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Improving students' mathematical critical thinking abilities: A systematic literature review

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Abstract

One of the objectives of 21st-century learning is to help students become more adept critical thinkers. Thus, the purpose of this systematic literature review is to identify strategies for improving students' critical thinking abilities, particularly when it comes to learning mathematics. The Scopus database was used to collect data. For additional examination, 25 publications that were released between 2019 and 2023 were retrieved. Mendeley, VosViewer, and Microsoft Excel are the tools that are used. The analysis' findings demonstrate that teaching material, teaching method, and oral questions are all employed to enhance students' critical thinking abilities. Modules and media are the most popular teaching materials used in mathematics education to foster critical thinking. The goal of this literature study is to provide educators with more insight into instructional strategies that enhance students' capacity for critical thought.

***Keywords*:** critical thinking; mathematics; literature review; teaching material; teaching method.

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1. Introduction

One of the most significant abilities of the twenty-first century is critical thinking (Redecker and Punie, 2014; Scott, 2015; Davies and Barnett, 2015; Smith et al., 2018; Zetriuslita et al., 2018; Dwi Susandi et al., 2019; Mahanal et al., 2019; Hujjatusnaini et al., 2022). The International Commission (2021) has identified critical thinking ability as a targeted achievement in education by 2050. If taught effectively, it will stimulate logical problem-solving thinking (Dwyer et al., 2011) and contribute to educational improvement. Critical thinking abilities are one of higher-order thinking (Astuti et al., 2020). Globally, curricula for mathematics education now prioritize developing students' mathematical critical thinking abilities (Weng et al., 2022; Yildrim et al., 2011). According to the Ministry of Education and Culture Decree Number 22 of 2020 on the Ministry of Education and Culture's strategy plan for the period 2020-2024, critical thinking has been named as one of the Pancasila Youth Profiles in Indonesia. Because of this, teachers require that children acquire critical thinking abilities as part of the Merdeka Curricula. Critical thinking is an ability in thinking that combines cognitive processes and enables students to consider circumstances critically.

Critical thinking abilities will assist students in thinking rationally (Dwyer et al., 2014), developing analytical abilities, and decision-making abilities when confronted with several options (Mapeala et al., 2015), connecting and evaluating all parts of a topic holistically (Hughes et al., 2015). Students with critical thinking abilities are more cautious while solving problems, resulting in proper conclusions and logical solutions (Berestova et al., 2022). Students who possess critical thinking abilities are equipped to handle a lot of knowledge and issues for which there is no apparent solution (Angeli and Valanides, 2009). This competence is also required to make the proper decisions (Aizikovitsh and Amit, 2009; Niu et al., 2022; Sutini et al., 2017; Gurcay and Ferah, 2018; Plummer et al., 2022), present the right justifications (Gurcay and Ferah, 2018), and make to the proper logical solution (Ramirez et al., 2022; Sasson et al., 2022; Berestova et al., 2022). Furthermore, critical thinking abilities can predict academic and professional success (Starkey, 2004; Irfan, 2017). Critical thinking abilities can be given, and mathematics may play a part in their development.

Critical thinking abilities are essential in mathematics learning which involves student participation and involvement in a more active learning process (Lugosi and Uribe, 2022). The learning of mathematics requires the stimulation and development of critical thinking abilities (Hafni et al., 2019; Yumiati and Kusumah, 2019; Zetriuslita et al., 2018) because one of the abilities needed in the twenty-first century. Critical thinking in mathematics can boost creativity by encouraging students to try novel approaches to addressing mathematical issues (Su et al., 2016). It entails mental actions that involve connecting, manipulating, and transforming prior knowledge and experiences to help with decision-making and problem-solving in novel situations. As a result, teachers must be capable of developing students' mathematical critical thinking abilities (Afriansyah et al., 2019; Abramovich et al., 2019 Kusaeri and Aditomo, 2019).

Permana et al., (2021) and Galimullina et al., (2020) concentrated on sharing research findings that employed their STEM (Science, Technology, Engineering, and Mathematics) techniques employing the Problem-Based Learning (PBL) model to enhance mathematical critical thinking abilities in their study on critical thinking abilities. Similar to Setyawati et al., (2020), they concentrated on analyzing the outcomes of earlier research that enhanced mathematical critical thinking skills through the application of their STEM – Project-based learning (STEM-PjBL) model. The findings of Putri et al., (2023) and Forde et al., (2023) researches also showed that STEM-based blended learning can improve critical thinking abilities in all indicators with moderate to high categories. Furthermore, research by Susandi and Widyawati (2022) and also Susanti et al., (2022) focused on discussing research results that used the Realistic Mathematic Education (RME) learning model is more effective in improving critical thinking abilities than the conventional learning model.

