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Trends in the Use of Critical Thinking as Mathematics Learning over the last 20 Years: Analysis Bibliometric

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Abstract: This research aims to analyze research trends on the topic of critical thinking in mathematics learning using bibliometric analysis. By selecting documents in Scopus Database using the PRISMA method, 94 documents were obtained which were analyzed using the R Program and VOSviewer. From the results of the analysis, it can be concluded that research on the Scopus database began in 2004 to 2024 or the last 20 years, with a 3-fold increase in publications in the last 6 years. 2020 was the year with the highest citation impact, namely 130(10.53%) citations. Indonesia stands out as the country with the highest number of publications at 19(20.21%) and number of citations is 145(11.75%). International Journal of Instruction stands out as the source with the highest h-index, namely 5. Universitas Islam Negeri Mataram leads with a total of 8(8.51%) publications. Suparman from the Universitas Pendidikan Indonesia is the author with the highest contribution with an h-index of 5. The article with the highest number of citations of Şendağ et al. (2009) with 241 citations. 39 keywords were obtained which were divided into 7 groups, with the keywords "Problem Solving", "Flipped Learning", "Analysis", and "Mathematics Course" the latest keywords which can be used as recommendations for further research in the field of critical thinking in mathematics learning.

Keywords: critical thinking, mathematics learning, bibliometric, biblioshiny.

▪ INTRODUCTION

Since the end of World War II, education has become one of the main pillars in human and societal development (Elfert, 2023; Machmud et al., 2021). The post-war period marked a massive push to improve the accessibility and quality of education worldwide (Bromley et al., 2024; Dunlop & Bekkouche, 2024). Education is not only seen as a means of acquiring knowledge and skills, but also as a foundation for social, economic and cultural progress (Abulibdeh et al., 2024; Vesterinen, 2024). The existence of education is no longer only considered as a necessity, but has become an indisputable necessity in the formation of a developing individual and society. Education not only provides access to information and learning, but also empowers individuals to think critically, act independently, and participate productively in social life (Alstete et al., 2024). Thus, the role and existence of education is becoming increasingly important as a foundation for human development and the progress of civilization in the post-world war era. One important part of education is a critical mindset, which allows individuals to analyze information in depth, make wise decisions, and solve problems effectively.

Mindset is the way a person views and processes the information received, including the ability to think critically, creatively and reflectively (Benvenuti et al., 2023; Essel et al., 2024). A well-developed mindset is key to individual and societal progress, as it enables people to face challenges more effectively and find innovative solutions (Klenner et al., 2022). Therefore, developing mindsets is very important and effective if

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studied by students from an early age. By learning and honing critical thinking patterns, students can be better prepared to face various problems and complex situations in the future (Gunawardena & Wilson, 2021; Yuan et al., 2021). This allows them to contribute more significantly to the development and progress of society. A strong mindset not only improves academic abilities but also prepares individuals to become leaders who are able to think strategically and act wisely in various aspects of life. One mindset that can be developed to improve analytical and problem-solving skills is to use critical thinking.

Critical thinking is a key ability that allows someone to analyze information in depth, evaluate arguments critically, and make decisions based on logic and strong evidence (Le et al., 2024; Obodoagu et al., 2024; Van Le & Chong, 2024). By applying critical thinking, individuals can see beyond the surface of information and understand deeper implications, differentiate between fact and opinion, and identify biases that may influence their judgment (Dwyer, 2023; Gandana et al., 2021). These abilities are not only useful in academic contexts, such as in reading texts or solving math problems, but are also invaluable in everyday life and in the workplace. By using critical thinking, a person can make better decisions, solve complex problems, and communicate effectively (Tang et al., 2020; Wale & Bishaw, 2020). Therefore, it is important for individuals to develop critical thinking skills from an early age, both through formal education and informal learning experiences, in order to be successful in facing the challenges they face in their personal and professional lives (Scalabrino et al., 2022; Thornhill-Miller et al., 2023). Critical thinking is important so it is the key to enriching the mathematics learning experience.

Critical thinking is important to apply in everything, including mathematics learning, because this ability allows individuals to develop a deeper understanding of mathematical concepts and apply logical reasoning in solving problems (Ananda et al., 2023; Setiana & Purwoko, 2021). This is because critical thinking allows students to identify hidden patterns, analyze the relationship between different concepts, and evaluate the truth of a statement or solution (Yan et al., 2024). In addition, by applying critical thinking, students can overcome obstacles in understanding mathematics, such as difficulties in interpreting problems or finding the right approach to solving a problem (Cahya & Juandi, 2021; Ridwan et al., 2022; Zafrullah et al., 2023). So it is important for educators to pay attention to developing critical thinking skills in the mathematics learning process, because this not only improves students' logical thinking skills, but also prepares them to become more independent and successful learners in solving problems in their lives.

The development of the times has encouraged many researchers to conduct research related to critical thinking, especially in the context of mathematics learning. This invites the author's interest in carrying out bibliometric analysis which aims to explore developments and research trends related to critical thinking in mathematics learning. With bibliometric analysis, the author aims to identify important contributions, emerging research trends, as well as knowledge gaps that still need to be explored in the literature on critical thinking in the context of mathematics learning. It is hoped that this analysis will provide deeper insight into how critical thinking has been researched and integrated in mathematics learning, as well as providing a strong basis for further research and the development of more effective learning practices.

▪ METHOD

This research aims to analyze research trends in the field of critical thinking in the context of mathematics learning. The method used is bibliometric analysis, which is a quantitative approach to exploring and evaluating relevant literature in a research domain (Goyal et al., 2021; Hanaa & Abdul, 2024; Ramadhani & Retnawati, 2024; Zafrullah & Ramadhani, 2024). Through bibliometric analysis, researchers will identify and analyze patterns in related literature, such as publication frequency, the most productive authors, the journals that produce the most work on the topic, and the keywords that are most frequently used. This analysis will provide a deeper understanding of the development and focus of research in this domain, as well as help identify further research directions and opportunities in the field of critical thinking in mathematics learning. Before carrying out the analysis, the author first conducted a data search using the Scopus database and selected using the PRISMA method.

