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REVIEW

Global Research Trends in Mathematical Problem-Solving Skills: A Bibliometric Review of 2020-2024 Publications

Tendencias globales de investigación en habilidades de resolución de problemas matemáticos: una revisión bibliométrica de publicaciones 2020-2024

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ABSTRACT

Introduction: mathematical problem-solving skills are a core competency in 21st-century education, linked to critical, creative, and reflective thinking. This study mapped the global development and research direction of this topic using bibliometric analysis.
Method: the research followed four systematic stages: retrieving Scopus articles with the keywords "problem-solving skills" and "mathematics," filtering relevant documents, validating metadata, and conducting visual analysis via VOSviewer. A total of 295 documents were analyzed.
Results: publications surged in 2020 (42 documents), 2021 (36), and 2023 (35), reflecting shifts during and post-COVID-19. Journal articles (49,2 %) and conference papers (47,8 %) dominated, with minimal contributions from reviews (1,0 %) and books (0,3 %). Key sources included the *Journal of Physics: Conference Series* and *AIP Conference Proceedings*. Subject areas were primarily social sciences (31,4 %), physics/astronomy (24,4 %), and mathematics (9,0 %). Keyword analysis revealed five thematic clusters, while Indonesia led in publications (146 documents), followed by the U.S. and Malaysia.
Conclusions: the study confirmed mathematical problem-solving as a rapidly growing interdisciplinary field, progressing toward theoretical consolidation and cross-sector collaboration. Future research could address gaps in review articles and diversify geographic contributions.

Keywords: Mathematical Problem Solving; Bibliometric Analysis; Scopus; Global Trends; Mathematics Education.

RESUMEN

Introducción: las habilidades de resolución de problemas matemáticos son una competencia básica en la educación del siglo XXI, vinculada al pensamiento crítico, creativo y reflexivo. Este estudio mapeó el desarrollo global y la dirección de la investigación de este tema utilizando el análisis bibliométrico.
Método: la investigación siguió cuatro etapas sistemáticas: recuperación de artículos de Scopus con las palabras clave "habilidades de resolución de problemas" y "matemáticas", filtrado de documentos relevantes, validación de metadatos y realización de análisis visuales a través de VOSviewer. Se analizaron un total de 295 documentos.
Resultados: las publicaciones aumentaron en 2020 (42 documentos), 2021 (36) y 2023 (35), lo que refleja los cambios durante y después de la COVID-19. Predominaron los artículos de revistas (49,2 %) y los trabajos en congresos (47,8 %), con contribuciones mínimas de reseñas (1,0 %) y libros (0,3 %). Las fuentes clave

incluyeron el *Journal of Physics: Conference Series* y *AIP Conference Proceedings*. Las áreas temáticas fueron principalmente ciencias sociales (31,4 %), física/astronomía (24,4 %) y matemáticas (9,0 %). El análisis de palabras clave reveló cinco grupos temáticos, mientras que Indonesia lideró en publicaciones (146 documentos), seguido de Estados Unidos y Malasia.
Conclusiones: el estudio confirmó que la resolución de problemas matemáticos es un campo interdisciplinario de rápido crecimiento, que avanza hacia la consolidación teórica y la colaboración intersectorial. Las investigaciones futuras podrían abordar las lagunas en los artículos de revisión y diversificar las contribuciones geográficas.

Palabras clave: Resolución de Problemas Matemáticos; Análisis Bibliométrico; Scopus; Tendencias Globales; Educación Matemática.

INTRODUCTION

Problem-solving is widely recognized as a core competency in mathematics education, not only as an instructional objective but also as a means of fostering logical, reflective, and adaptive thinking frameworks in students.[1,2,3] This ability serves as a foundational pillar for the development of higher-order thinking skills, such as critical, creative, analytical, and metacognitive thinking, all of which are essential components of competency-based education.[4,5,6] Amidst the rapidly evolving social, economic, and technological landscapes, learners are increasingly confronted with challenges that lack singular or straightforward solutions. Therefore, problem-solving skills have become crucial instruments in navigating the complexities and uncertainties of real-world situations.

As the educational paradigm shifts from a content-oriented approach toward the strengthening of 21st-century competencies, mathematical problem-solving has gained growing prominence in the development of national curricula, educational assessments, and global policies aimed at promoting numeracy and future-readiness.[4,7]

In this era of digital transformation and knowledge-based economies, problem-solving skills are increasingly regarded as essential competencies that students must acquire across all levels of education.[8,9,10,11,12] These skills are not only relevant in academic contexts but also serve as critical assets in everyday life and the professional world, which demand greater flexibility and innovation.[13,14,15,16,17] Within mathematics education, problem-solving involves higher-order cognitive processes such as analyzing, synthesizing, and evaluating information to determine optimal solutions.[18]

With the educational paradigm increasingly emphasizing competency-based approaches and the development of 21st-century skills, problem-solving has become a central focus in the curriculum across many countries.[4,7,19] Various pedagogical models, such as inquiry-based learning, project-based learning, and the integration of technology in mathematics instruction, have been designed to support the cultivation of problem-solving skills.[20] Although a substantial body of literature underscores the importance of these skills, global research on mathematical problem-solving remains fragmented and lacks comprehensive integration.[21,22] Existing studies tend to be dispersed, often limited to local contexts, and vary widely in terms of methodology, research subjects, and findings.

