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Research Trend of Mathematical Critical Thinking Studies In the Last Decade: A Systematic Review and Bibliometrics Analysis

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A B S T RAK

Berpikir kritis matematis merupakan salah satu keterampilan berpikir abad 21 yang hingga saat ini masih dikaji dari berbagai jenis dan model penelitian. Namun masih banyak hasil-hasil penelitian yang belum terlaporkan dalam publikasi ilmiah. Tujuan penelitian bibliometrik ini yakni mempresentasikan tinjauan systematic review dan analisis bibliometrik terkait kemampuan berpikir kritis matematis yang ada pada database scopus. Analisis bibliometrik ini dilakukan dengan menggunakan data berupa dokumen yang mengandung kata kunci berpikir kritis matematis sebanyak 665 dokumen yang dipilih dari database scopus. Analisis dokumen, citation, kata bersama, penulisan bersama dilakukan menggunakan software publish or perish dan VOSviewer. Hasil penelitian ini menunjukan bahwa perkembangan publikasi terkait berpikir kritis matematis, terdapat beberapa kata kunci yang muncul terkait berpikir kritis matematis seperti diantaranya mathematical education, STEM approach, problem-based learning, reciprocal teaching ICT and ICT models. Kemudian model problem-based learning, reciprocal teaching serta STEM approach merupakan model dan strategi yang banyak digunakan dalam mengembangkan dan menganalisis terkait berpikir kritis matematis serta ICT juga menjadi salah satu media penduking dalam mengembangkan berpikir kritis matematis.

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A B S T R A C T

Mathematical critical thinking is one of the 21st century thinking skills which is still being studied from various types and research models. However, there are still many research results that have not been reported in scientific publications. The aim of this bibliometric research is insight into systematic reviews and bibliometric analysis related to mathematical critical thinking skills in the Scopus database. This bibliometric analysis was carried out using data in the form of documents containing the

Keywords:
critical thinking, systematic review, bibliometric analysis.

keyword mathematical critical thinking as many as 665 documents selected from the Scopus database. Analysis of documents, quotes, co-words, co-authorship was carried out using the software Publish or Perish and VOSviewer. The results of this research show that the development of publications related to mathematical critical thinking is increasing, there are several keywords that appear related to mathematical critical thinking, such as mathematics education, STEM approaches, problem-based learning, reciprocal ICT teaching and ICT models. Then the problem-based learning model, reciprocal teaching and the STEM approach are models and strategies that are widely used in developing and analyzing mathematical critical thinking and ICT is also one of the supporting media in developing mathematical critical thinking.

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1. INTRODUCTION

The development of science and technology in the current global era regarding 21st century mathematics learning focuses on student centers with the aim of developing students' thinking skills. The students' thinking skills in question include: (1) critical thinking, (2) problem solving, (3) metacognition, (4) communicating, (5) collaborating, (6) innovation and creativity, (7) information and technology literacy (Lubis et al., 2023). These six skills are related to each other, and have different concepts and analyzes in achieving learning. Further complicating the process of improving students' thinking skills are disputes about what content should be taught and how it should be taught (Wilkinson et al., 2023).

Some learning theories explain that mathematics should be taught, especially by teachers who provide clear and organized explanations of concepts and procedures, then give students the opportunity to practice those procedures and apply those concepts. In addition, it was also explained that teachers must design ways to directly involve students in exploring the meaning of mathematical procedures, not just showing them how to carry them out. However, there are also those who want their students to memorize procedures and develop skills so that understanding can be obtained from these activities (Das, 2020). Piaget's learning theory about cognitivism greatly influenced the learning system so that the teacher center turned into a student center. This is very suitable for mathematics learning at school, where through student center learning as age develops, children's cognitive abilities are increasing (Trigatti et al., 2022).

The ability to think critically mathematically allows a person to be able to solve problems in social life reasonably and responsibly and make decisions based on positive values in a multidimensional society (Ghimby, 2022). Critical thinking is also seen as a fundamental educational goal in learning and improving students' critical thinking-related skills (Barnabè et al., 2023). A person with good critical thinking skills can navigate technological advances to distinguish between misinformation and valid sociological claims related to aspects of complex

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social problems (Trigatti et al., 2022). Therefore, critically consider the main study that is the most urgent in this study.