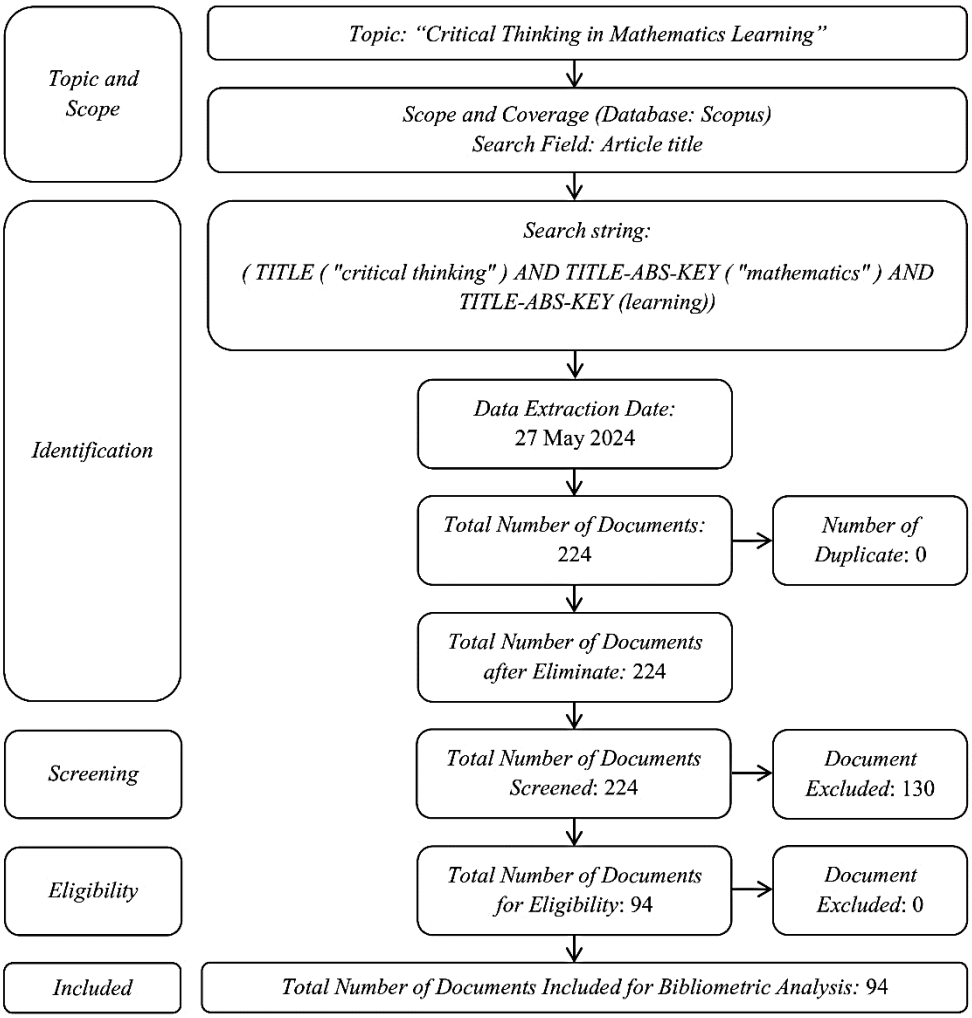

Figure 1. Data search in the scopus database and selection using the PRISMA method

By using predetermined keywords, researchers succeeded in collecting initial data of 224 documents at the identification stage. Furthermore, in the screening process, the researchers limited the search to the "Social Sciences" category and chose to consider

only articles and conference papers, which resulted in the elimination of 130 documents from the initial data. At the eligibility stage, the researcher carried out further selection by checking all the remaining documents, and from this, 94 documents were selected that met the criteria to be included in further analysis at the Included stage. The next step involves in-depth analysis using tools such as VOSviewer and R Program, which aims to uncover existing research trends and research focuses in the domain of critical thinking in mathematics learning. Thus, this process provides a clear picture of how research related to critical thinking in mathematics learning has developed, as well as providing a strong basis for further understanding of the topic.

▪ RESULT AND DISSCUSSION

Main Information

This research covers the time span from 2004 to 2024, with a total of 66 sources consisting of journals, books, and others, and collected 94 documents. The annual growth rate of documents in this field reached 10.96%, indicating a steady increase in critical thinking research in mathematics learning. With an average document age of 4.5 years and an average of 13.12 citations per document, this research also has a fairly strong foundation in the scientific literature. Of the 3782 references cited, this analysis also shows that there are 261 keywords used by the author and 176 additional keywords. In terms of author contributions, there were 266 authors involved, with 9 documents written by a single author. The level of international collaboration also appears quite significant with 7,447% of documents having authors from various countries. In addition, there were an average of 3.07 authors per document, indicating the high level of collaboration between authors in this research. The documents analyzed consisted of 83 articles and 11 conference papers, indicating a primary focus on the publication of scientific articles.

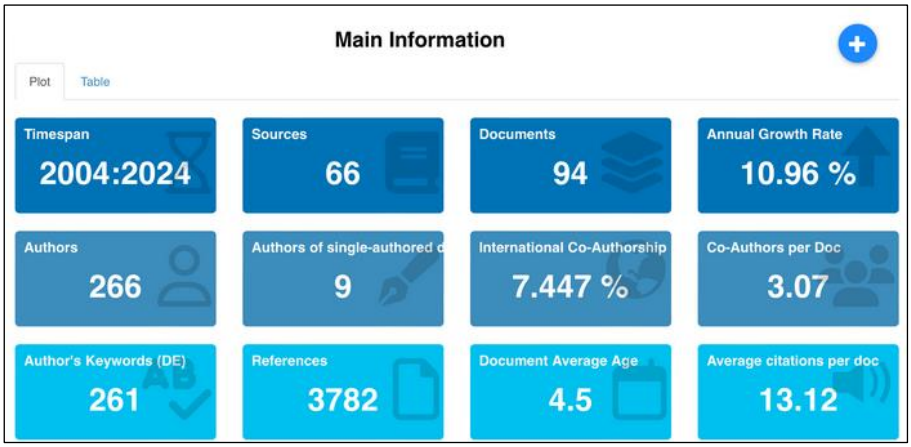

Figure 2. Main information about critical thinking in mathematics learning at R program