In addition, Kertiyani and Sarjana (2022) used 175 published research generated from a systematic search on Google Scholar, Educational Resource Information Center (ERIC), Science Direct, and Directory of Open Access Journal (DOAJ) to determine the level of students' critical thinking abilities which are

published between 2019-2022. This systematic literature review of the research by Kertiyani and Sarjana (2022) has not expressly mentioned tools or models utilized to improve students' mathematical critical thinking abilities. Conducting a review of the critical thinking abilities of mathematics education students, as well as the learning model that can be used to optimize the students' mathematical critical thinking abilities will be essential topics to investigate.

It takes thinking abilities to overcome the challenges of life. This includes the ability to think critically, and creatively, and solve problems. Critical thinking is one of the abilities needed to handle societal and personal obstacles. Here are a few ways to define critical thinking. The ability to apply knowledge to obtain understanding that can be prudently accepted is known as critical thinking. As a result, one can solve difficulties by making informed decisions (Mumtahanah, 2013). The ability to plan and produce assessments, interpretations, inferences, and analyses, as well as to reveal ideas or formulas, criteria, evidence, procedures, or contextual considerations as the foundation for decision-making making is what Facione (2011) defines as critical thinking. Critical thinking according to Angelo as cited by Santoso (2009) is applying rational, high thinking activities, including analyzing, synthesizing, recognizing problems and their solutions, concluding, and evaluating. Ennis (2011) argues that critical thinking is reflective thinking and the ability to make decisions. This means that critical thinking is not only about proficiency in inference or argument but also the ability to evaluate questions. Critical thinking abilities include among other things, basic clarification, decision making, inference, offering a further explanation, estimation, and incorporation.

The goal of critical thinking is to learn how to think more deeply to solve issues more efficiently (Mapeala et al., 2015; Berestova et al., 2022; Plummer et al., 2022), communicate, collaborate, and innovate (Murawski, 2014; Ramirez et al., 2022; Sasson et al., 2022). Students with strong critical thinking abilities can learn at a higher level (As'ari, 2014). Therefore, teachers are crucial in developing students' critical thinking abilities. Teachers can help students enhance their critical thinking in a variety of ways. According to the research findings of Umam and Susandi (2022) demonstrated that creating a learning model is a highly recommended way to boost students' mathematical critical thinking abilities.

Facione (2015) suggested that interpretation, analysis, evaluation, inference, explanation, and self-regulation are some markers of critical thinking abilities. The markers of critical thinking abilities developed by Ennis (1985) are abbreviated as Focus, Reason, Inference, Situation, Clarity, and Overview (FRISCO). In addition, Ennis (2011) was looking for another recent reference, there are twelve markers of critical thinking abilities which are classified into five stages, as follows basic clarification, basic support, inference, advanced clarification, conjecture, and alignment. Jacob and Sam (2008) proposed some indicators of critical thinking abilities, namely clarifications, assessment, inference, and strategy. Similar to Angelo in Santoso (2009) indicators of critical thinking ability include analysis, synthesis, problem-solving, inference, and evaluation. Additionally, Glaser and Watson (2012) offer a few indicators such as interpretations, deduction, evaluations, inferences, and awareness of assumptions, such as selecting tools in the academic sector.

1.1. Purpose of study

The goal of this study is to look into students' mathematical critical thinking abilities and the learning model that may be used to encourage these abilities. The findings of this study are intended to be the primary consideration in selecting an effective learning model to enhance critical thinking abilities. The goal of this systematic literature review was to identify potential answers to the following research question.

1. According to the year of publication, how well does the description of improving students' mathematical critical thinking abilities?
2. According to the research methodologies, how well does the description of improving students' mathematical critical thinking abilities?
3. Depending on the level of study, how does the description of improving students' mathematical critical thinking abilities?

4. What are the most common techniques utilized to improve students' mathematical critical thinking abilities?
5. Which country has conducted the greatest study on mathematical critical thinking abilities?
6. How is the description of the trend of five-year publication in improving students' mathematical critical thinking abilities?