This study aims to present a systematic review and bibliometric analysis related to mathematical critical thinking skills in the Google Schoolar and Scopus databases. The research questions in this study are directed based on the objectives of bibliometric analysis, namely:

1) What keywords often appear related to mathematical critical thinking?
2) Which documents, authors, countries, institutions and sources are the most productive and influential in terms of mathematical critical thinking?
3) Which learning models, methods, approaches, strategies and techniques are productive for mathematical critical thinking?
4) Is ICT widely used to improve mathematical critical thinking?

2. METHOD

Scopus was used in this study. "Selected Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA) was used to conduct a systematic review of the articles in the analysis, and the bibliometric analysis method was used to generate knowledge maps utilizing Biblioshiny software for co-citation and co-author analysis.The four steps of bibliometric analysis research are collecting data, pre-processing the data, calculating statistics, and analyzing how the data is used.

Keywords are used to start bibliometric analysis. For this, more than 100 research articles will be highlighted that were recently published and had a decent amount of citations collected from the Scopus Database to list important author keywords that are regarded as the central theme of "Augmented Reality in Mathematics Education." With this query string TITLE-ABS-KEY ("augmented reality" AND "mathematics education" OR "mathematics learning" OR "mathematics classroom"), it generates 107 documents on January 6, 2023, on the website www.scopus.com.

At this level, 107 documents were obtained that met the criteria for the first stage. No language is screened during the second phase of the procedure. Investigations are limited to documents published in Scopus-indexed journals. The initial data is still used in this stage, but no

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data is excluded from the data generated in the first stage. In the third stage, the researcher evaluates the feasibility of the article by examining the article title and abstract to determine whether it meets the researcher's criteria, such as discussing the use of AR in learning mathematics or not. In the final stage, the researcher still used 107 documents from the previous data collection procedure. In the final stage, data stored in *.ris, *.csv, and *.bib formats was analyzed using the Biblioshiny program, which is a library from Bibliometrix in the R programming language (Aria et al., 2017; Gupta et al., 2020; Kore et al., 2022; Supriyadi et al., 2022).

Documents that have been obtained from the database are downloaded in the form of Comma Separated Value (CSV) and Research Information System (RIS) formats. The format contains bibliometric information, bibliographic information, abstracts and keywords. Furthermore, using Publish or Perish (PoP) software, observations were made of some initial statistical data, namely in the form of document titles, document types, citations, authors, year of publication, publishers and sources. This PoP application also assists researchers in providing a summary of descriptive analysis in the form of Total Citations (TC), Total Publication (TP), Number of Author per Publication (NAP), Number of Citation per Publication (NCP), Number of Citation per Year (NCY), g-index, m-index, and h-index (Suyanto et al., 2023).