Publications and Citations Trends

Research in the field of critical thinking in mathematics learning shows a significant increasing trend in recent years. From 2004 to 2018, only 23(24.46%) publications were published in that period. Meanwhile, from 2019 to 2024 or the last 6 years, the number of publications experienced a very significant increase, namely 71(75.53%) publications or a 3-fold increase. In 2019 the number of published documents experienced a very

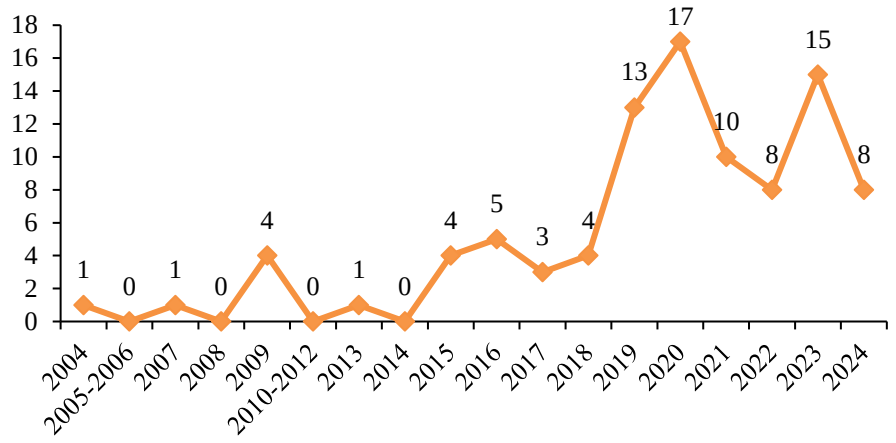

Figure 3. Line chart of publication trends from year to year about critical thinking in mathematics learning

significant increase, namely 13(13.82%) documents. This increase continued and peaked in 2020 with a total of 17 documents, reflecting the extraordinary surge in interest and research activity in that period. That. This drastic increase may be due to the development of new methodologies, increased awareness of the importance of critical thinking in mathematics education, or various other factors that encourage more researchers to contribute to this topic. After peaking in 2020, the number of published documents decreased slightly, but remained high, indicating continued interest and active research in this area with 10(10.64%) documents in 2021, 8(8.51%) documents in 2022, and 15(15.96%) documents in 2023.

Table 1. Citation trends about critical thinking in mathematics learning

Years	Total of Documents[a]	Total of Citations[b]	Number of Citations[c]	h-index
2004	1(1.06%)	8(0.65%)	1(1.39%)	1
2005-2006	-	-	-	-
2007	1(1.06%)	43(3.48%)	1(1.39%)	1
2008	-	-	-	-
2009	4(4.26%)	279(22.61%)	4(5.56%)	4
2010-2012	-	-	-	-
2013	1(1.06%)	-	-	-
2014	-	-	-	-
2015	4(4.26%)	76(6.16%)	4(5.56%)	4
2016	5(5.31%)	117(9.48%)	4(5.56%)	3
2017	3(3.19%)	32(2.59%)	3(4.17%)	3
2018	4(4.26%)	187(15.15%)	4(5.56%)	3
2019	13(13.82%)	102(8.27%)	11(15.28%)	7
2020	17(18.09%)	130(10.53%)	16(22.22%)	7
2021	10(10.64%)	126(10.21%)	10(13.89%)	6

2022	8(8.51%)	105(8.51%)	8(11.11%)	6
2023	15(15.96%)	15(1.22%)	5(6.94%)	2
2024	8(8.51%)	14(1.13%)	1(1.39%)	1

a: Total publications for that year
b: Total citations in all documents for that year
c: Number of documents cited in that year

In publication trends, a total of 1234 citations were made on 72(76.59%) documents. In 2020, it was seen that the h-index reached its peak, with 17 articles or documents (18.09%) making a major contribution to the literature, while 130 citations (10.53%) provided evidence of the significant impact of the research. In terms of publications and citations, 2020 stood out compared to other years. In addition, there are 16 documents that comply with the required criteria, demonstrate high research quality and relevance, and 7 of them have sufficient citations to be categorized in the h-index. This shows that although the number of documents is not the largest, the high citation rate of these articles indicates a deep influence in the field. This data represents a peak in academic productivity and greater impact in 2020, reflecting an emphasis on relevant, high-quality research.

Research trends in the field of critical thinking in mathematics learning have shown significant impact in recent years. With a striking increase in the number of publications since 2019, the tremendous research interest and activity has been clearly reflected. This drastic increase not only reflects an increased awareness of the importance of critical thinking in mathematics education, but also demonstrates the substantial impact of these studies on academic development and educational practice. The availability of high-quality research not only enriches the understanding of mathematical concepts, but also provides a strong foundation for the development of more effective learning methods that are relevant to the needs of today's students.

