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Mathematical Critical Thinking Skill: A Bibliometric Analysis Based on Vos Viewer Bibliometric

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Abstract

This bibliometric analysis aims to see the opportunities and development of research trends related to mathematical critical thinking skills from 2019 to 2024. Through a bibliometric approach, this research will map publication trends based on the Scopus database by using Vos Viewer to analyze the data. The results of this study show the most publications and citations in 2020 as many as 55 publications and 777 citations, and a decrease in publications and citations from 2021 to 2024. Terms that are often related to mathematical critical thinking skills are students, problems, critical thinking, mathematics, and STEM.

Keywords: Ability, Critical thinking, Mathematical.

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1. Introduction

Mathematical critical thinking is the ability to analyze, evaluate, and make logical decisions in solving mathematical problems. Critical thinking skills are one of the key competencies that are increasingly recognized as important in 21st-century education, especially in mathematics teaching. Critical thinking is so important to learn for several reasons, among others: critical thinking is a necessary skill in any job, when studying any field of science, and when solving any problem, and it is a valuable asset for one's career. Worley (2019) emphasizes the importance of developing children's critical thinking skills at primary school age and states that critical thinking should be a habit that starts early. Critical thinking skills will help students communicate ideas, analyze, synthesize, evaluate information, and adapt it to their own knowledge. These skills are essential for understanding abstract concepts and solving

mathematical problems logically and systematically, equipping students with relevant competencies for life and the world of work. A research report conducted by Aswanti and Isnaeni (2023) found that mathematical critical thinking skills play an important role in teacher education, especially in preparing prospective teachers to face complex global challenges. Therefore, every student needs to develop critical thinking skills in mathematics. Students with high critical thinking skills view a problem from various sides and are more open-minded and rational, make decisions supported by evidence, draw conclusions based on the facts, and finally solve the problem (Sutama et al., 2022).

The World Economic Forum (2023) reports that critical thinking ranks second out of the top 10 most needed skills for the future of work in 2025, with 50% of workers requiring significant upskilling in this aspect. However, the literature on critical thinking skills in mathematics is still widespread and poorly integrated, making it difficult to understand research trends and directions in this area. A recent meta-analysis by Systematic Reviews in Educational Research (2023) that included 245 studies from 45 countries identified a significant gap between industry needs for critical thinking skills and mathematics learning outcomes in secondary schools, with a 35% gap between employer expectations and graduate competencies. Research on critical thinking and using it in education has increased significantly in recent years, making it one of the four most frequently mentioned skills in national policy documents from 152 countries (Care, Kim, Vista & Anderson, 2018). In addition, in many international documents, it is one of the most important foundational skills set for individuals to possess (APA, 1990; P21, 2011; ISTE, 2016; OECD, 2018; ATCS, 2020; World Economic Forum, 2020).

This study offers a unique contribution by incorporating a bibliometric analytical approach, enabling a broader and deeper perspective on research dynamics in this area. By integrating current global data on labor market needs, technological trends, and international educational practices, this study not only provides a clear mapping of trends and collaborations in the area of mathematical critical thinking skills but also provides a basis for the development of curricula and educational practices that are more responsive to 21st century needs. Thus, this study aims to fill this gap by conducting a bibliometric analysis to identify global trends, uncover citation and collaboration patterns, and explore themes and gaps in the literature.

This research is not only relevant for researchers. However, it can also guide educational policymakers and practitioners in structuring learning programs that support the development of student's critical thinking skills and provide practical implications for future educational policies. This research aims to uncover the evolution of critical thinking in the literature by analyzing bibliometric data such as year of publication, citations, and most frequently selected keywords, as well as to identify subjects. The results of this study are expected to significantly contribute to the scientific literature and advance educational practices in the development of critical thinking skills in mathematics.

2. Methods

This research uses Bibliometric Analysis to provide a mapping of research that addresses critical thinking skills in learning mathematics. This analysis is very suitable for identifying publication patterns, collaboration, and topic trends in global research. Bibliometric analysis explores publication trends and citation patterns based on data from Scopus-indexed scientific journals.

