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## Application of Critical Thinking in Mathematics Education: Bibliometric Analysis (1991-2023)

**Abstract:** Critical thinking is an important skill in the 21st century and plays a major role in learning. This bibliometric research evaluates previous academic work on the use of Critical Thinking in mathematics education. Through Scopus analysis, research uses RStudio Biblioshiny and VosViewer to map research trends and search for new keywords. The results show an increase in publications of approximately 10.58% annually, reflecting growing interest in this topic. The Indonesian University of Education stands out as a productive research center in this field, with more than 25 related articles. "Journal of Physics: Conference Series" and "International Journal of Instruction" stand out as the most prolific publications, with "Soter et al. (2008)" having the highest number of citations, reaching 217 citations. Keywords such as systematic reviews, critical mathematics education, science technologies, and e-learning stand out as key trends, providing potential for further exploration in future research. This underscores the importance of continued research in applying Critical Thinking in mathematics education, indicating growing interest as well as areas requiring further focus for the development of critical skills in this context.

**Keywords:** Critical Thinking, Mathematics Education, Bibliometrics

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### Introduction

The end of the Second World War was a trigger for all countries in the world to undertake extensive recovery efforts (Zetriuslita, Nofriyandi, & Istikomah, E., 2020; Zetriuslita & Ariawan, 2021). Countries are committed to repairing damaged infrastructure, rebuilding their economies, and increasing human resources through various reconstruction and development programs. One aspect that has received great attention is the education sector, where many countries have launched programs to increase access to education for all levels of society and improve the quality of education to ensure a brighter future (Fitriani, 2023; Hakim & Angga, 2023; Rezeki et al., 2020).

Education is an integral part of human life where each individual is considered the greatest investment in overall human development and formation (Arraniri et al., 2021; Saputra, 2021). Education can also be explained as the process by which individuals acquire the knowledge, skills, and values necessary for their growth and development in society (Rahmadania et al., 2021). So, educational position is very important for a

person because it can make a greater contribution to the journey of life (Zafrullah, Bakti, et al., 2023; Zafrullah, Suyanto, et al., 2023; Zafrullah & Zetriuslita, 2021). One thing that is experiencing development is mathematics learning.

Mathematics plays a vital role in the realm of education and has experienced significant development as a scientific discipline that continues to develop to this day (Asdar et al., 2021; Priyatna & Wiguna, 2021). Mathematics is an integral foundation for various scientific disciplines, because it penetrates every aspect of knowledge, and as a substantial science that has broad uses in various areas of social life (Nurulaeni & Rahma, 2022; Yahya, 2022). So it can be concluded that mathematics is a crucial foundation that cuts across various scientific disciplines, provides an important foundation and has a substantial role in continuity and understanding in various fields of life and human knowledge. One of the important things in learning mathematics is the application of Critical Thinking.

Critical thinking ability itself is a systematic skill in evaluating information, explaining reasons, and analyzing, which is an urgent need in facing the impact of the dynamics of life in the era of information flow (Kurniawan et al., 2021; Kusumawati et al., 2022). Critical thinking is not only a cognitive aspect that allows identifying problems and finding solutions, but also a process that aims to enable rational and reasonable decision making in dealing with various situations and complexities that occur in everyday life (Fitriyah & Ramadani, 2021; Rahmad et al., 2022). Thus, critical thinking as a high-level thinking skill that is important in developing 21st century skills, becomes very essential in the learning process because it increases students' thinking abilities in learning practices (Rahardhian, 2022; Salamudin & Amelia, 2022).

Much research has been conducted regarding the application of Critical Thinking in mathematics education. Therefore, researchers are interested in conducting bibliometric analysis to see the latest trends and innovations in this research. Through this analysis, it is hoped that research development trends and novelties in the application of Critical Thinking in the context of mathematics education can be understood. This can provide a more comprehensive view of how critical thinking concepts are integrated into mathematics learning and how this approach continues to develop to improve students' understanding and mastery of mathematics material.

## Research Methods

This bibliometric research aims to evaluate previous academic work that has been carried out in the context of the use of Critical Thinking in Mathematics Education. Bibliometric analysis is an approach to examining the evolution of a research domain, including topics and authors, based on the social, intellectual, and conceptual structure of scientific disciplines (Supinah & Soebagyo, 2022). Bibliometric analysis is commonly used in scientific disciplines and focuses on the quantitative study of journal papers, books, or other types of written communication (Sidiq, 2019). The overall analysis of the article mapping was carried out through R-Studio, which is the Bibliometric platform used (Saifudin, 2013).