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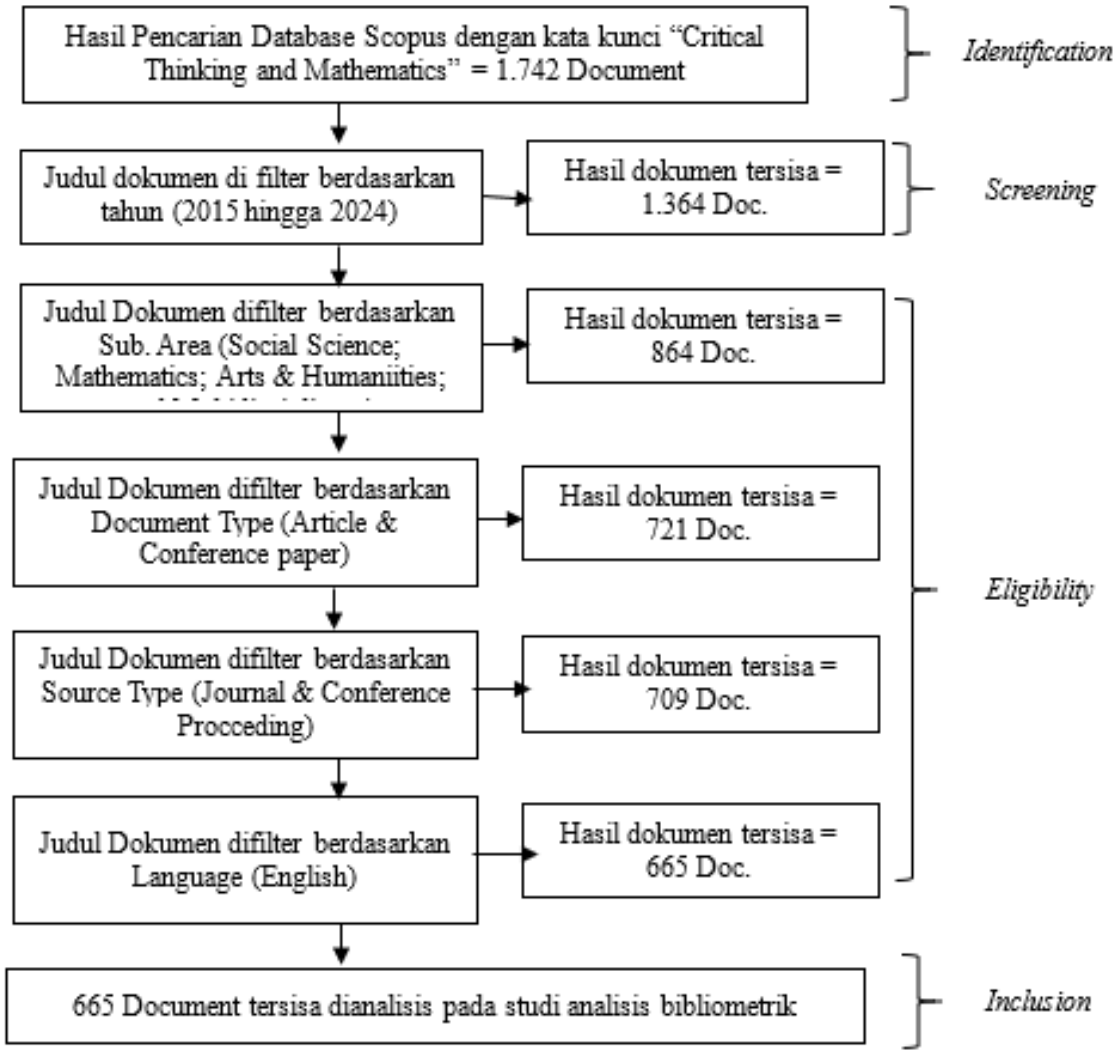

Figure 1. The Stages of Document Selection

Performance analysis related to the study of mathematical critical thinking using PoP software in the form of citation analysis, joint word analysis, and co-author analysis was used to test the relationship between research constituents [9], [10]. Keyword analysis is used to present the most productive and influential documents, authors, countries, affiliates and sources related to mathematical critical thinking. Citation analysis is used to present the distribution of the most keywords related to mathematical critical thinking in 2015-2024. In addition, co-authorship analysis is also used to present social interactions between authors and countries related to mathematical critical thinking. Furthermore, to expand the analysis of science mapping, science mapping analysis and network analysis were carried out using VOSviewer software (Suyanto et al., 2023).

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3. RESULT AND DISCUSSION

a. Performance Analysis

This performance analysis presents the development of journals, publications, and citations related to mathematical critical thinking from 2015 to 2024 (See figure 2). Performance analysis tests research constituents in a specific field. Descriptive analysis is a hallmark of bibliometric studies (Donthu et al., 2021; Suyanto et al., 2023).