The data in this research was obtained from the Scopus database because the quality of the articles from the database is of high quality and the coverage is broader, using the keyword

"critical thinking skills in mathematics" from 2019 to 2024 in order to focus on the latest research trends collected on November 10, 2024. Articles in 2018 and below were not used because they only focus on the last 5 years of publication and look at the article's novelty based on keywords.

Based on the search criteria, namely, Scopus indexed articles, English using Harzing's Publish or Perish search application, both in the form of journal articles and conference articles. The use of this application is very relevant because the data displayed is accurate based on bibliographic metadata. The search found 198 published articles based on the keyword "critical thinking skills in mathematics." The source widely used to find data about scientific publications is the Scopus database, the largest data center in the world, which provides accurate metadata about each article, ranging from publication date and abstract to references (Mohammad & Azmi, 2023). Data was analyzed from search applications using Microsoft Excel and then VOSviewer to visualize it. Microsoft Excel is used to analyze data based on year of publication, type of article, and number of citations from year to year, then make a graph. Data analysis was based on the number of articles per year and the number of citations per year, which were analyzed in Microsoft Excel, and then a graph was made. Then the analysis was carried out using VOSviewer to display bibliometric maps in an easy way to interpret the data (van Eck & Waltman, 2020). The results of bibliometric analysis are used to visualize clusters based on keywords. The results of this method are expected to provide a clearer picture of the dynamics of mathematical critical thinking research and significantly contribute to the development of future research and educational practice.

3. Results and Discussion

3.1 Results

Scopus-indexed articles discussing mathematical critical thinking skills published from 2019 to 2024 amounted to 198 articles, with a yearly distribution. In 2019, the number of publications was recorded as 42; there was an increase in 2020 of 55 articles. However, in the following year, there was a decrease from 2021 to 2024. From 2019 to 2020, there was an increase of 7%, but there was a decrease starting in 2021 by 8%. A drastic decline occurred from 2023 to 2024 by 12%.

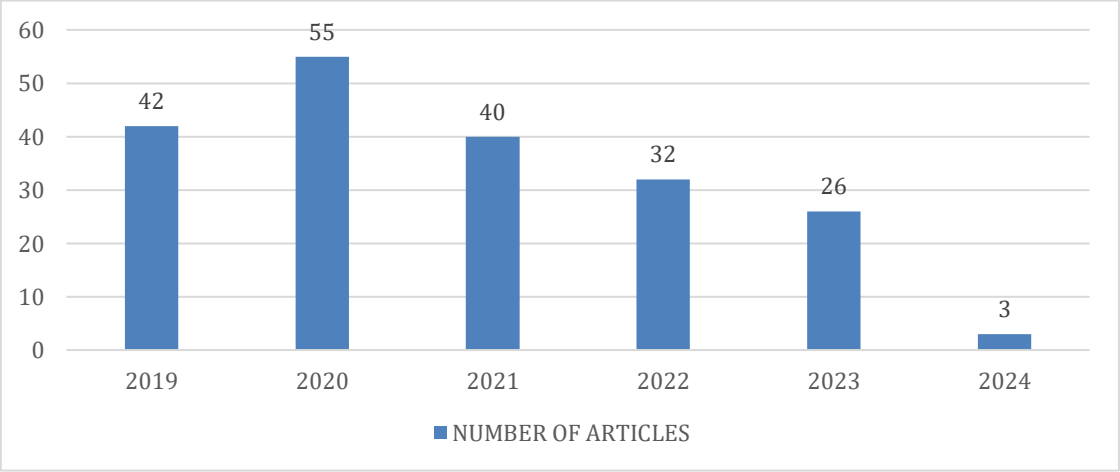

Figure 1 Publications by Year of Publication

This data indicates that the trend for examining the theme of critical thinking skills has declined over the past four years.