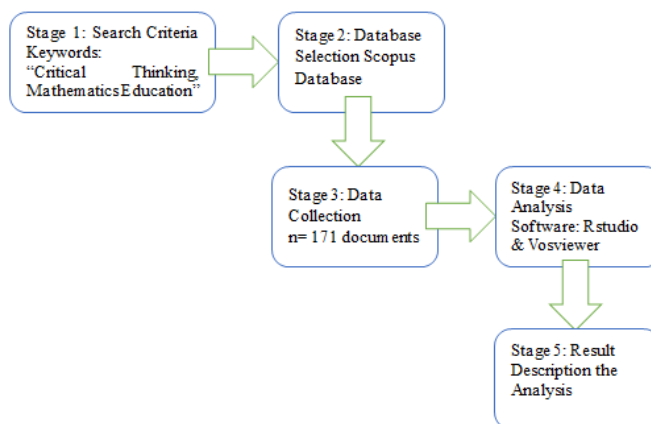


Fig 1. Bibliometrics Flow of Critical Thinking in Mathematics Education

This research describes a series of structured steps that begin by using keywords related to Critical Thinking in the context of mathematics education to ensure focus and relevance in the search. This was

followed by a search in a database that was considered to have a high reputation, namely Scopus, where 171 documents were obtained that were ready for analysis. The next stage involves evaluating the selected documents with bibliometric methods using open source software such as R Bibliometrix. In addition, researchers utilized VOSviewer to map innovations in the research. The final step focuses on presenting the results, conclusions and quantitative evaluation of the research after the data has been processed and analyzed. This process displays an explanation of the findings along with a visual representation of the research results. This research approach is outlined in clear stages, starting from keyword selection, leading databases, document analysis, to presentation of results, which not only focuses on the search process but also on evaluation and use of software that supports bibliometric analysis to obtain comprehensive research results.

## Research Results and Discussion

### Research Results

**Main Information.** Once the relevant data is transferred to RStudio, the software's initial interface displays basic information about all articles that have been uploaded and are ready for analysis. Main information about documents to be analyzed using bibliometric methods can be accessed via Figure 2.

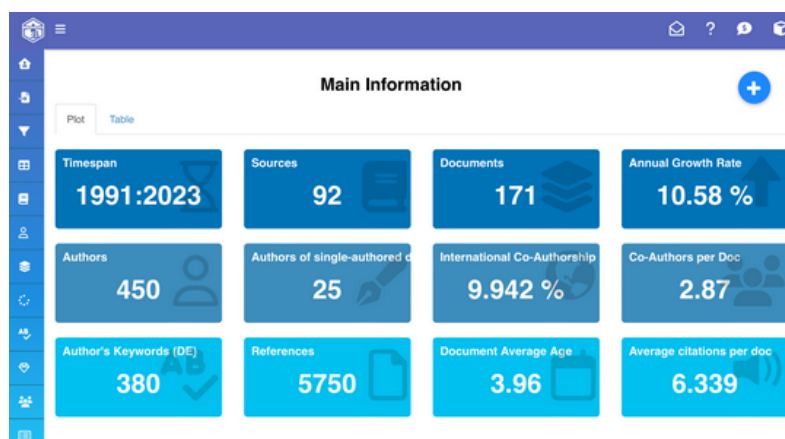


Fig 2. Main information about Critical Thinking in Mathematics Education

Figure 2 provides general information about research that looks at Critical Thinking in mathematics across 171 documents. These documents come from a variety of sources, including journals, proceedings, and books, for a total of 92 sources in the Scopus database. Interestingly, there is an increase in publications of around 10.58% each year, indicating increasing interest in Critical Thinking research in mathematics education. The analysis results also show the author's contribution and international collaboration in this research. Of the total 450 authors, 76 of them wrote themselves. Although there is variation in authorship, only about 9.942% of author collaborations involve international collaboration with an average of 2.87 authors per document. There are also 380 keywords and 5750 references related to this topic, indicating the diversity and depth of research regarding Critical Thinking in mathematics in the world of education.

**Publication Trends.** Of course, Critical Thinking research experiences a trend in the number of publications each year. Table 1 will explain publication trends from 1991 to 2023.