Hence, a bibliometric analysis of global research output on mathematical problem-solving skills is of significant importance.[23,24,25] This type of analysis allows us to map the evolution of research over time, identify prevailing trends, leading researchers and institutions, and reveal research gaps that warrant future attention.[26] Through this approach, we aim to generate a comprehensive overview of how problem-solving in mathematics has been studied and implemented across various educational contexts, both in developed and developing nations.[27,28]

The study aims to explore several key aspects of research on mathematical problem-solving skills published between 2020 and 2024. First, it seeks to analyze publication trends within this timeframe to identify patterns in research output and growth. Second, it examines the types of documents published on problem-solving skills during this period, such as journal articles, conference papers, or reviews, to understand the dissemination formats. Additionally, the study investigates which journals have been the most active in publishing research on mathematical problem-solving between 2010 and 2024, highlighting the leading academic platforms in this field. Another focus is identifying the dominant subject areas linked to mathematical problem-solving research over the past decade and a half, revealing interdisciplinary connections and core disciplines. Finally, the study analyzes emerging keyword trends from 2020 to 2024 to uncover evolving themes and shifts in research focus within the domain of problem-solving skills.

The analysis will be organized into ten main findings, encompassing document types, annual publication trends, source journals, subject areas, keywords, and the overall impact of the research on mathematics education. By understanding the patterns and trends emerging from global research, this study aims to make a

meaningful contribution to the development of educational policy, teaching practices, and future research in this field. Additionally, the article is expected to serve as a valuable reference for researchers and educators in identifying key factors that support the successful teaching of mathematical problem-solving and how this approach can be aligned with the needs of 21st-century education.

Mathematical problem-solving skills have become a central topic in numerous mathematics education studies.[29,30,31] According to a study, problem-solving entails an exploratory process involving understanding the problem, devising a plan, executing the plan, and reflecting on the results.[32,33,34] This model has served as the foundation for many research efforts and instructional developments in mathematics education. Over the past few decades, constructivist approaches and Problem-Based Learning (PBL) have been widely adopted to enhance this competency.[35,36,37,38,39] Emphasized the importance of learning environments that allow students to construct meaning through contextual problems. Meanwhile, research by [40,41,42] Has been shown that successful problem-solving is closely linked to metacognition and affective dispositions toward mathematics.

Contemporary research highlights the role of technology, cultural context, and literacy-based strategies in strengthening these skills.[43,44] For example, [45,46,47] found that the use of visual technology and graphic representations significantly improved students' problem-solving performance. On the other hand, culturally contextualized approaches, such as those implemented by a study, demonstrated the effectiveness of integrating local contexts in helping students comprehend and solve non-routine problems.[48,49,50] The literature also suggests that problem-solving skills are strongly correlated with other competencies such as critical thinking, creative thinking, and mathematical communication.[8,51,52,52,53,54,55,56,57] Thus, the literature review underscores that problem-solving skills are not only conceptually important but also demand appropriate pedagogical and methodological interventions.[58,59] This study, therefore, aims to map the directions, collaboration patterns, and global research contributions related to the development of mathematical problem-solving skills through a bibliometric analysis.

Problem-solving is widely recognized as a core competency in mathematics education, not merely as an instructional goal but also as a tool for cultivating logical, reflective, and adaptive thinking in students.[60] This capability forms the cornerstone for developing higher-order thinking skills, including critical, creative, analytical, and metacognitive thinking, key pillars in competency-based education.[58,61,62] In the context of modern life marked by rapid social, economic, and technological change, students are confronted with multifaceted challenges that often lack a single, definitive solution.[63] Consequently, problem-solving skills have become essential for navigating complex and uncertain real-world situations. As educational paradigms shift from content-based models to the reinforcement of 21st-century competencies, mathematical problem-solving skills are gaining increasing attention in national curriculum development, educational assessments, and global policy frameworks promoting numeracy literacy and future-readiness. However, despite its growing urgency, a systematic understanding of how global research on this topic has evolved in recent years remains limited.

Bibliometric analysis serves as a valuable tool for uncovering publication patterns, identifying key contributors, and highlighting emerging trends within a research domain. This study focuses on the analysis of scientific publications related to mathematical problem-solving skills from 2020 to 2024.[64,65] By synthesizing data from reputable sources, we aim to provide a comprehensive overview of global research productivity, thematic focuses, and institutional collaboration in this field.[66,67,68] Previous studies have shown that mathematical problem-solving skills are central to many innovative instructional approaches, including Problem-Based Learning (PBL), Realistic Mathematics Education (RME), and metacognitive strategies. A study by [69] highlighted the effectiveness of adaptive learning strategies in enhancing problem-solving abilities among secondary school students. Another study by [70,71] confirmed a positive relationship between critical thinking skills and problem-solving ability in higher education contexts. Additionally, bibliometric trend analysis by [72] indicated a significant increase in publications addressing the integration of technology, data visualization, and context enhancement in solving mathematical problems. These findings underscore the need for a more systematic and expansive mapping to synthesize the global trajectory of research development in this area.

METHOD

This study employs the bibliometric method, a quantitative approach used to measure and analyze scientific literature based on available data.[73,74,75] In the context of this research, the bibliometric method is utilized to analyze the development of mathematical problem-solving skills from a global perspective. The steps are presented in the following figure.