Most Productive and Collaborative Between Countries

Table 2. The top 10 countries with the highest publications about critical thinking in mathematics learning

Rank	Country	Continent	Total of Publications	Total of Citations
1st	Indonesia	Asia	19(20.21%)	145(11.75%)
2nd	United States	North America	5(5.32%)	190(15.40%)
3rd	Portugal	Europe	4(4.26%)	4(0.32%)
4th	Turkey	Europe	4(4.26%)	321(26.01%)
5th	Malaysia	Asia	3(3.19%)	17(1.38%)
6th	China	Asia	2(2.13%)	20(1.62%)
7th	Germany	Europe	2(2.13%)	22(1.78%)
8th	Spain	Europe	2(2.13%)	21(1.70%)
9th	United Arab Emirates	Asia	2(2.13%)	46(3.73%)
10th	United Kingdom	Europe	2(2.13%)	29(2.35%)

Source: R Program

In this table, Indonesia stands out as the country with the highest number of publications, namely 19(20.21%), although the number of citations is 145(11.75%), not as high as some other countries. The United States had the highest number of citations with 190(15.40%) of 5(5.32%) publications, indicating the great impact of its publications. Turkey also showed significant contribution with 4(4.26%) publications and 321(26.01%) citations, indicating highly influential research. Other countries such as Portugal, Malaysia, China, Germany, Spain, the United Arab Emirates, and the United Kingdom each contributed a smaller number of publications, but still participated in the global collaboration. Contributions from multiple continents, including Asia, North America, and Europe, demonstrate the diversity and breadth of the international research network, with each country playing an important role in enriching scientific knowledge globally.

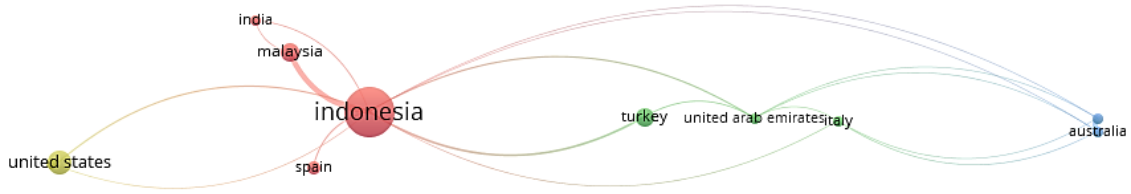

Figure 4. Collaboration between countries in the field of critical thinking in mathematics learning. analysis with VOSviewer (At least 2 papers)

In this visualization, Indonesia is the center of attention, marked by the largest circle. This shows that Indonesia has the most significant number of publications and collaborations compared to the other countries shown. The lines connecting Indonesia with countries such as India, Malaysia, Turkey, the United Arab Emirates, Spain, Italy, Australia and the United States show collaborative relationships in scientific publications. The thickness of the lines connecting Indonesia with other countries can also indicate the frequency or intensity of collaboration, where thicker lines indicate stronger or more frequent ties. Indonesia's dominance in this network reflects its important role in international research collaboration in the field of critical thinking in mathematics learning.

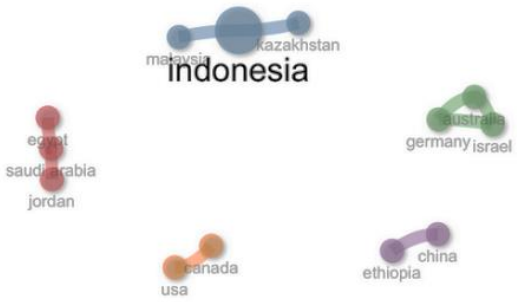

Figure 5. Collaboration between countries in the field of critical thinking in mathematics learning using R program

In this visualization, Indonesia remains the center of attention as marked by the largest circle, highlighting its main role in collaborative scientific publications. The country is connected with various other countries grouped into several clusters based on regions or collaborative relationships. For example, the cluster with Malaysia and Kazakhstan around Indonesia shows strong collaborative relations within the Asian region. Other clusters such as Australia connected to Germany and Israel, or the United States cluster connected to Canada, illustrate different collaboration patterns with Indonesia at the center. There is also a cluster from the Middle East with countries such as Egypt, Saudi Arabia and Jordan, as well as an African cluster with Ethiopia and China. Each of these clusters shows a pattern of regional collaboration that strengthens Indonesia's position as a center in this network. The thickness and size of the lines indicate the frequency and intensity of collaboration, where Indonesia has broader and more significant links in this network.

Indonesia stands out as the country with the highest number of publications, indicating a great contribution in generating academic literature in this field. However, Indonesia's citation rate is not as high as other countries, indicating the potential to further increase the impact of these studies. Meanwhile, other countries such as the United States and Turkey also made significant contributions, with high citation rates, indicating the great impact of their publications. The diversity of journals and institutional affiliations from different countries and continents reflects the strong international collaboration in developing knowledge on critical thinking in mathematics learning, which in turn enriches the education and technology literature globally.

The Most Productive Source

Table 3. The top 10 the most productive source with the highest h-index about critical thinking in mathematics learning

No	Journal	SQ[a]	Publishing	Country	h[b]	TC[c]	NP[d]
1st	International Journal of Instruction	Q2 (2022)*	Gate Association for Teaching and Education	Switzerland	5	55	5
2nd	International Journal of Scientific and Technology Research	Q4 (2019)*	-	India	4	37	7
3rd	European Journal of Educational Research	Q2 (2023)	Eurasian Society of Educational Research	Netherlands	3	43	4
4th	Universal Journal of Educational Research	Q4 (2019)*	Horizon Research Publishing	United States	3	32	5
5th	International	-	-	United States	2	15	2

	Conference on Engineering Education (ICEED) 2009						
6th	Educational Studies in Mathematics	Q1 (2023)	Springer Netherlands	Netherlands	2	51	2
7th	Eurasian Journal of Educational Research	Q3 (2023)	Ani Publishing	Turkey	2	51	2
8th	Journal on Mathematics Education	Q2 (2023)	Sriwijaya University	Indonesia	2	52	2
9th	Jurnal Pendidikan IPA Indonesia	Q3 (2023)	Universitas Negeri Semarang (UNNES)	Indonesia	2	95	2
10th	ZDM - International Journal on Mathematics Education	Q1 (2023)	Springer Verlag	Germany	2	21	2

a: Scopus Quartile, data accessed from 4 June 2024 at scimagojr.com
b: h-index at Scopus Database
c: Total of Citation
d: Number of Publication
*: Discontinues in Scopus at 2024

In this table, the International Journal of Instruction from Switzerland stands out as the source with the highest h-index, namely 5, with a total of 55 citations and 5 publications, indicating a significant impact in the field of education. The International Journal of Scientific and Technology Research from India, despite being in the Q4 (2019), has an h-index of 4 with 37 citations and 7 publications, indicating a considerable contribution to technology and scientific research. All sources from various countries contribute to education and technology literature. For example, the European Journal of Educational Research from the Netherlands (h-index 3, 43 citations, 4 publications) and the Universal Journal of Educational Research from the United States (h-index 3, 32 citations, 5 publications) show active involvement from Europe and America. Sources from Indonesia such as the Journal on Mathematics Education and the Indonesian Science Education Journal also contributed with an h-index of 2 and a significant number of citations and publications. Other journals from Germany, Türkiye, and the Netherlands add to the diversity of global contributions to this research. This diversity of sources reflects strong international collaboration and broad contributions from various countries in advancing knowledge in critical thinking in mathematics learning.