Table 1. Publication Trends

Year	TP	Percentage	TC	NCP	h	g
1991	1	0.58%	8	1	1	1
1992-2004	-	-	-	-	-	-
2005	1	0.58%	1	1	1	1
2006-2007	-	-	-	-	-	-
2008	1	0.58%	217	1	1	1
2009	4	2.34%	56	4	4	4

2010	3	1.75%	46	3	3	3
2011	3	1.75%	6	1	1	2
2012	2	1.17%	12	2	2	2
2013	2	1.17%	36	2	1	2
2014	3	1.75%	48	3	2	3
2015	4	2.34%	30	4	3	4
2016	7	4.09%	111	7	3	7
2017	7	4.09%	76	7	4	7
2018	9	5.26%	34	7	3	5
2019	17	9.94%	111	15	7	10
2020	37	21.64%	185	27	8	12
2021	21	12.28%	30	10	4	4
2022	24	14.04%	64	13	5	7
2023	25	14.62%	13	6	2	3
Total	171	100%				

*TP= Total Publications, TC= Total Citations, NCP= Number of Citation Publications, h= h-index, g=g-index*

The data contained in Table 1 clearly shows that between 1991 and 2018, only 17 publications were recorded that discussed Critical Thinking in the domain of mathematics education. However, from 2019 to 2023, there was a significant increase in the total number of publications, with the addition of 124 articles, meaning approximately two-fold growth. This reflects a substantial change in interest in research related to Critical Thinking in the context of mathematics learning. The peak of the increase in the number of publications was recorded in 2020, with 37 articles (21.64%). The Citations trend can be seen from the NCP value, where the highest NCP occurred in 2020 with an NCP value = 27, followed by 2019 with an NCP = 15. However, if we look at the total citations (TC), the publication in 2008 is in the spotlight with the highest number of citations, reaching 111 citations, making the publication in 2011 the most influential in this field.

**Most Productive Affiliates.** Below is presented data regarding the most productive affiliations in the Critical Thinking theme in the field of mathematics education. The results of the bibliometric analysis can be seen in Table 2.

**Table 2.** Affiliates with the highest number of publications

Affiliation	Country	Articles
Universitas Pendidikan Indonesia	Indonesia	25
University of Groningen	Netherland	8
University of Southern Queensland	Australia	8
University of Salamanca	Spain	7
Universitas PGRI Madiun	Indonesia	6
Universitas PGRI Semarang	Indonesia	6
Western Philippines University	Philippines	6
State University of Malang	Indonesia	5
The Chinese University of Hong Kong	China	5
Universitas Negeri Yogyakarta	Indonesia	5

In continuation of the data analysis presented, it can be concluded that the Indonesian Education University stands out as a very productive research center on the topic of Critical Thinking in mathematics education. With more than 25 articles related to this topic, the university shows consistency in contributing knowledge regarding critical approaches to mathematics learning. Meanwhile, the University of Groningen

and the University of Southern Queensland, although with lower numbers than the Indonesian University of Education, still have significant contributions in this field with more than 8 articles. This indicates a strong commitment from these universities to participate in the development of the concept of Critical Thinking in the context of mathematics education.

It is important to note that five affiliates from Indonesia, with a total of 47 publications, show that collaborative efforts in developing Critical Thinking knowledge in mathematics education do not only come from one institution, but from a number of academic institutions in Indonesia. This reflects a positive trend in the development of critical approaches in the field of mathematics education at the national level. From these data, it can be concluded that cross-institutional and international collaboration plays an important role in developing the concept of Critical Thinking in the context of mathematics education. This opens up opportunities for the exchange of ideas, methodologies and best practices among various affiliates, enriching the understanding and application of these concepts in educational settings.

**Most Productive Source.** Citation analysis begins with the ten main sources that have the largest number of publications in the field of Critical Thinking in mathematics education listed in the Scopus index.

**Table 3.** Sources with the highest h-index

Journal Name	SQ	NP	h_index	TC
Journal Of Physics: Conference Series	-	32	5	79
International Journal of Instruction	Q2	4	4	48
Sustainability	Q1	6	4	50
Eurasian Journal of Educational Research	Q3	3	3	48
Journal on Mathematics Education	Q2	3	3	84
ASEE Annual Conference and Exposition, Conference Proceedings	-	6	2	16
Canadian Journal of Science, Mathematics and Technology Education	Q2	4	2	8
Eurasia Journal of Mathematics, Science and Technology Education	Q2	2	2	15
Mathematics	Q2	2	2	9
Participatory Educational Research	Q3	2	2	14

SQ= Scopus Quartile, NP=Number of Publication, TC=Total Citation

Table 3 presents information about the most productive journals and publication sources in terms of the number of publications and citations related to critical thinking in mathematics education. From this table, "Journal of Physics: Conference Series" is the most productive publication with 32 articles and 79 citations. This is followed by "International Journal of Instruction" with 4 publications and 48 citations. Apart from that, information from this table also shows that the higher the number of citations to a journal or source, the higher the h-index value. This indicates that journals or sources with a high number of citations have a significant impact in the field of critical thinking in mathematics education and are highly recognized by researchers in this field.