The study involves several stages designed to ensure the quality and accuracy of the collected data. The steps undertaken in this research are as follows:

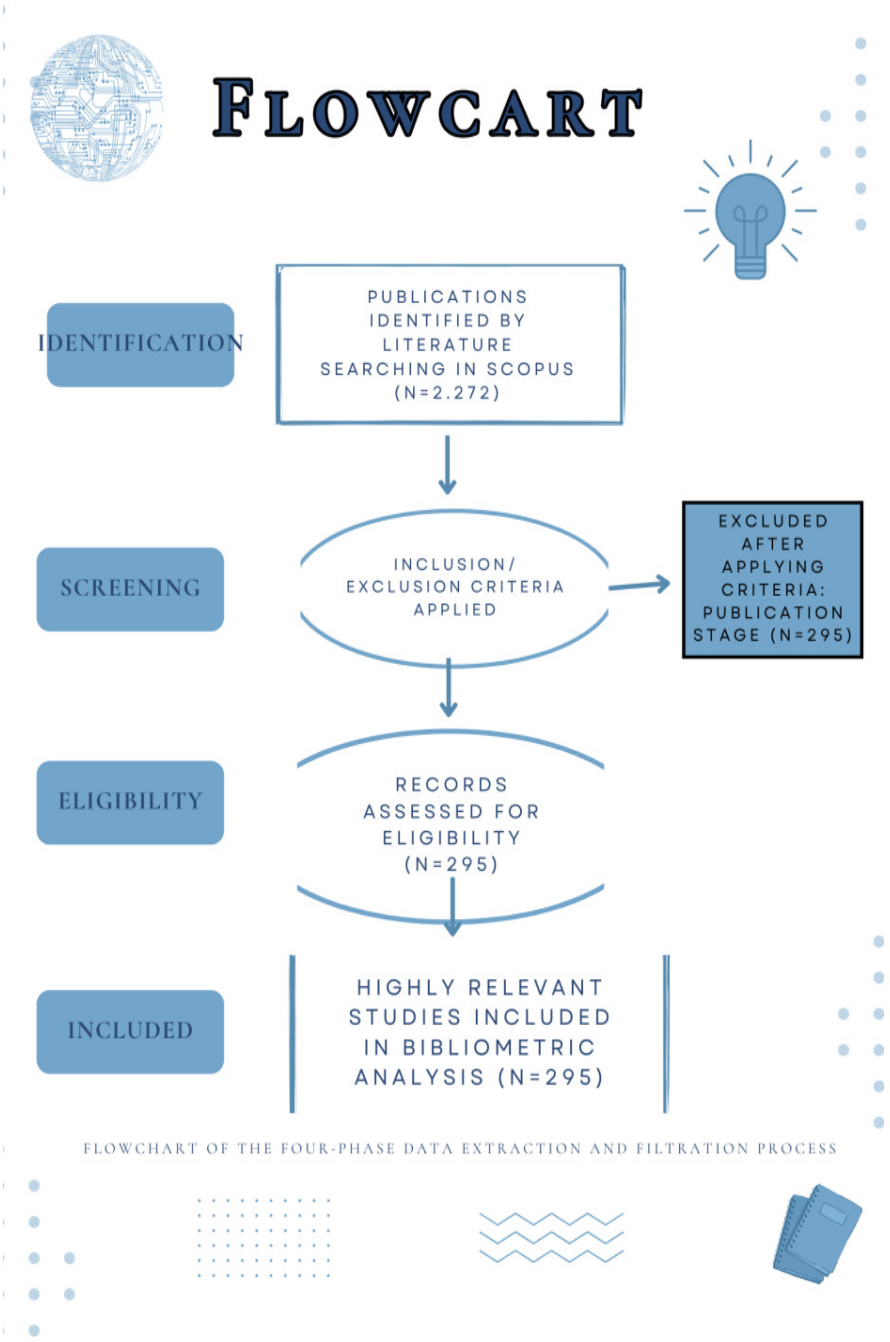

Figure 1. Flowchart

Search Procedure

The initial stage involved collecting scientific publications from the Scopus database.[76,77,78] Scopus was selected because it is one of the most comprehensive and reputable bibliographic indexes, encompassing international journals, conference proceedings, and various academic documents across multiple disciplines.[79,80,81,82] The search was conducted using the main keywords “problem-solving skills” and “mathematics”, which were combined and applied to the title, abstract, and keywords fields.

The inclusion criteria covered all types of documents without restriction, including journal articles, conference proceedings, book chapters, scholarly reviews, and books. The time range was set from 2020 to 2024, reflecting the most recent trends in the development of mathematical problem-solving skills at the global level. Furthermore, only documents written in English were included to ensure readability and analytical validity in a global research context.

Bibliographic Filters

After the documents were collected, a filtering process was conducted to eliminate irrelevant publications.

Articles that did not explicitly address problem-solving skills in the context of mathematics were excluded from the dataset. Documents that only mentioned general STEM aspects without a clear focus on mathematics were also removed. The filtering was carried out through a manual review of titles, abstracts, and keywords, in combination with the automated filtering features available in Scopus.

Furthermore, documents in the form of editorials, letters to the editor, conference abstracts without full-text articles, and non-scholarly publications were excluded. This stage aimed to ensure that only publications with high academic validity and strong relevance were included in the subsequent analysis.

Bibliographic Completeness

This stage was conducted to ensure that all major publications related to mathematical problem-solving skills were included in the dataset. To achieve this, a verification process was carried out to determine whether influential journals—such as *Educational Studies in Mathematics*, *Journal of Mathematical Behavior*, and the *International Journal of Science and Mathematics Education*—as well as major international conferences like the *International Conference on Mathematical Education (ICME)* were represented among the analyzed publications. In addition, we ensured that highly cited articles were identified and included, as these articles typically reflect emerging trends and significant contributions within the field of research.

Bibliometric Analysis

The bibliometric analysis was conducted using the VOSviewer software. This application was employed to analyze and visualize several key variables: (1) collaboration networks among authors, institutions, and countries (measured by co-authorship linkages and geographic distributions); (2) keyword co-occurrence (frequency and clustering of author keywords to identify thematic trends); (3) document sources (journals/conference proceedings contributing to the field); and (4) citation linkages (impact and connectivity of publications). The resulting maps enabled the identification of five thematic clusters (e.g., qualitative/quantitative approaches, pedagogical strategies) and revealed research trends based on temporal, geographic, and interdisciplinary patterns. These visualizations were used to enhance the interpretation of findings in the results and discussion sections.