The Most Productive and Collaboration Affiliations

Table 4. Top 10 the most productive affiliations about critical thinking in mathematics learning

Rank	Affiliation	City	Country	Continent	TP*	%
1st	Universitas Islam Negeri Mataram	Mataram	Indonesia	Asia	8	8.51%
2nd	An-Najah National University	Nablus	Palestine	Asia	7	7.45%
3rd	Universitas Muhammadiyah Surakarta	Surakarta	Indonesia	Asia	7	7.45%
4th	Universitas Negeri Semarang	Semarang	Indonesia	Asia	7	7.45%
5th	Universitas Islam Negeri Raden	Bandar Lampung	Indonesia	Asia	6	6.38%
6th	Universitas Negeri Yogyakarta	Yogyakarta	Indonesia	Asia	6	6.38%
7th	Chitkara University Institute of Engineering and Technology	Rajpura	India	Asia	5	5.32%
8th	Nanyang Technological University	Singapore	Singapore	Asia	5	5.32%
9th	Bethune-Cookman University	Daytona Beach	United States	North America	4	4.26%
10th	Universitas Negeri Gorontalo	Gorontalo	Indonesia	Asia	4	4.26%

*: Total of Publications

In this table, affiliates located in various cities and countries, as well as from several continents, represent a significant contribution to the number of publications. Universitas Islam Negeri Mataram leads with a total of 8(8.51%) publications. An-Najah National University from Palestine also showed an important contribution with 7(7.45%) publications, in line with Universitas Muhammadiyah Surakarta and Universitas Negeri Semarang, both from Indonesia. These institutions are predominantly located in Asia, reflecting the continent's dominance in academic contributions. Additionally, Bethune-Cookman University from the United States is the only representative from North America with 4(4.26%) publications. This diversity of affiliations highlights the global contribution to academic research in the field of critical thinking in mathematics learning.

Each university group is marked with a different color, indicating clustering based on research linkages or collaborations. Indonesian universities such as the Indonesian Education University, Yogyakarta State University, and Mataram State Islamic University appear dominant, closely connected to each other, and form a separate group. Other universities from various countries such as the University of Melbourne and the California Institute of Technology were also identified, but they formed separate clusters. This shows the existence of an international network in critical thinking research in mathematics learning, with significant contributions from various countries.

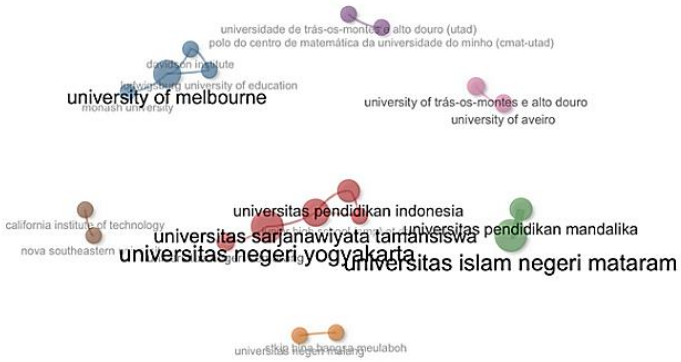

Figure 6. Affiliations collaboration in the field of critical thinking in mathematics learning

The Most Productive Authors

Table 5. Top 10 the most productive authors about critical thinking in mathematics learning

Rank	Authors	Affiliation	Country	h[a]	TC[b]	NP[c]
1st	Suparman	Universitas Pendidikan Indonesia	Indonesia	5	45	7
2nd	Cholis Sa'dijah	Universitas Negeri Malang	Indonesia	3	16	3
3rd	Darhim	Universitas Pendidikan Indonesia	Indonesia	2	17	2
4th	Yahya Hairun	Universitas Khairun	Indonesia	2	14	2
5th	Siti Noor Ismail	Universiti Utara Malaysia	Malaysia	2	13	2
6th	Yaya S. Kusumah	Universitas Pendidikan Indonesia	Indonesia	2	52	2
7th	Shamsuddin Muhammad	Teacher Education Institute	Malaysia	2	13	2
8th	Sufyani Prabawanto	Universitas Pendidikan Indonesia	Indonesia	2	17	3
9th	Jozua Sabandar	IKIP Siliwangi	Indonesia	2	52	2
10th	Bambang Eko Susilo	Universitas Negeri Semarang	Indonesia	2	17	2

a : h-index at Scopus Database
b : Total of Citation
c : Number of Publication

The data above shows that Suparman from the Indonesian University of Education is the author with the highest contribution with an h-index of 5, 45 citations and 7 publications. Authors from Indonesia dominate this list, accounting for eight of the top ten spots. Apart from Suparman, names such as Cholis Sa'dijah, Darhim, Yahya Hairun, Yaya S. Kusumah, Sufyani Prabawanto, Jozua Sabandar, and Bambang Eko Susilo also contributed significantly, showing the strong role of Indonesia in this research. However, there are also important contributions from Malaysian writers, namely Siti Noor Ismail and Shamsuddin Muhammad. All of these authors demonstrate a strong commitment to advancing critical thinking research in mathematics learning, and a number of

publications and citations reflect the impact of their research in the field of critical thinking in mathematics learning.