**Articles with the Most Citations.** Below are presented the ten most cited articles obtained from various sources and authors. The table below reveals the results of a bibliometric analysis highlighting the articles that have received the highest number of citations in various sources.

**Table 4.** Top 10 Most Article Citations

Paper	DOI	Affiliation	TC	TC/Y
(Soter et al., 2008)	10.1016/j.ijer.2009.01.001	The Ohio State University	217	13.56

(Holmes & Hwang, 2016)	10.1080/00220671.2014.979911	Hope Collage	67	8.38
(Dewolf et al., 2014)	10.1080/00220973.2012.745468	Katholieke Universiteit (KU) Leuven	45	4.5
(As'ari et al., 2017)	10.22342/jme.8.2.3961.145-156	Universitas Negeri Malang	41	5.86
(Gal et al., 2020)	10.1007/s11858-020-01155-9	University of Haifa	37	9.25
(Palinussa, 2013)	10.22342/jme.4.1.566.75-94	Universitas Pattimura	35	3.18
(Ülger, 2016)	10.16986/HUJE.2016018493	Sivas Cumhuriyet University	31	3.88
(Aizikovitsh & Amit, 2010)	10.1016/j.sbspro.2010.03.596	Ben Gurion University	29	2.07
(Erdogan, 2019)	10.14689/ejer.2019.80.5	Firat Universitesi	27	5.4
(Sriraman & Knott, 2009)	10.1007/s10780-009-9090-7	University of Montana	26	1.73

The information in Table 4 highlights the authors and highest number of citations of the articles tracked by Scopus. These data show that the article written by (Soter et al., 2008) received the highest number of citations, namely 217, among all articles discussing critical thinking in mathematics education. This article is followed by papers from (Holmes & Hwang, 2016), (Dewolf et al., 2014), (As'ari et al., 2017), and (Gal et al., 2020), which are included in the five the most cited article on the topic. This data highlights that (Soter et al., 2008) is the author who received the highest citations, indicating that his research has a significant impact regarding critical thinking in the context of mathematics education. It should be noted, however, that a high number of citations is not always the sole determinant of the quality of a study, given that other factors can influence this, such as the popularity of the topic or the availability of access to the research.

**Author with the Most Articles.** Below is presented data regarding the most productive writers on the Critical Thinking theme in mathematics education. The results of the bibliometric analysis can be seen in Table 5.

**Table 5.** Top 10 Authors of the Most Articles

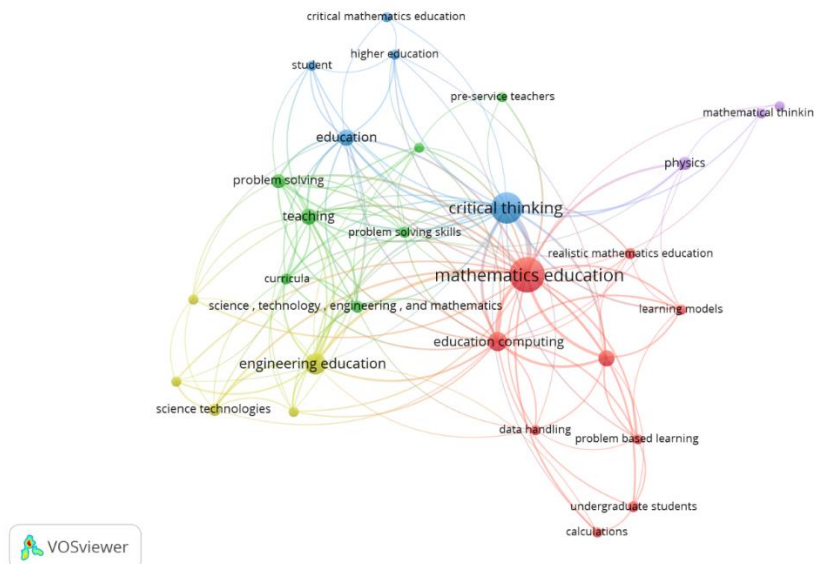
Authors	Affiliation	Articles
Abdur Rahman As'ari	Universitas Negeri Malang	5
Sufyani Prabawanto	Universitas Pendidikan Indonesia	4
Herawati Susilo	Universitas Negeri Malang	4
Darhim	Universitas Pendidikan Indonesia	3
Agung Purwanto	Universitas Negeri Jakarta	3
Arief Agoestanto	Universitas Negeri Semarang	2
Giovannina ALBANO	University of Salerno	2
Hugo Bronkhorst	University of Groningen	2
Jose M <sup>a</sup> Chamoso Sánchez	Salamanca University	2
Robertas Damaševičius	Kaunas University of Technology	2