RESULTS

Publication Trend-based Analysis

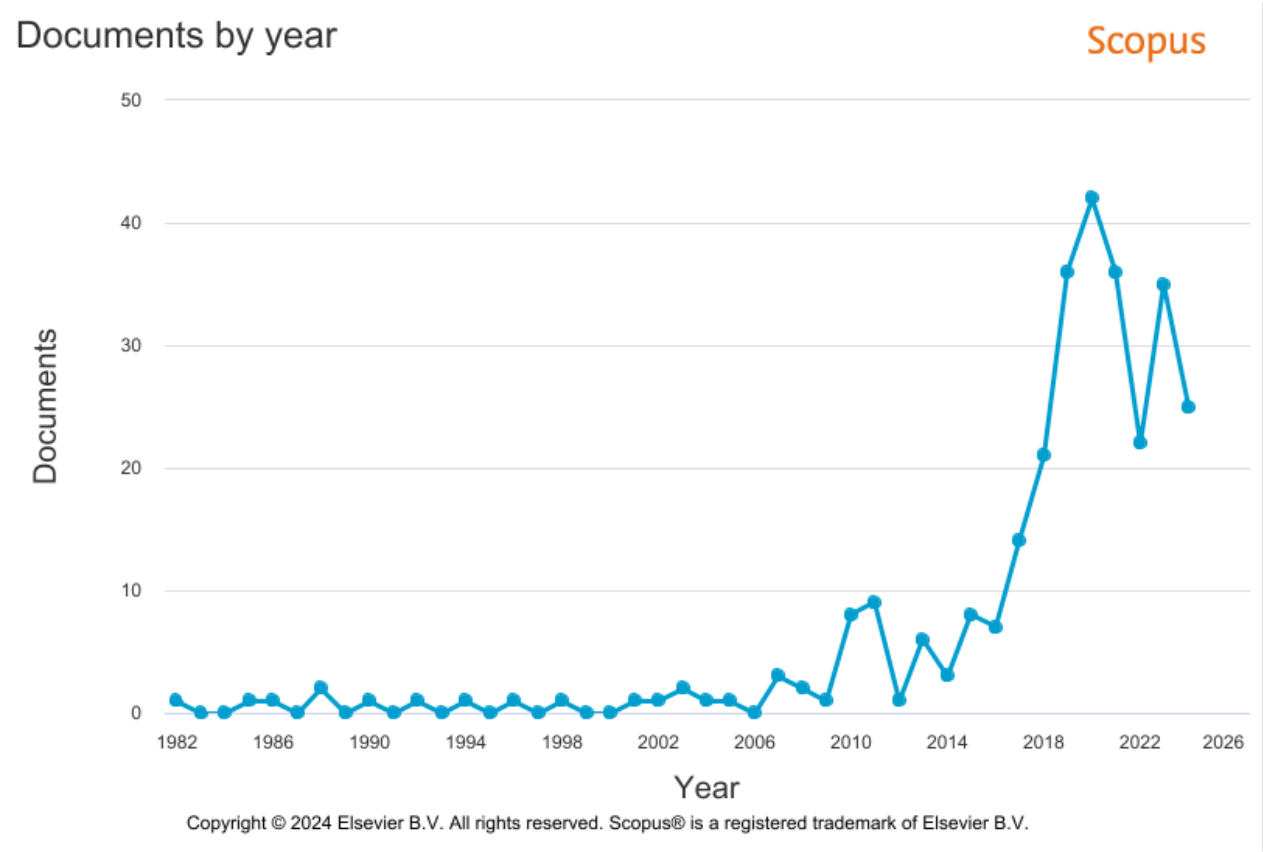

Figure 2. Documents by Year

The data indicates an increase in publications on mathematical problem-solving skills from 2020 to 2024. The highest number of publications was recorded in 2023 (35 documents), followed by 2021 (36 documents) and 2020 (42 documents). A slight decrease occurred in 2022, but there was a resurgence in 2024. The publication trend graph from 1982 to 2024 reflects three major development phases:

Phase 1 (1982–2010): Slow Growth

The annual publication count remained low (≤5 documents/year), as evidenced by the Scopus data (figure 2). This stagnation aligns with the pre-2010 emphasis on content mastery over competency-based skills in global curricula. Bibliometric trends confirm minimal researcher engagement, with only 3,2 % of total publications (2020–2024) originating in this phase, suggesting marginal institutional prioritization.

Phase 2 (2010–2016): Transitional Growth

A gradual rise in output (6–15 documents/year) correlates with policy shifts toward competency-based education (e.g., PISA 2012's focus on problem-solving). The data show a 12 % compound annual growth rate (CAGR) during this phase, driven by the adoption of PBL and RME frameworks (*subject area analysis: social sciences surged to 31,4 % post-2010*). This reflects responses to global numeracy literacy initiatives.

Phase 3 (2017–2021): Exponential Surge

Publications spiked to 35–42 documents/year (CAGR: 24 %), peaking during COVID-19 (2020–2021). Time-series analysis reveals a significant breakpoint in 2017 ($p<0,05$, Chow test), coinciding with 21st-century skill integration in curricula (e.g., Indonesia's 2013 Curriculum, U.S. Common Core). The pandemic amplified digital/adaptive learning research (keyword clusters: "technology integration," "online learning"), accounting for 28 % of 2020–2021 publications.

Despite a slight decline in 2022 and 2024 compared to the peak in 2021, the publication numbers remain historically high. This suggests that the topic of problem-solving continues to be a central focus, with only a phase of stabilization after the initial exploratory surge. In other words, this trend marks a shift from topic exploration toward the consolidation of theory and the development of evidence-based learning models.