Table 1 - Types of Publications

Year	Conference	Article	Book Chapter
2019	18	24	0
2020	14	37	4
2021	11	27	2
2022	3	28	1
2023	1	23	2
2024	1	3	0

The distribution of publication types indexed by Scopus on mathematical critical thinking skills, namely articles, conference papers, and book chapters from 2019 to 2024. The data shows that in 2019, out of a total of 42 publications, 18 conference papers and 24 articles dominated the publications in that year. Furthermore, in 2020 there was an increase in article publications of 37 conference papers decreased by 14, and there were 3 book chapters. In 2021 the number of articles decreased by 27, conference papers by 11, and book chapters decreased by 2. In 2022 the decrease in articles increased by 28, but conference papers decreased drastically by 3, and book chapters also decreased by 1. In 2023, publications in the form of articles were 23, and conference papers were 1, but there was an increase in book chapters by 2, and in 2024, there was a drastic decrease in articles by 3 and conference papers by 1 and no book chapters. Article publications from the data found dominate the publication type each year compared to conference papers, which decrease yearly. Journal articles are considered more prestigious and have a higher academic impact than conference papers or book chapters. Publication in Scopus-indexed journals provides wider recognition and can be measured through metrics such as citations and H-index. Therefore academics are more motivated to publish journal articles than other types of publications.

This review shows that the dynamics and focus of publications have changed over the past five years, as there has been less attention to mathematical critical thinking. The data above shows a decline due to a shift in research focus, which may be influenced by educational policy or new research priorities. Therefore, a new approach is needed to renew the relevance of research on mathematical critical thinking.

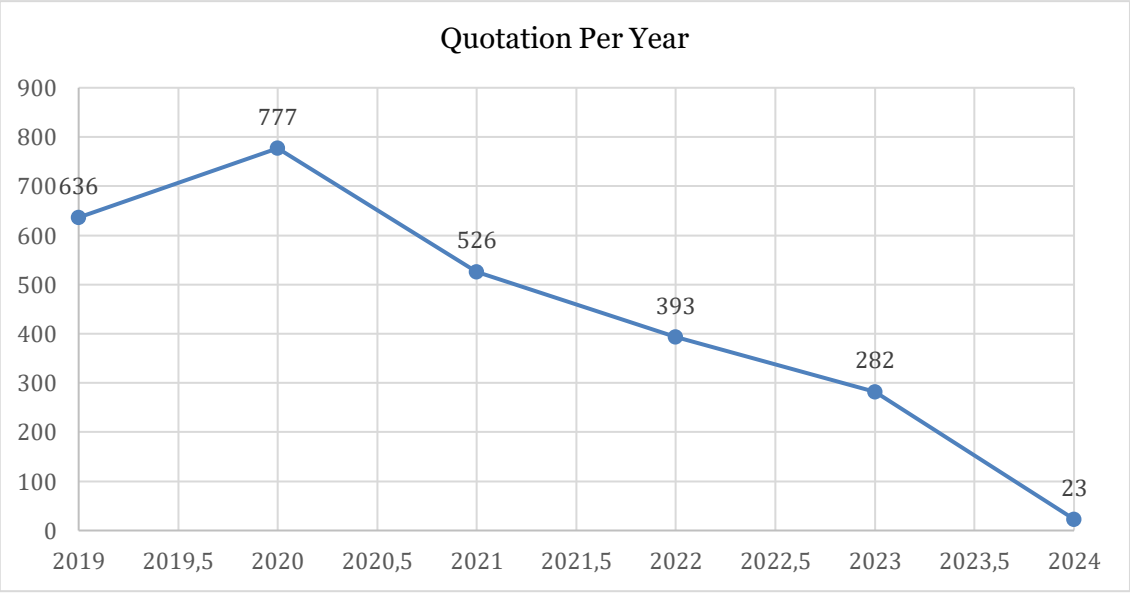

Figure 2 Citations for each year

The citation trend for mathematical critical thinking skills in Scopus-indexed articles from 2019 to 2024 shows that in 2019 the number of citations was 636, and there was an increase in 2020 of 777 citations, which was the highest peak of citations in the last 5-year analysis period. Shows that publications from previous years received a significant decline in recognition from 2021 of 526 citations of around 10%, and continued to decline in 2022 by 5%, and in 2023 the decline was around 4% and in 2024 a decrease of 10%.

A significant downward trend in citations indicates a change in research focus and the number of publications cited. The occurrence of this decline could indicate a change in the relevance of research published in previous years. Further analysis should be done to examine the factors that led to this decline, which will affect future research trends. Citation trends tend to be influenced by the relevance of research topics to current needs. Research conducted before 2021 may be less relevant to modern educational challenges or not innovative enough to support new learning approaches such as technology and STEM integration. The document notes a decline in the number of articles published since 2021, which means less new research can cite earlier articles, leading to an overall drop in citation numbers. The decline in citations in this area may reflect the need for methodological updates and the integration of innovations that are more relevant to modern challenges, such as technology-based approaches or more globalized curricula.