1.2. Literature review

Mathematics is a subject that deals with numbers, measurements, quantities, and shapes. Mathematics instruction cannot be implemented effectively unless the information, pedagogy, and skills that will be employed in teaching and learning sessions are understood (Oslund, 2016). Mathematics teacher's strategies for improving their teaching and learning processes vary as technology advances.

One of the factors that influence the success of the teaching and learning process is the selection and use of appropriate methods for a concept. Learning that is carried out in a varied manner, is not monotonous, and can increase student activity is important in the teaching and learning process to achieve learning objectives. So learning is needed that can stimulate student learning and create a pleasant classroom atmosphere.

Teachers act as creative facilitators and mediators. The teacher's job is not only to convey information but also to create a learning experience for students. Teachers must be able to find models and techniques that can support their role so that teaching and learning activities can be carried out effectively (Wang et al., 2022). Teachers are required to use learning models or learning materials that are appropriate to the material to be delivered so that students understand the concepts being studied. The mathematics learning process using the conventional model does not encourage students to actively search for and discover concepts independently. The process of learning mathematics is not only based on theory but places greater emphasis on the principles of a teaching and learning process and their relationship to everyday life.

2. Method and materials

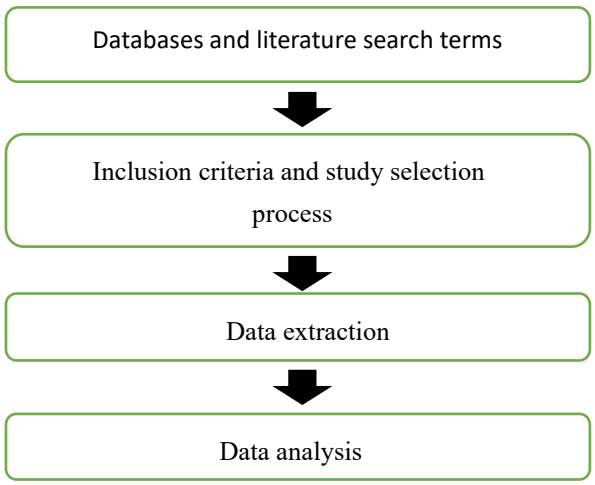
2.1. Design of research

This study is an SLR (Systematic Literature Review). SLR is a comprehensive analysis of study findings. To address previously posed research objectives, a systematic literature review employs clear and comprehensive techniques for locating, assessing, and interpreting all available data on a given topic (Iskandar and Juandi, 2022). The findings of original research on mathematical critical thinking abilities are examined in this study. The Preferred Reporting Items for Systematics Review and Meta-Analysis (PRISMA) were used for this review. PRISMA offers three primary advantages (Sierra-Correa and Cantera Kintz, 2015).

It starts by outlining precise research questions that make careful study possible. Secondly, it provides for inclusion and exclusion. Thirdly, it attempts to review a sizeable body of scientific literature published within a given period. Lastly, the PRISMA declaration enables a comprehensive search for subjects related to critical thinking. The guidelines contain four main stages, as shown in Figure 1.

Figure 1

Stages of systematic review



2.2. Stage 1: Identification

The Scopus database is used to search for articles. For more detailed searches and to avoid filtering too many integers, a search string is required. Use the following search term for this study: ("Critical Thinking Abilities, Critical Thinking Skills", "Critical Thinking Ability, Critical Thinking Skill", "Mathematical Critical Thinking Abilities, Mathematical Critical Thinking Skills"), and ("Mathematical Critical Thinking Ability, Mathematical Critical Thinking Skill).

2.3. Stage 2: Screening

The selection process begins with a study of the abstracts and titles of the articles to determine the relevance of the studies (Zawacki-Ritcher et al., 2020). Furthermore, the papers were split depending on inclusion and exclusion criteria. The following table lists the study's inclusion and exclusion criteria.