Researchers such as Suparman, Cholis Sa'dijah, Darhim, and others from Indonesia feature prominently in this list, demonstrating the strong role of Indonesia in this research. However, Malaysian researchers such as Siti Noor Ismail and Shamsuddin Muhammad also made important contributions. The most cited articles, such as the work of Şendağ et al. (2009), reflect the importance of technology in improving students' understanding and critical thinking skills through online problem-based learning. These contributions reflect academic interest in innovation in teaching and learning. From the various methods and contexts examined, it appears that efforts to develop critical thinking skills in education are diverse and constantly evolving, thereby making an important contribution to educational practice globally.

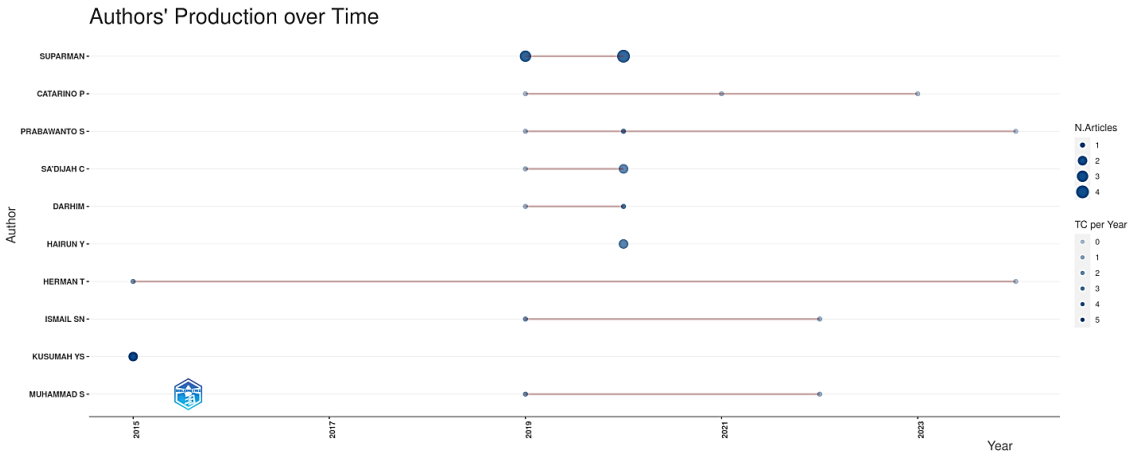

Figure 7. Authors production over time about critical thinking in mathematics learning. analysis with R program

The graph above shows the production of articles by several authors in the field of critical thinking in mathematics learning from 2015 to 2023. Each dot depicts the number of articles published by each author in one year, with the size of the dot reflecting the number of articles. Writers such as Suparman and Cholis Sa'dijah had fairly consistent article production during this period. Suparman has the highest contribution with 4 articles in one year. Herman T and Yaya S. Kusumah contributed at the beginning of the period with one article, while Shamsuddin Muhammad showed recent activity. Other authors such as Paula Catarino and Sufyani Prabawanto contributed 2-3 articles in several years. This graph shows the variation in author contributions to the research, with some authors being very prolific and others with more sporadic contributions.

Documents with the Highest Citations

Table 6. Top 10 the documents with the highest citations about critical thinking in mathematics learning

Rank	Citations and Year	Title	Total Citations
1st	(Şendağ & Odabaşı,	Effects of an online problem based	241

	2009)	learning course on …	
2nd	(Mutakinati et al., 2018)	Analysis of students critical thinking skill of middle school …	92
3rd	(Styers et al., 2018)	Active learning in flipped life science courses promotes ..	82
4th	(Faridi et al., 2021)	A framework utilizing augmented reality to improve …	55
5th	(Su et al., 2016)	Mathematical teaching strategies: Pathways to …	51
6th	(Innabi & Sheikh, 2007)	The change in mathematics teachers' perceptions of critical thinking …	43
7th	(Shanta & Wells, 2022)	T/E design based learning: assessing student critical thinking …	39
8th	(Ülger, 2016)	The relationship between creative thinking and critical thinking …	36
9th	(Widyatiningtyas et al., 2015)	The Impact of Problem-Based Learning Approach …	35
10th	(Erdogan, 2019)	Effect of cooperative learning supported …	34

Source: R Program, data accessed by 4 June 2024

From the data provided, it can be seen that the article with the highest number of citations is the work of Şendağ et al. (2009) with 241 citations. This article examines the effects of online problem-based learning courses on the acquisition of content knowledge and critical thinking skills, demonstrating the importance of technology in education to improve students' understanding and critical thinking abilities. This study has received significant attention in the field of education due to its relevance in integrating technology with effective learning methods, reflecting academic interest in innovation in teaching and learning processes.

The contributions of each document listed in this list demonstrate a variety of approaches and contexts in developing critical thinking skills. For example, research by Mutakinati et al. (2018) and Styers et al. (2018) demonstrated the importance of project-based learning and active learning in the development of critical thinking skills in high school students and in life sciences courses. Meanwhile, Faridi et al. (2021) and Su et al. (2016) highlighted the use of technology such as augmented reality and mathematics teaching strategies to improve students' critical thinking skills. From these diverse methods and contexts, it is clear that efforts to develop critical thinking skills in education are diverse and continue to evolve, reflecting the important contributions of this research to educational practice worldwide.

Focus Resarch and Keywords Novelty

Researchers also analyzed keywords using VOSviewer to determine keyword groups and keyword novelty. By using Keyword Occurance ≤ 3, 39 keywords were obtained which were divided into 7 groups. Next, the author gives a name to each group of keywords at Table 7.