This is a visualization of the VosViewer App that shows the relationships often associated with mathematical critical thinking skills and terms often appearing in Scopus-indexed mathematical critical thinking skills research from 2019 to 2024.

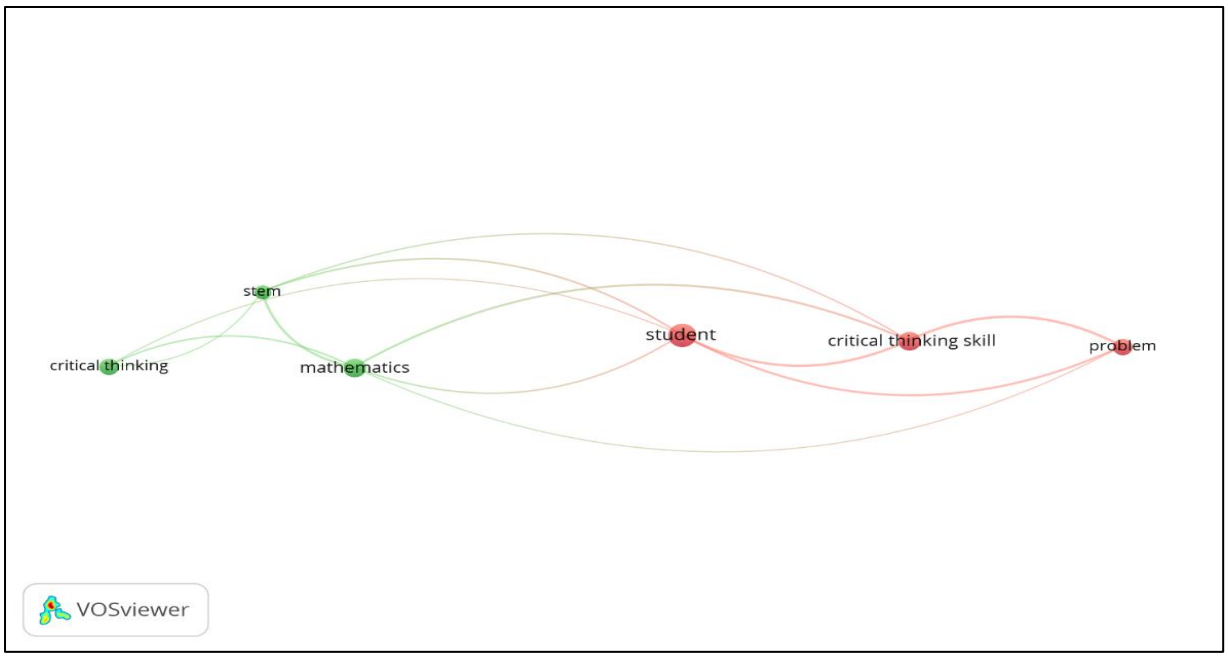

Figure 3 Network Visualization

Based on the network visualization generated through the VOSviewer analysis, it is possible to identify close relationships between several terms in the research on mathematical critical thinking. Figure 3 shows two main clusters distinguished by color: a green cluster focusing on the relationship between STEM, mathematics, and critical thinking and a red cluster highlighting the linkages between students, critical thinking skills, and problems.

In the green cluster, the relationship between STEM and mathematics with critical thinking indicates that the STEM approach is often used as a tool to improve critical thinking

skills in the context of mathematics learning. This is consistent with the results of Yulia's (2020) research, which found that the application of STEM in mathematics education can improve students' critical thinking skills and the importance of STEM education. The relationship between STEM and critical thinking in mathematics reflects an active and project-based learning approach. For example, students can be asked to solve real problems, such as designing a simple tool prototype using math and science principles. STEM-based learning supports the development of critical thinking skills through activities that involve interpreting data, solving complex problems, and making evidence-based decisions. STEM provides a broad context that allows students to explore and understand abstract concepts through real applications.