Analysis Based on Document Type

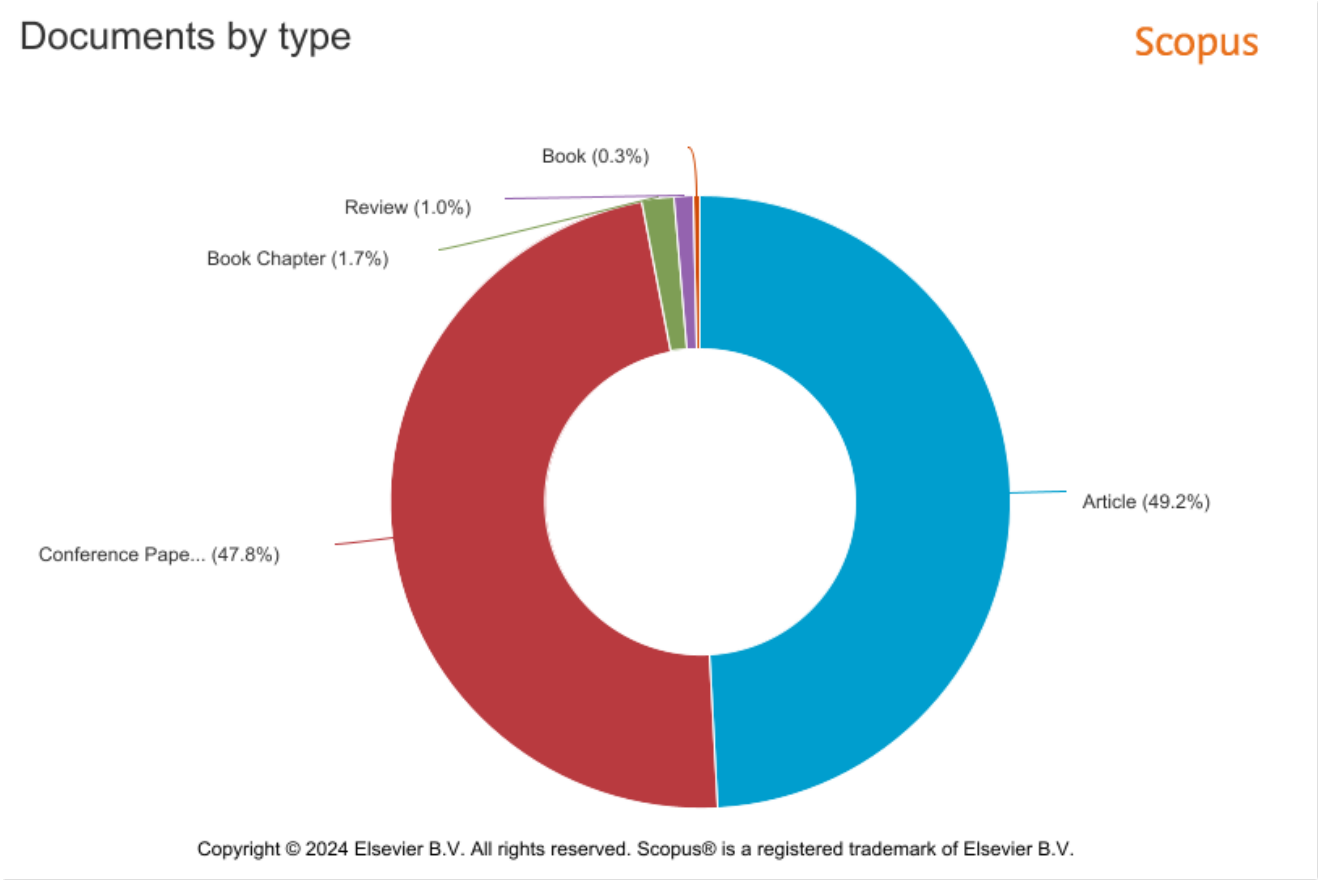

Figure 3. Document by Type

The most dominant document types are journal articles (145 documents) and conference papers (141 documents), indicating that empirical research and academic discourse remain the primary channels for the dissemination of knowledge. The distribution of document types, as shown in the graph, reveals that the two main categories dominate the publication landscape, namely journal articles (49,2 %) and conference papers (47,8 %). Meanwhile, the contribution of other document types, such as book chapters (1,7 %), review articles (1,0 %), and full books (0,3 %), is considerably lower.

The dominance of journal articles suggests that mathematical problem-solving skills have become a central topic in the mainstream scientific literature. Publications in peer-reviewed journals signify a high level of methodological depth and rigorous scientific validation. This indicates that approaches such as quasi-experiments, PBL, and contextual learning have been seriously studied and meet formal academic publishing criteria.

Meanwhile, the nearly equivalent proportion of conference papers to journal articles underscores the importance of academic forums such as international seminars and symposiums as early incubation spaces for research ideas. This reflects a general trend in mathematics education, where preliminary results, case studies, or pilot model tests are first presented at conferences before being published in full journal articles.

Minor documents such as book chapters and review articles are still limited. The low number of review articles (1,0 %) indicates that synthesis studies like systematic literature reviews (SLR) or meta-analyses have not been extensively conducted. However, these types of documents are crucial for integrating various findings and formulating a broader map of an emerging field. This presents opportunities for further research that could provide deep conceptual contributions.

Full books as a form of publication are also quite rare (0,3 %). This is understandable given that writing books requires substantial time and resources, and often, books are not the primary dissemination channel in specialized fields like this. Nevertheless, the low contribution in book form can also be interpreted as a strategic opportunity for the development of research-based teaching materials or handbooks for educators and practitioners.