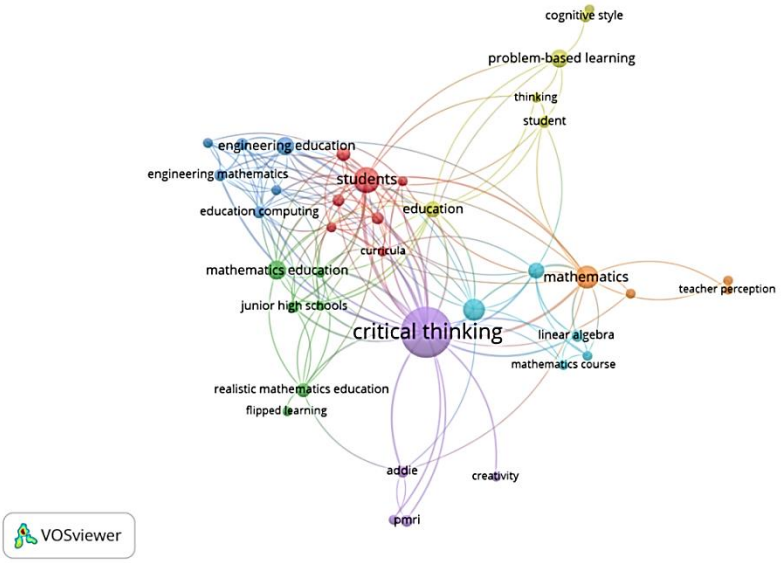

Figure 8. Focus research (keyword occurance ≤ 2). analysis with VOSviewer

Table 7. Grouping and name of each group

Rank	Color Group	Group Name	Keywords
1st	Red (7 items/17.94%)	Innovative Educational Approaches	Curricula, Engineering Research, Geometry, Information and Communication, Problem Solving, Students, Undergraduate Students
2nd	Green (6 items/15.38%)	Innovative Pedagogical Approaches	Control Groups, Flipped Learning, ICT, Junior High Schools, Mathematics Education, Realistic Mathematics Education
3rd	Blue (6 items/15.38%)	Innovative Pedagogical Technology Integration	Education Computing, Engineering Education, Engineering Mathematics, Mathematics Techique, Online Systems, Teaching and Learning
4th	Yellow (6 items/15.38%)	Enhancing Student Problem-Solving Skills	Assessment, Cognitive Style, Education, Problem-based Learning, Student, Thinking
5th	Purple (5 items/12.82%)	Innovative Module Development Approach	ADDIE, Creativity, Critical Thinking, Module, PMRI
6th	Navy Blue (5 items/12.82%)	Integrated STEM Curriculum Development	Higher Education, Linear Algebra, Mathematics Course, Statistics, STEM
7th	Orange (4 items/10.25%)	Teacher Preparedness Assessment	Analysis, Mathematics, Teacher Perception, Teacher Readiness

Source: VOSviewer, data accessed by 3 June 2024

The red cluster entitled “Innovative Educational Approaches” includes studies that highlight innovative methods and strategies in learning that aim to improve students'

critical thinking skills in mathematics. These studies involve specially designed curricula, research in engineering, geometry, and the use of information and communication technology to solve problems. In addition, the cluster also includes studies that focus on developing critical thinking skills among undergraduate students (Din, 2020; Reynders et al., 2020). Through these approaches, the cluster makes a significant contribution to improving the quality of mathematics education and preparing students for the complex challenges of the academic and professional world.

The green cluster entitled "Innovative Pedagogical Approaches" explores learning methods that utilize information and communication technology (ICT) and the concept of flipped learning at the junior high school level. With a focus on mathematics education, this approach integrates group control to improve student understanding. In this context, ICT is used as a tool to provide access to diverse resources and support independent learning (Lembani et al., 2023). Through the flipped learning approach, students are given the responsibility to learn the material independently before class, while class time is used to discuss, apply and explore complex concepts (Aidoo et al., 2022; Huang, 2020). Thus, the combination of group control, flipped learning, and ICT integration not only facilitates deeper understanding of mathematical concepts, but also stimulates students' critical thinking through active interaction and reflection on the material learned.

The blue cluster entitled "Innovative Pedagogical Technology Integration" explores ways in which computing and mathematical engineering education can be brought together through online systems in the context of engineering education. By using online technology, teachers can present math and engineering materials with an interactive and dynamic approach, allowing students to participate in experiments, simulations and exercises that reinforce understanding of critical concepts (Engelbrecht et al., 2020; Low et al., 2021). With this approach, students not only develop technical skills in solving problems, but are also trained in thinking critically towards the application of mathematics in an engineering context, strengthening their critical thinking skills.

The yellow cluster entitled "Enhancing Student Problem-Solving Skills" explores how problem-based learning approaches and cognitive assessment can enrich student thinking in the context of mathematics education. With a focus on developing students' thinking skills, this approach utilizes the various cognitive styles that students have to solve complex problems (Surur et al., 2020). Through the use of problem-based learning methods, students are encouraged to identify, analyze and solve mathematical problems independently or in groups (Altun & Yildirim, 2023). Thus, this approach not only strengthens students' mathematical understanding, but also stimulates their ability to think critically and creatively in solving problems.

The cluster entitled 'Innovative Module Development Approach' explores how the ADDIE (Analysis, Design, Development, Implementation, Evaluation) approach can be combined with the PMRI (Pendidikan Matematika Realistik Indonesia) approach to create learning modules that promote creativity and critical thinking in the context of mathematics education. Through the ADDIE process, these modules are designed and developed with student needs in mind, an interactive learning structure, and ongoing evaluation of their effectiveness. The PMRI approach enriches the modules by incorporating real-life contexts, bridging abstract mathematical understanding with its application in real situations (Inharjanto, 2019). Thus, these modules not only teach

mathematical concepts, but also encourage students to think critically, creatively, and skillfully in applying mathematical knowledge in various contexts.

The navy blue cluster entitled 'Integrated STEM Curriculum Development' explores curriculum development approaches that integrate higher education, specifically mathematics and statistics courses, with a focus on linear algebra, within a STEM education environment. This approach aims to encourage students' critical thinking through project-based learning that allows students to apply mathematical concepts in a real context (Issa & Khataibeh, 2021). By incorporating elements from various STEM disciplines, such as science, technology, and engineering, this curriculum not only strengthens students' mathematical understanding, but also prepares them to be creative problem solvers and skilled in applying their knowledge in various fields of science.