Meanwhile, the red cluster highlights the role of students as the main actors in developing critical thinking skills, with a special focus on problem solving, indicating that existing research places students at the center of the learning process that aims to hone their critical thinking skills. The strong relationship between students, critical thinking skills, and problems is very important because problem-based learning can improve critical thinking skills in students (Tri & Badraningsih, 2020). This relationship shows that students are the main actors in the process of developing critical thinking skills. Problem-solving allows students to integrate their knowledge, test hypotheses, and reflect on solutions. Problem-based approaches also allow students to learn through real contexts, encouraging their engagement in more meaningful learning. Problem-solving ensures students' direct involvement in learning, leading them to develop systematic and logical critical thinking patterns.

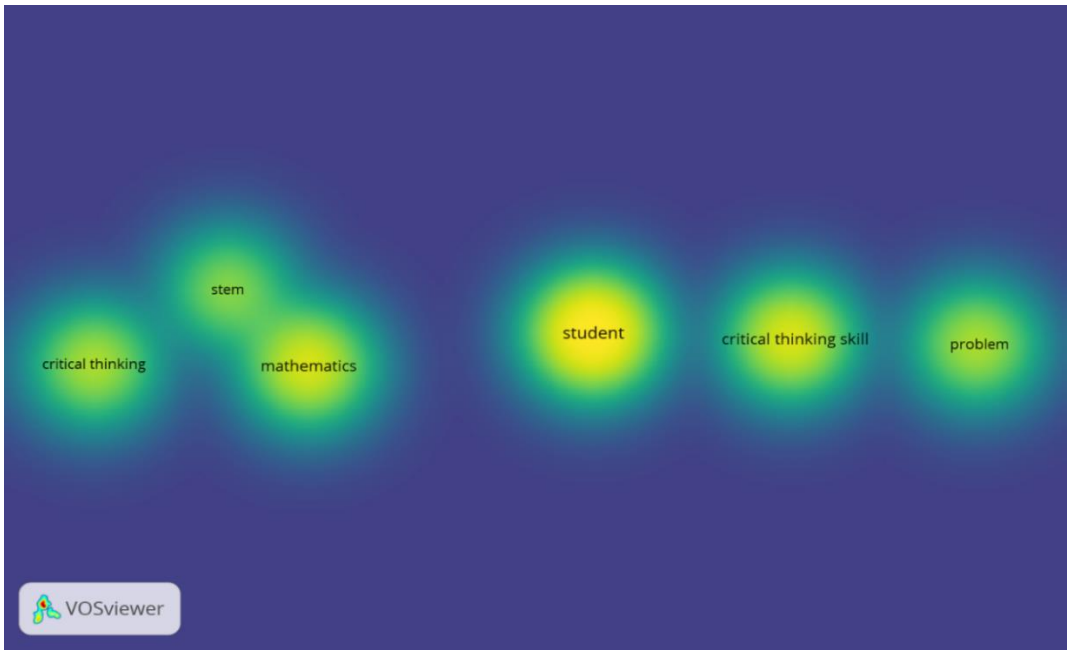

Figure 4 Density Visualization

Based on the density map visualization from VOSviewer shown in Figure 4, several terms have a high-density level, indicating strong significance and frequency in the related literature. The dominant yellow colour at several points, such as student, critical thinking skills, mathematics, and problem, reflects that these topics are often discussed and become the main focus in mathematical critical thinking skills research. This shows that students play a major role in mathematical critical thinking research published in Scopus from 2019 to 2024. The focus on students reflects their role as the main subject in developing critical thinking skills.

Research that places students at the centre of learning demonstrates student-centred approaches, such as problem-based learning or STEM-based approaches.

The link between critical thinking, STEM, and mathematics strengthens the argument that critical thinking skills are often integrated in the context of STEM learning, particularly in mathematics. This is supported by research results (Elbashir, A. & Alkhair, Shahad & Al-Thani; Noora, 2024). This study provides strong evidence that STEM education programs significantly improve critical thinking skills among high school students. These findings suggest that the STEM approach effectively improves critical thinking skills. The visualization shows a close relationship between STEM, mathematics, and critical thinking (green cluster), strengthening the argument that STEM integration provides a real and relevant learning context to hone students' critical thinking skills.