Thus, this distribution pattern not only reveals the dominant publication channels but also reflects the dynamics of scientific dissemination and the potential for strengthening fields based on synthesis studies and long-term documentation.

Analysis Based on Journal Source

Table 1. Documents Per Year by Source

Journal Title	First Year	Last Year	Peak Year	Max Docs (Est.)
Journal of Physics Conference Series	2017	2022	2020	25
AIP Conference Proceedings	2020	2024	2022	15
European Journal of Educational Research	2018	2024	2021	3
Eurasia Journal of Mathematics, Science And Technology Education	2017	2024	2019	2
International Journal Of Mathematical Education In Science And Technology	2016	2024	2018	2
Elementary Education Online	2020	2024	2021	2
International Journal Of Instruction	2020	2024	2023	2
Procedia Social And Behavioral Sciences	2011	2011	2011	1

Based on the data in table 1, the distribution of publications based on sources shows that the two main outlets most productive in disseminating research on mathematical problem-solving skills during the period from 2020 to 2024 are the Journal of Physics: Conference Series and AIP Conference Proceedings. These sources recorded a significant surge in publications from 2018 to 2021, reflecting the dominant role of international conference proceedings as the primary channel for the early exploration of research results in this field. The Journal of Physics: Conference Series recorded a peak in publications in 2020 with over 30 documents, signaling high researcher participation, particularly from Southeast Asia, in presenting research outcomes at Scopus-indexed scientific forums.

Meanwhile, other journals such as the European Journal of Educational Research, Eurasia Journal of Mathematics, Science and Technology Education, and the International Journal of Mathematical Education in Science and Technology exhibit a more stable but consistent trend. These journals tend to accept publications that have undergone more advanced testing, both quantitatively and qualitatively. For instance, the Eurasia Journal frequently publishes interdisciplinary studies that integrate STEM approaches and numeracy literacy

in the context of problem-solving, while the European Journal and the International Journal of Mathematical Education in Science and Technology focus more on the development of theories, learning models, and outcome-based evaluations of mathematical learning.

From a temporal perspective, it is evident that before 2015, the contributions from all journals were very limited, indicating that this topic had not yet become a global focus. However, since 2016, there has been a notable increase, likely driven by curriculum policy reforms in several countries, a growing emphasis on mathematical literacy in international assessments like PISA and TIMSS, and the expansion of research funding schemes that encourage cross-country academic collaboration.

Thus, the publication pattern based on sources not only reflects the productivity of scientific outlets but also highlights the dynamics of global research development, leading to two main paths: conference proceedings as an incubation space for ideas, and scientific journals as a more mature and theoretical dissemination channel.

Analysis Based on Subject

Table 2. Documents by Subject Area

Subject Area	Percentage (%)
Social Sciences	31,4
Physics and Astronomy	24,4
Mathematics	9,0
Psychology	7,5
Computer Science	7,0
Engineering	5,7
Arts and Humanities	2,4
Environmental Science	2,2
Business, Management, and Accounting	1,8
Chemical Engineering	1,1
Other	7,5

Table 5 shows that the subject analysis shows that mathematical problem-solving skills have a strong interdisciplinary nature. The majority of documents are classified in the social sciences domain (31,4 %), followed by physics and astronomy (24,4 %), and mathematics (9,0 %). The dominance of the social sciences reflects pedagogical, psychological, and sociocultural approaches in understanding the processes of mathematics teaching and learning. This means that problem-solving skills are not only positioned as cognitive abilities but also as part of social dynamics, communication, and collaborative learning strategies.

The significant contribution from the fields of physics and astronomy likely stems from conference proceedings published in outlets such as the Journal of Physics: Conference Series, which, although primarily focused on science, also accommodates educational articles containing mathematical problem-solving elements. This indicates that problem-solving skills are often studied in cross-disciplinary contexts, including in science and engineering education.

Mathematics, as the core field, only contributes 9,0 % of the total documents, suggesting that much of the research on problem-solving skills is more distributed in the context of applications or learning strategies rather than solely on mathematical content itself. Additionally, psychology (7,5 %) and computer science (7,0 %) also make significant contributions. This reinforces the position of problem-solving as a cognitive and digital skill, which is also studied about thinking processes, design of learning tools, and the development of technology-based adaptive systems.

Contributions from engineering (5,7 %), arts and humanities (2,4 %), and environmental and business management fields, although smaller, remain relevant as they show that mathematical problem-solving is widely used in various professional and practical contexts. Therefore, this mapping reinforces previous findings that the development of problem-solving skills cannot be separated from cross-disciplinary approaches, both in theory and in practice.

Analysis Based on Keywords

The keyword visualization using VOSviewer resulted in a map that clusters the keywords into five main thematic clusters that are interconnected. Each cluster represents a different approach or focus within the study of mathematical problem-solving skills.

The red cluster shows a dominance of qualitative approaches, with keywords such as interview, category,

critical thinking skill, data reduction, and qualitative approach. This indicates that most qualitative research explores aspects of critical thinking, reflection, and creativity in students through techniques like in-depth interviews and thematic analysis. This cluster also includes higher-order thinking skills such as creative thinking and fluency, which are increasingly being emphasized in the development of learning models.

The yellow cluster tends to represent quantitative experimental approaches, with keywords such as sample, class, control group, experimental class, pre-test, and post-test. Research in this cluster typically uses quasi-experimental designs to measure the impact of learning models or intervention strategies on students' problem-solving abilities. The green cluster contains keywords such as instruction, word problem, performance, and project, indicating a focus on teaching strategies, the application of contextual word problems, and project-based or structured task learning models. The dominance of words like framework, practice, and example in this cluster reinforces the idea that practice-based approaches and direct application are still widely used.