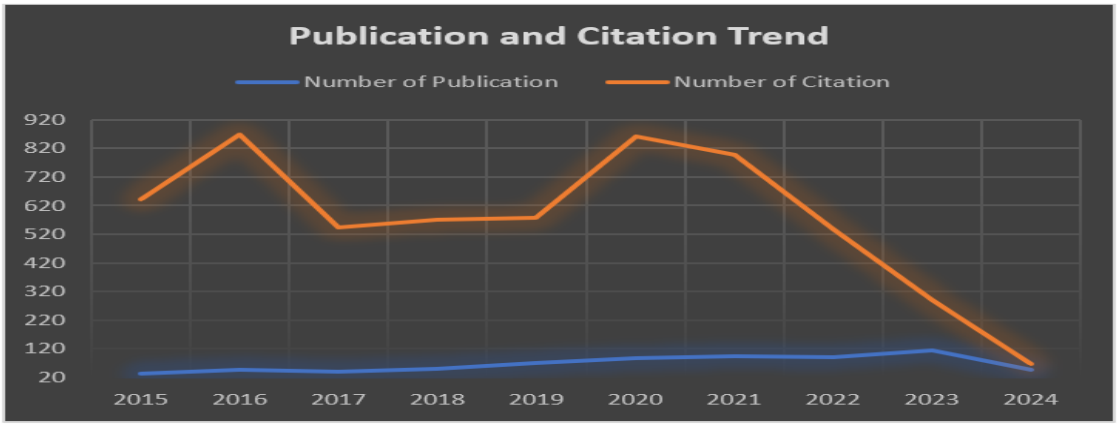

Figure 2. Development of Publications and Citations Related to Mathematical Critical Thinking

Figure 2 shows that the development of publications related to the study of mathematical critical thinking increased from 2015 to 2023 and then fluctuated in 2024. In detail, of the 665 documents published in the period 2015 to 2024, there are five documents published in 2015, namely four articles and one conference paper, then there are 6 documents published in 2016, namely five articles and one conference paper, followed by twenty-five documents published in 2017, 2018 and 2019, namely twenty-two articles and three conference papers, Thirty-two documents in 2020 and 2021, namely thirty articles and two conference papers, and thirty-one documents in 2022, 2023 and 2024, namely twenty-nine articles and two conference papers. Meanwhile, of the 5,096 citations recorded in the Scopus database related to mathematical critical thinking, there were six hundred and eleven citations in 2015, eight hundred and twenty-two citations in 2016, five hundred and five citations in 2017, five hundred and twenty-two citations in 2018, five hundred and eight citations in 2019, seven hundred and seventy-eight citations in 2020,

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seven hundred and seven citations in 2021, four hundred and forty-nine citations in 2022, one hundred and seventy-four citations in 2023 and twenty citations in 2024.

b. Science Mapping and Network Analysis

1) Citation Analysis

Citation analysis reflects the intellectual linkages between publications that are formed when one publication cites another publication (Talan, 2021; Donthu et al., 2021). By using citation analysis, one can analyze the most influential publications in a study to obtain intellectual dynamics related to mathematical critical thinking. The analysis of citations in this study is described in the subchapter. The following is an analysis of each unit in the form of documents, authors with the highest publications, the best institutions with the highest publications and citations, and the best countries and sources with the highest publications and citations (see Table 1).

Table 1. Bibliometric Analysis Results of Each Unit Related to Critical Tinking Keywords

Judul Dokumen	Writer/Year	Source	Country	TC
Active learning in flipped life science courses promotes development of critical thinking skills	Styers (2018)	CBE Life Sciences Education	United States	82
The relationship between creative thinking and critical thinking skills of students	Ülger (2016)	Hacettepe Egitim Dergisi	Turkey	37
Effect of cooperative learning supported by reflective thinking activities on students' critical thinking skills	Erdogan (2019)	Eurasian Journal of Educationa l Research	Turkey	34
Assessing students' critical thinking skills viewed from cognitive style: Study on implementation of problem-based e-learning model in mathematics courses	Kusaeri (2022)	Eurasia Journal of Mathemati cs, Science and Technolog y Education	Indonesia	25