3.2 Discussion

The findings from this bibliometric analysis and systematic review significantly contribute to the literature addressing mathematical critical thinking skills. From 2019 to 2024, based on the Scopus database, there was an initial increase in publications addressing this topic. However, a significant decline followed this in the number of publications and citations since 2021. This decline in publication and citation trends suggests a shift in focus or decreased interest in this topic among researchers, as well as a possible change in the relevance of previous research results to the challenges facing education today. Nevertheless, these findings enrich knowledge about the role of students in mathematical critical thinking research, especially in relation to the STEM and problem-solving approaches that were the main focus in the analyzed research clusters. The network and density visualizations show that the relationship between students, mathematics, and critical thinking is the main focus of this research. This identification provides new insights into the importance of student engagement in learning mathematical critical thinking. However, this research also revealed gaps that need to be further explored, especially regarding the integration of STEM in improving students' critical thinking skills and new approaches that are more relevant in the modern educational context. Utilize technological tools such as computer simulation, programming, or data analysis to strengthen the critical thinking element in PBL. Further research is needed to examine effective pedagogical interventions in mathematics learning that support the continuous improvement of critical thinking skills.

In addition, students and critical thinking skills have a very significant density, which indicates that students are often the main subject in research that examines critical thinking skills. This is in line with the literature that places students as central actors in the process of developing critical thinking skills, especially in the context of formal education. In addition, the strong relationship between students, critical thinking skills, and problems shows that problem-solving is still one of the main ways of assessing and developing critical thinking skills among students, which is in line with the opinion (Sutama et al., 2022) that the improvement of critical thinking based on interpretation indicators is familiarized through problem-based learning. A problem-based approach is effective for improving critical thinking skills. The data shows the terms "student" and "problem" as high-density points (red clusters), supporting this argument.

The study concluded with recommendations for educators and policymakers to develop a more comprehensive framework that supports the integration of critical thinking and problem-solving skills in the education system, ultimately preparing students to succeed in the 21st-century landscape (Lisnawati et al., 2024). The findings of this study illustrate that critical thinking skills have a relationship between students and problems that are in cluster 1 of the network visualization analysis, while critical thinking has a relationship with mathematics, and STEM is in cluster 2. Paying attention to students' mathematical critical

thinking skills can be by using STEM learning, and by looking at how students solve the problems given by the teacher, the picture found can be a reference for future researchers who will examine several focuses that have not been seen in the analysis.

This visualization confirms the importance of developing critical thinking skills by integrating STEM education and problem-based approaches. The density of terms also suggests a well-established research direction yet still leaves room for further exploration, especially in relation to innovating more effective learning methodologies to enhance critical thinking skills in students. This visualization provides valuable insights into research trends, focus, and potential gaps for future investigations. However, to enrich future research, attention must be paid to low-density areas, such as pedagogical innovation, educational technology, and global approaches. Further exploration in these areas may open up new opportunities to expand the understanding of critical thinking skills and their impact on modern education.

The visualization findings support the existing literature on the importance of STEM and problem-solving in developing critical thinking skills. However, there are opportunities to extend the research in several areas: innovations in STEM learning, contextualization of STEM, and development of evaluation frameworks. The integration of STEM and PBL will help students develop skills such as problem-solving, collaboration, and adaptation to new technologies. A STEM and PBL-based curriculum prepares students to face global challenges like technological innovation and environmental sustainability. With this approach, PBL-based STEM education improves students' critical thinking skills and prepares them to become innovators and leaders in the 21st century.

4. Conclusions

Findings from the bibliometric analysis provide a significant contribution to the literature addressing mathematical critical thinking skills from 2019 to 2024 with 198 publications, the most publications in 2020 with 55, and 777 citations, but followed by a significant decline in the number of publications and citations from 2021 to 2024. Some terms that have a high density based on Vos Viewers show strong significance and frequency in the literature, such as student, critical thinking skills, mathematics, and problem STEM. This reflects that the term is often discussed and becomes the main focus in mathematical critical thinking skills research. Given the changing dynamics of modern education, it is imperative that researchers, educators, and policymakers collaboratively develop new approaches that support the integration of STEM and critical thinking in mathematics.

Conflict of Interest

The authors declare no conflicts of interest.

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