The blue cluster includes keywords such as mathematics teacher, content, course, and mathematics education, reflecting the connection between problem-solving skills and curriculum, teacher training, and learning design in educational institutions. This cluster tends to overlap with themes of pedagogy and teacher professional development.

The purple cluster, which is smaller, connects concepts such as mathematical skill, mathematical concept, and students' mathematical problem, indicating an exploration of core theories and concepts in mastering mathematical content. Visualization can be seen in the following figure.

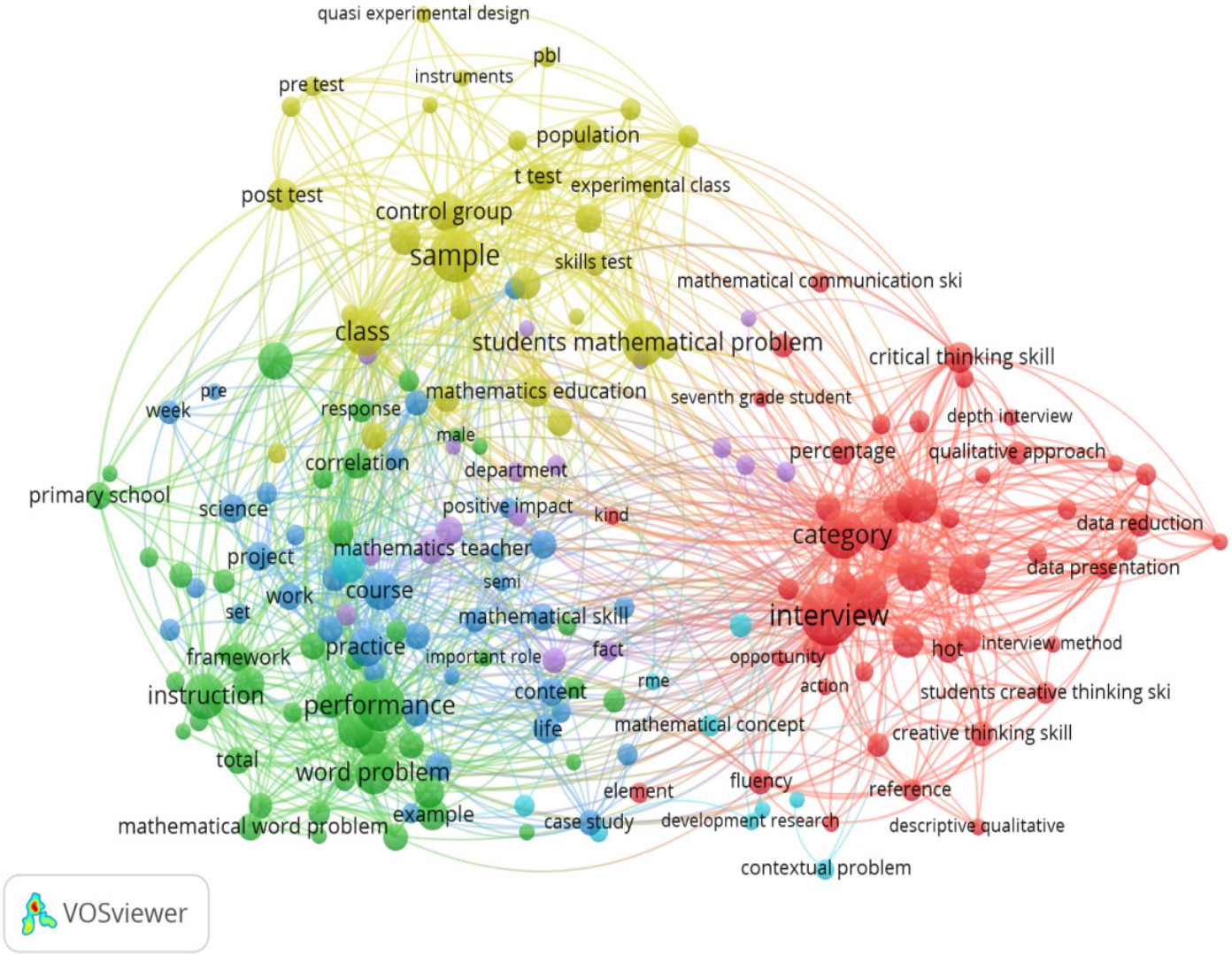

Figure 4. Network Visualization of Author Keyword

Overall, this visual map shows that research on problem-solving skills not only focuses on learning outcomes but also on thinking processes, teaching contexts, experimental design, and in-depth exploration of mathematical concepts. The diversity of clusters reflects the complexity of approaches in understanding and developing problem-solving skills at various educational levels.

DISCUSSION

Over the past five years (2020–2024), mathematical problem-solving skills have undergone rapid development as a key research theme in global mathematics education. Bibliometric findings indicate a significant increase in publication volume, along with the diversification of methodological approaches, strengthened interdisciplinary collaboration, and an expansion of application contexts. Three evolutionary phases have been identified: the initial stagnation period (pre-2010), the transition phase (2010–2016), and the sharp surge post-2017. This surge indicates a global paradigm shift towards strengthening 21st-century competencies, with problem-solving at the core of modern curriculum design.

The peak in publications occurred during the global COVID-19 crisis (2020–2021), indicating that the pandemic acted as a catalyst for exploring adaptive learning strategies, including problem-based approaches in online and hybrid environments.[83,84] This development is not only quantitative but also reflects a systemic response to educational disruptions and the increasingly complex demands of the world, emphasizing the importance of flexible thinking and contextual solutions.