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A Bibliometric and Content Analysis of Critical thinking in Primary Education	Aktoprak (2022)	Thinking Skills and Creativity	Cyprus	25
The effects of subject-based critical thinking education in mathematics on students' critical thinking skills and virtues	Arisoy (2021)	Eurasian Journal of Educational Research	Turkey	21
Critical thinking in national tests across four subjects in Swedish compulsory school	Nygren (2019)	Education Inquiry	Sweden	21
Structural Relationships among High School Students' Scientific Knowledge, Critical Thinking, Engineering Design Process, and Design Product	Yu (2020)	International Journal of Science and Mathematics Education	Taiwan	20

Citation analysis based on scopus metrics shows that documents written by Styer (2018), Ülger (2016), Erdogan (2019), Kusaeri (2022), Arisoy (2021) and Nygren (2019) experienced a decrease in the number of citations in 2024, although Kusaeri (2022) and Arisoy (2021) experienced an increase in the number of citations in 2023 from the previous year, but in 2024 there was a fluctuation in the number of citations. Meanwhile, Aktoprak (2022) and Yu (2020), experienced an increase in the number of citations in 2023 and 2024. On the other hand, Turkey is one of the countries that has the highest number of publications and citations related to critical thinking keywords in the period 2020 to 2024. Then followed by other countries such as the United States with the highest number of citations, namely 82, Indonesia 25 citations, Sweden 21 citations and Taiwan 20 citations. Furthermore, the Eurasian Journal of Educational Research is one of the sources that publishes many documents based on the Scopus database related to mathematical critical thinking.

2) Co-Word Analysis

Joint word analysis is a technique to test the actual content of a publication (Donthu et al., 2021), which consists of network visualization and overlay visualization (Suyanto et al., 2023).

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Shared word analysis assumes that words that often appear together have a thematic relationship with each other (See Figure 3).

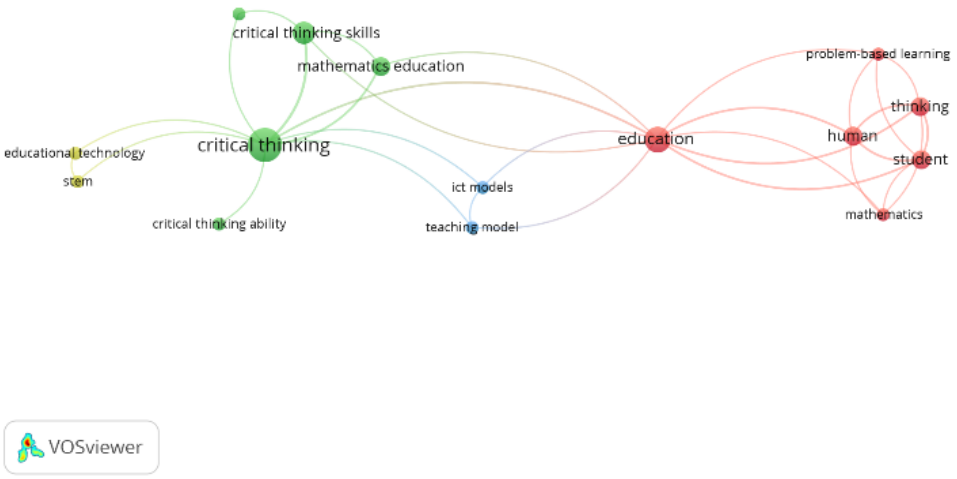

Figure 3. Related to Mathematical Critical Thinking

Table 2. Results of Hierarchical Clustering Analysis on Emerging Keywords Related to Mathematical Critical Thinking

Keyword	Occurrence	Total Link Strength
Critical Thinking	7	67
Education	4	52
Critical Thinking Skill	3	24
Human	2	32
Student	2	32
Thinking	2	32
Mathematics Education	2	20
Mathematics Education	1	19
Education Technology	1	13
Problem based Learning	1	13
STEM	1	13

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ICT Models	1	11
Teaching Models	1	11
Mathematics Learning	1	9
Critical Thinking Ability	1	8

Of the 15 keywords presented in Figure 3, there are seven keywords in the green cluster and six keywords in the red cluster, followed by two keywords in the blue cluster and two keywords in the yellow cluster. The clustering analysis of each keyword that appears is presented in Table 2 by grouping them based on occurrence and total link strength.