In Table 5, it can be seen that Abdur Rahman As'ari from the State University of Malang is the most productive writer with 5 articles on Critical Thinking in mathematics education. Meanwhile, Sufyani Prabawanto from the Indonesian University of Education and Herawati Susilo from the State University of Malang were ranked second with 4 articles. Of the ten authors listed, six come from universities in Indonesia. This indication shows the strong interest and involvement of researchers in Indonesia in exploring aspects of Critical Thinking in the context of mathematics education, which in turn can reflect the interest in developing innovative methods in mathematics education that focus on critical aspects of thinking. This can also encourage collaboration between researchers in the country to develop a deeper understanding of the topic.

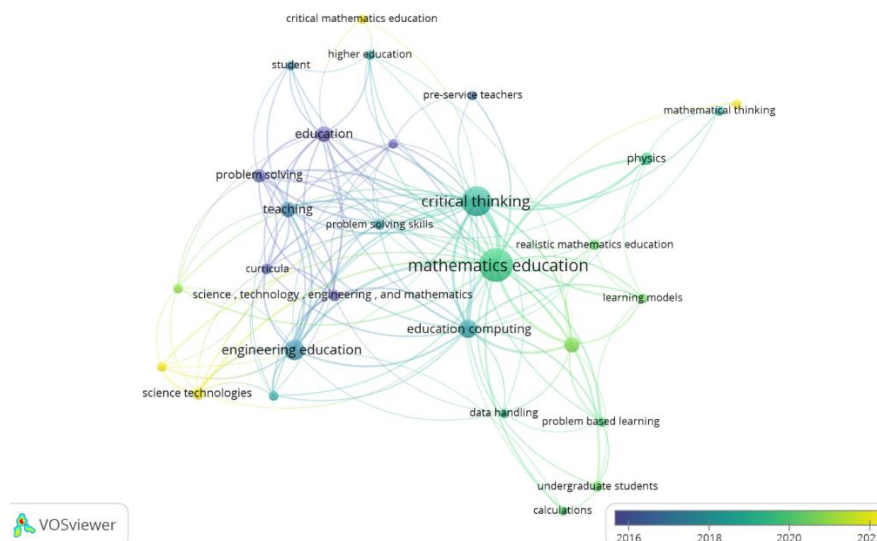
**Research Focus and Keyword Novelty.** Apart from using RStudio, researchers also use Vosviewer to map research focus and see the novelty of keywords. The research focus can be seen in Figure 3.

In the image above, there are different colors according to the cluster. This shows that there are several clusters of keywords that are often linked to others. There are five clusters in Figure 3. The first cluster (red) contains the words calculations, data handling, education computing, learning models, learning systems, mathematics education, problem-based learning, realistic mathematics education, and undergraduate students. The second cluster (green) contains the words curriculum, pre-service teachers, problem solving, teaching, problem solving skills, sustainable development, and stem (science, technology, engineering, and mathematics). Cluster three (blue) consists of the word’s critical mathematics education, critical thinking, education, higher education, and student. Cluster four (yellow) contains the words e-learning, engineering and mathematics, engineering education, robot programming, and science technologies. Cluster five (purple) contains the words mathematical thinking, physics, and systematic review.

The overlay visualization depicts various keywords with color groupings, where dark colors indicate keywords that have long been the focus of research, while light colors indicate keywords that have recently been used in research. From the data depicted, it can be seen that in 2022, keywords such as systematic review, critical mathematics education, science technologies, and e-learning appear in yellow. From this it can be concluded that for further research, these keywords can be used as recommendations because they became trends or the main focus of research in that year, providing potential for further exploration.



