources that can be refined into expert understanding. The thematic map shows little evidence that the field has adopted this resource-oriented perspective at scale, since most themes still cluster around identifying what is wrong rather than building on what students already know.

Comparing the results with previous studies shows both convergence and divergence. First, the growing weight of technology-related keywords aligns with Hwang and Tu (2021), who identified artificial intelligence as an expanding direction in mathematics education, and with Wardat et al. (2023), whose work on ChatGPT is the most-cited document in our dataset (324 citations). Second, the acceleration of misconception-related output during 2022–2024 parallels the post-pandemic strengthening of misconception themes reported in science education by Uyanik (2025). Third, the centrality of error analysis and conceptual understanding resonates with Mathaba et al. (2024), who connect algebra misconceptions to cognitive levels, and with Putri et al. (2025), who treat misconceptions as a continuing problem even in the context of collaborative learning. Fourth, the rising prominence of assessment is in line with Andersson and Palm (2017), who showed that changes in formative assessment practice improved students' mathematics achievement. Fifth, the peripheral position of teacher-related themes contrasts with Runnalls and Hong (2020), who demonstrated that teachers' responses to student misconceptions are pedagogically decisive; the theme is therefore educationally important even though it is bibliometrically underdeveloped. Sixth, the fragmented collaboration structure resembles the pattern described by Ha et al. (2020) for STEM education research in ASEAN, while the stronger pedagogical (rather than purely cognitive) foundation of the field differs from the science misconception literature analyzed by Kurtuş and Tatar (2021). Finally, M. Wang et al. (2025) reported broader curricular engagement in research on mathematical thinking, whereas misconception research appears to integrate curriculum perspectives less extensively.

The emergence of assessment as a supporting theme can be explained by assessment theory. Black and Wiliam (1998) showed that formative assessment, by revealing the gap between current and desired understanding, can raise learning standards, and Hattie and Timperley (2007) demonstrated that the effect of feedback depends on whether it addresses the task, the process, or self-regulation. Diagnostic instruments developed in science education, such as two-tier tests (Treagust, 1988) and the Certainty of Response Index (Hasan et al., 1999), allow researchers to distinguish genuine misconceptions from lack of knowledge and careless errors. The appearance of assessment and feedback among the supporting keywords therefore suggests that mathematics misconception research is moving from merely documenting errors toward measuring them more precisely. Compared with science education, where such diagnostic tools were adopted earlier, mathematics appears to be entering this phase later. A plausible reason is that mathematics errors have traditionally been handled through error analysis of written solutions rather than through multi-tier instruments, which would delay the uptake of confidence-based diagnosis.

A central implication of the thematic map is the gap between diagnosis and intervention. Conceptual change theory holds that learners abandon a conception only when they become dissatisfied with it and find the alternative intelligible, plausible, and fruitful (Posner et al., 1982). Applied to mathematics, this means that identifying a misconception is only the first step; the learning environment must also generate cognitive conflict and offer a more convincing alternative. The dominance of diagnostic themes and the thin presence of intervention-oriented keywords suggest that the field has been more successful at describing misconceptions than at validating strategies that change them. This reading should nevertheless be made with caution. Bibliometric keywords capture how studies label themselves, not necessarily what they do, and some intervention studies may use other terminology (for example "remediation," "conceptual change," or "refutation"). Even so, the pattern supports the proposal in Figure 12 that diagnosis, assessment, intervention, and evaluation should be studied as one connected cycle rather than as separate research lines.

The low centrality and density of teacher education, teacher knowledge, and lesson study deserve particular attention because they are theoretically pivotal. Shulman (1986) argued that effective teaching requires pedagogical content knowledge, that is, knowing how particular ideas are best represented and which conceptions students commonly bring to them. Ball et al. (2008) extended this into mathematical knowledge for teaching, which includes the ability to interpret students' non-standard reasoning. From a social constructivist standpoint, learning occurs through interaction and scaffolding within the zone of proximal development (Vygotsky, 1978), so a teacher with limited conceptual knowledge may inadvertently reinforce misconceptions rather than resolve them. Lesson study offers a practical mechanism for building this knowledge collectively (da Ponte, 2017), and reviews of teacher preparation emphasize the role of teachers' knowledge and beliefs (Akinsola, 2015). The peripheral position of these themes in our map therefore indicates not low importance but low integration with the misconception agenda, consistent with the observation that the connection between teacher competence and student misconceptions has been examined in a relatively small number of studies.