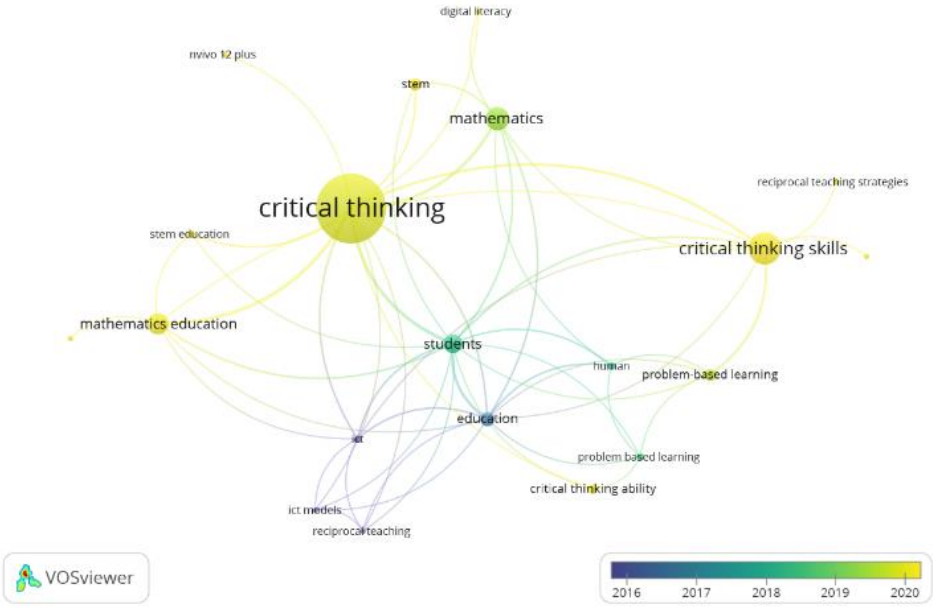

Figure 4. Distribution of Keywords That Emerged Regarding Mathematical Critical Thinking in the Last Period.

Some of the keywords that appear in Figure 4 for the period 2016 to 2020, such as critical thinking, critical thinking skill, mathematics, mathematics education, student, problem based learning, STEM, ICT models, reciprocal teaching, STEM education. These findings show that the keywords that have emerged have become trending research on mathematical critical thinking. The

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hierarchical clustering analysis in Figure 4 is presented based on occurrence and total link strength (See Table 3).

Table 3. Results of Hierarchical Clustering Analysis Based on Keywords Emerging Related to Mathematical Critical Thinking in the Last Period

Keyword	Occurrence	Total Link Strength
Critical Thinking	59	267
Student	8	108
Critical Thinking Skill	18	74
Mathematics	11	72
Education	5	60
Mathematics Education	9	50
Human	2	32
STEM	4	28
ICT	2	25
Problem Based Learning	4	24
Stem Education	2	18
Critical Thinking Ability	3	15
Problem Based Learning	2	15
ICT Models	1	14
Reciprocal Teaching	1	14
Digital Literacy	1	6
Nvivo 12 plus	1	4
Creative and Critical Thinking	1	3
High Order Thinking Skill	1	3
Mathematics Self Efficacy	1	3

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Reciprocal Teaching Strategies	1	3
STEM Approach	1	3
Critical Thinking in STEM	1	2

Table 3 shows that the keywords that appear the most in the yellow cluster are critical thinking, followed by STEM, mathemathic education, problem based learning and reciprocal teaching strategies. In the blue cluster, there are keywords education, ICT models, reciprocal teaching and ICT. Meanwhile, in the green cluster, education and human appeared.

3) Co-Authorship Analysis

Co-authorship analysis examines the interaction between scientists related to critical thinking. Collaboration between scientists has become commonplace (Donthu et al., 2021). Co-authorship analysis in country units is used to present social interactions between countries related to mathematical critical thinking (Suyanto et al., 2023). The number of documents that are cited the most and the smallest is selected based on the number of authors in which several related authors from various countries appear (See Figure 5).