**Fig 3.** Network Visualization (Keyword Occurrence  $\geq 3$ )



**Fig 3.** Overlay Visualization

## **Research Discussion**

Rapid developments in the realm of education have brought changes in various aspects, including evolution in learning styles (Andrian, 2019; Andrian et al., 2020). In this era of ever-growing educational transformation, the increasing emphasis on critical thinking skills is crucial because it not only encourages students to master information, but also to be able to understand, analyze and carefully evaluate the information obtained (Lismaya, 2019; Warsah et al., 2021). Thus, Critical Thinking becomes the center of attention in providing the skills needed to face complex challenges in an era of education that continues to develop, especially mathematics education.

The results of the analysis of main information from 171 documents examining Critical Thinking in the context of mathematics education, came from various sources including journals, proceedings and books. This research shows an increase in publications of around 10.58% every year, indicating increasing interest in the study of Critical Thinking in mathematics education. Detailed data shows that between 1991 and 2018, there were only 17 publications discussing the topic of Critical Thinking in mathematics education. However, from 2019 to 2023, there was a significant jump in the total number of publications, adding a total of 124 articles, reflecting almost double the previous growth.

The Indonesian University of Education stands out as a very productive research center on the topic of Critical Thinking in mathematics education with more than 25 related articles. Although the University of Groningen and the University of Southern Queensland had fewer contributions, they still played a significant role with more than 8 articles. Interestingly, five affiliates from Indonesia, with a total of 47 publications, show strong collaboration in developing Critical Thinking knowledge in mathematics education, beyond the contribution of one institution alone.

Regarding the source with the highest number of publications, "Journal of Physics: Conference Series" was recorded as the most productive publication with 32 articles and 79 citations in the context of critical thinking in mathematics education. Meanwhile, "International Journal of Instruction" followed with 4 articles and 48 citations. Information from this table also shows the correlation between the number of citations to a journal or source and its h-index value, where the higher the number of citations, the higher the h-index value. The authors and the highest number of citations from articles listed in Scopus show that (Soter et al., 2008) is the author with the highest number of citations, reaching 217 citations, among all articles discussing critical thinking in mathematics education. Abdur Rahman As'ari from Malang State University is the most productive writer with 5 articles discussing Critical Thinking in mathematics education. Meanwhile, Sufyani Prabawanto from the Indonesian Education University and Herawati Susilo from the State University of Malang were ranked second with 4 articles each.

The first cluster emphasizes improving mathematics education by utilizing technology, innovative learning strategies, and efforts to involve students in mathematics learning experiences that are more real and appropriate to their context. Meanwhile, the second cluster discusses the development of problem solving skills in the context of continuing education, especially for prospective teachers with a focus on STEM disciplines (science, technology, engineering and mathematics). The discussion centered on the integration of problem solving skills into the educational curriculum, aiming to prepare prospective teachers to teach students to be able to solve problems related to sustainable development.

The third cluster discusses the importance of developing critical thinking skills at the higher education level, especially in mathematics, with a focus on critical approaches in mathematics learning. The fourth cluster highlights engineering and science education with an emphasis on e-learning, seeking to develop innovative learning methods to improve student understanding. Meanwhile, the fifth cluster explores the relationship between mathematical thinking and physics through a systematic approach, to understand the influence and essential connection between the two.

The latest keywords consisting of systematic review, critical mathematics education, and science technologies, e-learning describe a substantial role in supporting the development of critical thinking skills in mathematics education. Systematization in the research approach, seen from the use of systematic reviews, shows a commitment to analyzing information in a structured manner, which is essential for strengthening critical aspects in mathematics education. The focus on critical mathematics education highlights the urgent need to promote critical thinking in mathematics learning, while the emphasis on science technologies and e-learning offers opportunities to utilize technology to enhance mathematics learning in ways that encourage critical thinking. Thus, the combination of these three keywords provides a strong foundation for the



development of mathematics education that considers critical thinking in an effort to improve the quality of student learning in mathematics.

## Conclusions

From the results of the analysis, it can be concluded that research highlighting Critical Thinking in the context of mathematics education shows an increase in publications of around 10.58% every year, reflecting the increasing interest in this topic. The Indonesian University of Education stands out as a highly productive research center in this field, with more than 25 related articles. Regarding the highest publication sources, "Journal of Physics: Conference Series" is the most productive publication with 32 articles and 79 citations in the context of critical thinking in mathematics education, followed by "International Journal of Instruction" with 4 articles and 48 citations. Additionally, authors Soter et al. (2008) recorded the highest number of citations, reaching 217 citations, indicating the significant influence of their work in the literature discussing critical thinking in mathematics education. In line with the analysis, keywords such as systematic reviews, critical mathematics education, science technologies, and e-learning stand out as key trends in research in that year, providing potential for further exploration in future research.

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