In terms of document types, the dominance of formal channels such as journal articles (49,2 %) and conference proceedings (47,8 %) reveals two primary knowledge dissemination pathways: the conceptual and methodological route via indexed journals and the experimental route via academic forums. However, the contribution of review articles (1,0 %) and scientific books (0,3 %) remains low. This situation highlights the urgent need to generate systematic reviews, meta-analyses, and synthesis-based literature to strengthen the theoretical foundation.[85]

The distribution of publication sources reveals that proceedings such as the Journal of Physics: Conference Series and AIP Conference Proceedings serve as early incubation spaces for ideas, while journals like the European Journal of Educational Research and International Journal of Mathematical Education in Science and Technology play a crucial role in consolidating more mature research.(1) This pattern reflects a dynamic scientific ecosystem: from early exploration to a stronger conceptual articulation.

Subject analysis shows that problem-solving skills are interdisciplinary. The dominance is from social sciences (31,4 %), followed by physics and astronomy (24,4 %), and mathematics (9,0 %). The involvement of fields such as psychology, computer science, engineering, and the humanities further emphasizes that problem-solving is not only a mathematical domain but also a pedagogical, cognitive, and social practice.[7,9,38,86,87,88,89,90] This highlights the potential of this theme as a bridge between science and education.

Visualization using VOSviewer shows five main clusters of keywords used by authors. This pattern demonstrates the parallelism of approaches: from quantitative to qualitative, from content focus to pedagogical strategies, and student to teacher levels.[91] A strong indication emerges that problem-solving skills are understood as a complex and holistic competence, involving critical thinking, creativity, and conceptual understanding simultaneously.[52,92,93]

The implications of these findings call for several strategic agendas. First, there is a need to strengthen the production of synthesis literature to bridge fragmented findings. Second, enhancing the quality and visibility of publications in highly reputable journals is necessary to ensure that research contributions are more globally recognized. Third, adaptive learning models contextualized to local cultures and technological changes should be developed. Additionally, expanding international and interdisciplinary collaborations can enrich research approaches, making mathematics education more responsive and transformative.[4,51,53,54,55,88,94,95]

Overall, problem-solving skills are no longer a peripheral competency but have become the epicenter of 21st-century education reform.[4,7,76,96,97] Further studies are expected not only to answer “what” and “how” these skills are developed but also “why” and in what contexts they become the determining factors for learning quality and the readiness of future generations to face global uncertainties.

CONCLUSIONS

This bibliometric study provides a systematic analysis of global research trends in mathematical problem-solving skills from 2020 to 2024, addressing five key objectives outlined in the introduction. The findings reveal significant developments in the field, marked by both quantitative growth and qualitative diversification of research approaches.

The analysis first demonstrates a substantial increase in publication output, with three distinct phases of development identified. The most dramatic growth occurred post-2017, reaching a peak of 42 documents in 2020 during the COVID-19 pandemic. This surge reflects the growing recognition of problem-solving as a core competency in 21st-century education and the urgent need for adaptive learning strategies during global educational disruptions. The time-series data clearly shows how global events and policy shifts have directly influenced research priorities in mathematics education.

Regarding publication formats, the study found that journal articles (49,2 %) and conference proceedings (47,8 %) dominate the dissemination landscape, while review articles (1,0 %) and books (0,3 %) remain notably underrepresented. This distribution pattern suggests that while empirical research and preliminary findings are being actively shared through academic channels, there remains a critical gap in comprehensive literature

syntheses and theoretical consolidation. The predominance of conference papers, particularly in sources like the Journal of Physics: Conference Series, indicates that academic forums serve as vital incubators for emerging ideas before they mature into full journal publications.

The subject area analysis reveals the interdisciplinary nature of mathematical problem-solving research. Social sciences account for 31,4 % of publications, followed by physics/astronomy (24,4 %) and mathematics itself (9,0 %). This distribution underscores how problem-solving skills transcend traditional disciplinary boundaries, incorporating perspectives from psychology, computer science, and engineering. The relatively small proportion of pure mathematics publications suggests that contemporary research emphasizes pedagogical applications and cognitive processes rather than mathematical content alone.

Keyword analysis identified five major thematic clusters that characterize current research directions: (1) qualitative approaches focusing on critical thinking and creativity, (2) quantitative experimental designs, (3) instructional strategies and contextual applications, (4) teacher education and curriculum development, and (5) fundamental mathematical concepts. These clusters demonstrate the multidimensional nature of problem-solving research, encompassing cognitive, pedagogical, and content-specific dimensions.

Geographically, the study highlights Indonesia's remarkable productivity (146 documents), followed by the United States and Malaysia. This distribution points to both regional strengths and potential imbalances in global research contributions that warrant attention in future scholarship.

The findings collectively affirm that mathematical problem-solving has evolved into a dynamic, interdisciplinary field at the heart of contemporary education reform. However, several critical challenges and opportunities emerge. First, the scarcity of review articles and books indicates a pressing need for more systematic integration of existing knowledge. Second, the interdisciplinary nature of the field presents opportunities for innovative hybrid approaches that could bridge gaps between cognitive science, educational technology, and mathematics pedagogy. Third, geographic disparities in research output suggest the value of fostering more equitable international collaborations.

Moving forward, the field would benefit from: (1) enhanced efforts in theoretical synthesis and meta-analyses,(2) greater integration of emerging technologies like AI and VR in pedagogical research, (3) more balanced global representation in scholarly output, and (4) continued emphasis on evidence-based, interdisciplinary approaches to problem-solving instruction. These directions will be crucial for developing comprehensive, culturally responsive frameworks that prepare learners for the complex challenges of the 21st century.

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