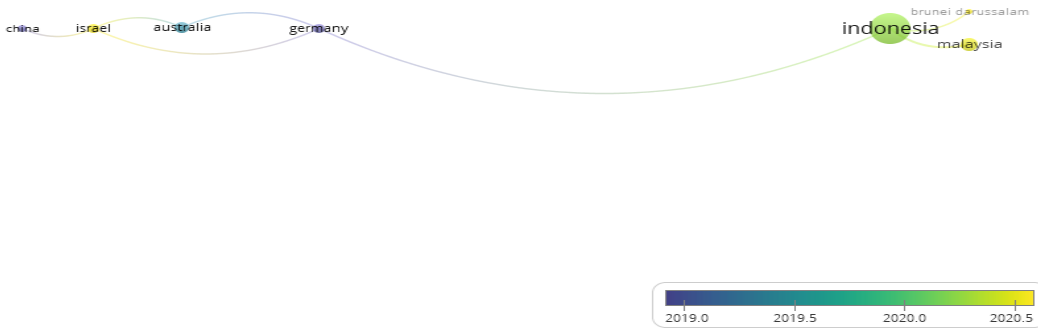

Figure 5. Social Interaction between Countries Related to Mathematical Critical Thinking

Figure 5 shows that Indonesia is one of the countries with the highest citations and has social relations with Brunei Darussalam and Malaysia in conducting research related to mathematical critical thinking. Then followed by Germany, Australia, Israel and China. This shows that Indonesia has a wide network in studying mathematical critical thinking (Suyanto et al., 2023).

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DISCUSSION

a. Publication Trends and Citations About Mathematical Critical Thinking Studies

Based on the analysis that has been carried out on the Scopus database, publications related to mathematical critical thinking have increased from 2015 to 2024. This shows the importance of studying mathematical critical thinking in the latest trend. Although in the analysis of the document, it can be seen that there are fluctuations in 2024, but this does not have much effect on the development of research on mathematical critical tinking. Many bibliometric studies reveal that the study of mathematical critical thinking studies will increase until 2024. And it is one of the warm studies because it is one of the thinking skills in the 21st century.

b. Most Productive and Influential Documents, Authors, Countries, Institutions, and Resources Regarding Mathematical Critical Thinking Studies

Broadly speaking, some of the keywords that are closely related to mathematical critical thinking are mathematical education, STEM approach, problem-based learning, reciprocal teaching ICT and ICT models. This can be used as one of the bases in analyzing the relationship between these keywords in other types of research. Several interventions from the results of analysis on the Scopus database such as learning models, approaches and the use of ICT are the focus of this research related to mathematical critical thinking.

c. Limitations of the Study

There are several limitations to this bibliometric analysis research, namely

1) This study only uses the Scopus database
2) The presentation of keywords that often appear related to mathematical critical thinking only uses co-word analysis
3) This study only utilizes the Publish or Perish and VOSviewer applications in visualizing keywords, authors, number of documents, number of citations, countries related to mathematical critical thinking

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4. CONCLUSSION

Based on bibliometric analysis that has been carried out using the publish or perish application and VOSviewer, some information related to mathematical ctitical thinking from 2015 to 2024 was obtained. Studies related to mathematical critical thinking are increasing every year both from the number of publications and from the number of citations from various institutions and countries. It can be seen that 665 documents published between 2015 and 2024 come from qualified sources and experienced authors who have many other publications. Of the 665 documents obtained, there are still most of the document titles that do not contain the keyword of mathematical critical thinking. Several keywords related to mathematical critical thinking can be used as the basis for up-to-date research in further research.

The results of this bibliometric research are presented based on the research questions in the introduction. First, there are several keywords that appear related to mathematical critical thinking such as mathematical education, STEM approach, problem based learning, reciprocal teaching ICT and ICT models. Second, the problem-based learning model, reciprocal teaching and STEM approach are models and strategies that are widely used in developing and analyzing mathematical critical thinking. Third, ICT also appears in many searches juxtaposed with mathematical critical thinking.

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