The orange cluster entitled 'Teacher Preparedness Assessment' explores teachers' perceptions and preparedness for the challenge of analysis in mathematics learning. By looking at teachers' views on the complexity of mathematical content and their preparedness to effectively deliver these concepts, this cluster aims to identify factors that influence teachers' understanding of mathematical analysis and their preparedness to teach it (Rodríguez-Muñiz et al., 2021; Zulnaidi et al., 2024). By better understanding teachers' perceptions and preparedness, this cluster can provide insights into how to improve training and support for teachers in developing students' critical skills in mathematics.

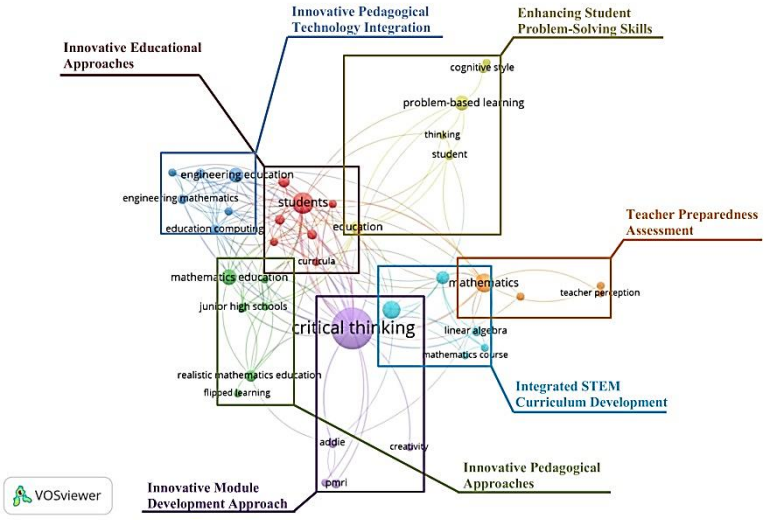

Figure 9. Focus research after rename

All clusters have their respective roles in building a collaborative and holistic educational ecosystem to support critical thinking in mathematics learning. Innovative educational approaches play an important role in developing critical thinking skills in mathematics learning. The use of innovative pedagogical technologies, such as flipped learning and ICT, allows students to access a variety of resources and facilitates deep independent learning. The integration of a comprehensive STEM curriculum helps students apply mathematical concepts in real contexts, strengthening their problem-

solving skills. The development of learning modules designed with ADDIE methodology and PMRI approach enriches students' learning experience with relevant real-life contexts. In addition, teachers' readiness and perception in facing math learning challenges play an important role in supporting students to think critically and creatively. All these approaches are interrelated in creating a dynamic and interactive learning environment where students are encouraged to dig deeper, question and apply mathematical concepts effectively. After grouping, the researcher then looked for new keywords by using the Overlay Visualization menu.

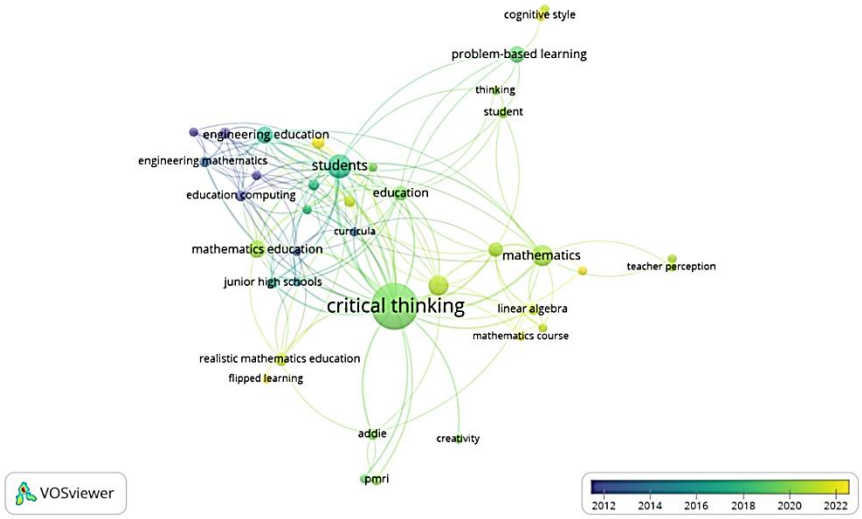

Figure 10. Overlay visualization at VOSviewer

In the Overlay Visualization view, bold words with bright colors indicate new usage. In the context of 2022, terms such as Problem Solving, Flipped Learning, Analysis, and Mathematics Course stand out in yellow, indicating new usage in the literature. Therefore, these terms are the latest research recommendations for the topic of Critical Thinking in Mathematics Learning. Problem Solving contributes by training students to confront and solve complex problems effectively. Flipped Learning allows students to study independently before class, maximizing class time for deeper discussion and application of concepts. Analysis teaches students to break down problems into smaller components and understand the relationships between them, which is important in critical thinking. The Mathematics Course as the research context provides a structured curriculum framework to integrate those methods effectively, thus creating a learning environment conducive to the development of critical thinking skills. So that all the recommended keywords can provide good benefits for future research related to critical thinking in mathematics learning.

▪ CONCLUSION

From the results of the analysis, it can be concluded that research on the Scopus database began in 2004 to 2024 or the last 20 years, with a 3-fold increase in publications in the last 6 years. 2020 was the year with the highest citation impact, namely 130(10.53%) citations. Indonesia stands out as the country with the highest number of

publications at 19(20.21%) and number of citations is 145(11.75%). International Journal of Instruction stands out as the source with the highest h-index, namely 5. Universitas Islam Negeri Mataram leads with a total of 8(8.51%) publications. Suparman from the Universitas Pendidikan Indonesia is the author with the highest contribution with an h-index of 5. The article with the highest number of citations of Şendağ et al. (2009) with 241 citations. 39 keywords were obtained which were divided into 7 groups, with the keywords "Problem Solving", "Flipped Learning", "Analysis", and "Mathematics Course" the latest keywords which can be used as recommendations for further research in the field of critical thinking in mathematics learning.

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