The rise of artificial intelligence, computer-aided instruction, and learning analytics can be interpreted through connectivism, which regards learning as the capacity to navigate networks of information and which positions technology as part of the cognitive infrastructure (Siemens, 2005). In practical terms, AI systems can analyze response patterns at a scale that individual teachers cannot, provide immediate feedback, and adapt tasks to each student's

conceptual needs. Research on intelligent tutoring systems has reported positive effects on learning outcomes (Kulik & Fletcher, 2016), and learning analytics has been used to model collaborative problem solving (Ouyang et al., 2023) and to support data-driven decision making in streamed data environments (Lu et al., 2020). Nevertheless, connectivism alone does not guarantee that an automated diagnosis leads to conceptual change. Without grounding in the assessment and conceptual change principles discussed above, AI tools risk becoming faster detectors of errors rather than effective promoters of understanding. This is why the framework in Figure 12 places technology alongside, not above, pedagogy, assessment, and teacher competence.

Several factors may explain the observed similarities and differences with prior studies. The similarities in dominant themes and in post-2020 growth probably reflect shared structural drivers: conceptual understanding is a persistent goal of mathematics education, the pandemic accelerated digital teaching and assessment, and generative AI tools drew rapid scholarly attention. The fragmented collaboration pattern, similar to that in Ha et al. (2020), may reflect the national and institutional organization of research groups, funding constraints, and language barriers. The differences, in turn, are likely to arise from methodological and contextual factors. Hwang and Tu (2021) and Phan et al. (2022) used broader topical scopes and different time windows, whereas the present study applied a narrow keyword, a 2016–2026 window with partial 2026 data, and restrictions to English-language, open-access articles and conference papers. These filters may over-represent open-access outlets such as the Eurasia Journal of Mathematics, Science and Technology Education and Infinity Journal, and the keyword threshold of five occurrences may push smaller themes such as teacher knowledge toward the periphery. Differences with science education may also reflect disciplinary characteristics: mathematical concepts are hierarchical and abstract, and the field has a long tradition of error analysis, which may explain why diagnostic assessment and intervention research developed along a different trajectory.

The collaboration findings can be discussed from the perspective of epistemic communities. When research groups work in relative isolation, shared theoretical frameworks, common instruments, and cross-cultural replication develop slowly (Ha et al., 2020; Phan et al., 2022). The visibility of Indonesia (22 documents) next to the United States and South Africa shows growing participation from the Global South, yet the network structure indicates that this participation has not been fully translated into sustained international partnerships. Because misconceptions are partly shaped by language, curriculum, and instructional culture, evidence generated in a few regions cannot be assumed to transfer to others. Stronger cross-country collaboration would therefore not only increase productivity but also improve the external validity of findings, which is particularly important for interventions.

The contribution of this study is theoretical, methodological, and empirical. Theoretically, it links bibliometric patterns with constructivism, conceptual change, assessment theory, pedagogical content knowledge, social constructivism, and connectivism to explain why diagnosis dominates while validated interventions, teacher knowledge, and integrative collaboration remain underdeveloped. Methodologically, it combines Bibliometrix and VOSviewer outputs (thematic maps, co-occurrence networks, thematic evolution, and collaboration maps) into a replicable multi-indicator procedure for a narrowly defined educational topic. Empirically, it identifies a diagnosis–intervention gap, the weak integration of teacher-related themes, and the under-representation of Global South perspectives, while confirming that technology integration is a rising driver of the field, as also emphasized by Li

and Li (2024). Together, these insights address the gap identified in Table 1, namely the absence of a mapping that focuses on mathematics misconceptions and their thematic evolution.

Table 4. Summary of Findings, Theoretical Interpretation, and Implications

Key finding	**Theoretical reading**	**Implication / future direction**
Dominance of misconceptions, conceptual understanding, and error analysis	Constructivism (Piaget, 1952); conceptual vs. procedural knowledge (Hiebert & Lefevre, 1986); misconceptions as resources (Smith et al., 1993)	Combine diagnosis with approaches that build on students' existing ideas
Rising assessment and feedback themes	Formative assessment (Black & Wiliam, 1998); feedback (Hattie & Timperley, 2007); two-tier tests and CRI (Treagust, 1988; Hasan et al., 1999)	Develop and validate diagnostic instruments for mathematics; train teachers to use results
Diagnosis outweighs intervention	Conceptual change theory (Posner et al., 1982)	Experimental studies of interventions that create cognitive conflict and offer plausible alternatives
Teacher themes in low-centrality, low-density quadrant	PCK (Shulman, 1986); mathematical knowledge for teaching (Ball et al., 2008); ZPD and scaffolding (Vygotsky, 1978)	Teacher professional development, lesson study, and reflective teaching focused on misconceptions
Growth of AI, computer-aided instruction, and learning analytics	Connectivism (Siemens, 2005); intelligent tutoring evidence (Kulik & Fletcher, 2016)	Pedagogically grounded AI diagnosis and adaptive feedback, with attention to ethics
Fragmented collaboration and uneven country contribution	Epistemic communities; cross-cultural validity of findings	International consortia and inclusion of Global South researchers

The findings carry practical, academic, and policy implications, summarized in Table 4. Practically, teachers and teacher educators should strengthen diagnostic and formative assessment, pedagogical content knowledge, lesson study, and reflective teaching so that misconceptions are detected early and addressed through cognitive conflict and multiple representations. Developers of educational technology should ground AI-supported diagnosis and feedback in conceptual change and assessment principles. Academically, future research should (1) design and experimentally test instructional interventions across diverse cultural and educational contexts; (2) examine the pedagogical effectiveness and ethical use of AI-based diagnostic systems; (3) extend the search to other databases such as Web of Science and to alternative terms such as "mathematical errors" and "conceptual errors"; (4) complement bibliometrics with content analysis or systematic review of the most influential documents; and (5) update the dataset once 2026 indexing is complete. In terms of policy, the fragmented and uneven collaboration pattern justifies support from ministries and research funders for international consortia, teacher professional development programs, and the participation of researchers from developing regions, including Indonesia.

CONCLUSION

This study demonstrates that research on misconceptions in mathematics learning has developed into an increasingly active but still structurally uneven field. The bibliometric evidence shows sustained growth in scientific production, while the intellectual structure remains strongly centered on misconceptions, conceptual understanding, and error analysis. At the same time, assessment, feedback, educational computing, computer-aided instruction, and artificial intelligence are becoming increasingly visible, indicating that the field is gradually expanding beyond the identification of conceptual errors toward more technology-supported and data-informed approaches to mathematics learning.

More importantly, the findings reveal a persistent imbalance between diagnosis and intervention. Although the literature has become increasingly effective in identifying and characterizing students' misconceptions, instructional interventions designed to produce and empirically validate conceptual change remain comparatively underdeveloped. Teacher education, teacher knowledge, and lesson study also remain weakly integrated within the research structure despite their theoretical importance for diagnosing and responding to students' misconceptions. In parallel, fragmented author and country collaboration suggests that the field has not yet developed sufficiently connected international research communities capable of supporting broader theoretical integration and cross-cultural validation.

The principal contribution of this study is therefore not only the mapping of publication and thematic patterns but also the development of an integrated research direction connecting diagnosis, diagnostic assessment, instructional intervention, teacher competence, and educational technology. The proposed framework suggests that future research should treat these dimensions as an interconnected cycle rather than as separate research agendas. In practical terms, teachers and teacher educators should strengthen diagnostic and formative assessment, pedagogical content knowledge, reflective teaching, and conceptually oriented instructional strategies, while educational technology and artificial intelligence should be developed as pedagogically grounded tools rather than as substitutes for teacher judgment. Future studies should empirically test intervention models, validate AI-supported diagnostic and adaptive assessment approaches, broaden database and terminology coverage, and strengthen international collaboration involving underrepresented regions. Such developments are essential for moving the field from documenting misconceptions toward producing evidence-based and contextually transferable solutions for improving students' conceptual understanding in mathematics.

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