Table 1

The Inclusion and The Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
The chosen articles are from international journals that Scopus has indexed.	Book and book chapters or articles are not indexed by Scopus
Publishing year 2019-2023	Publishing year before 2019
Using English	Non-English
Studies aimed to attempt to improve mathematical critical thinking abilities	Studies have not been conducted to improve mathematical critical thinking abilities

2.4. Stage 3: Eligibility

The eligibility process comes from the screening process. The extracted articles were manually examined by the author to ensure that all of the remaining papers fit the requirements. This was performed by reading the studies' titles, abstracts, and entire contents of the studies. The technique component resulted in the removal of 45 papers that were published as book chapters and did not attempt to improve students' mathematical critical thinking abilities. As a result, 25 studies could be included in the systematic literature review.

2.5. Stage 4: Included

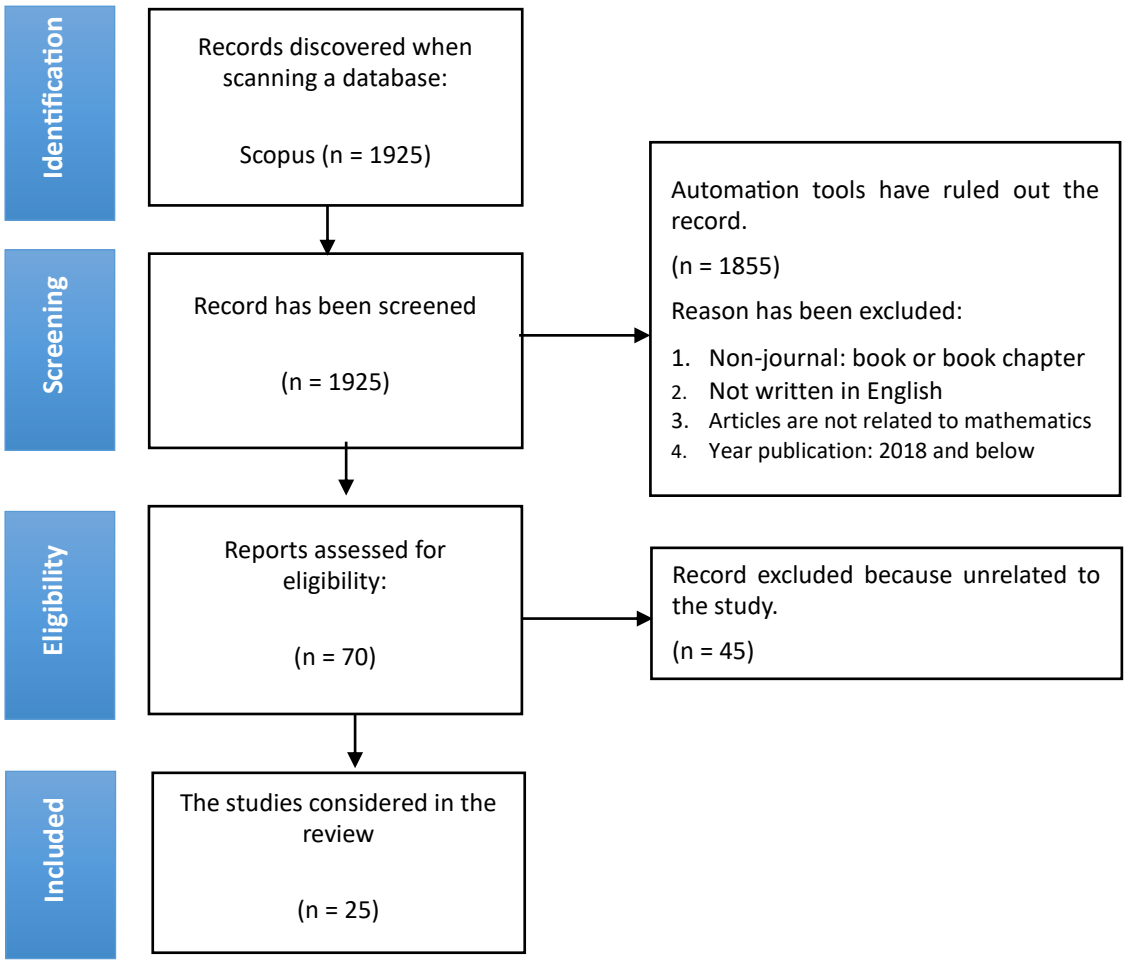
The articles included in this systematic literature review concentrated on methods for improving students' capacity for critical thinking when learning mathematics. 25 articles were selected from the databases of Scopus. The excellent caliber and variety of the articles in these databases, many of which are in the field of education, led to their selection. Only pertinent works that satisfy the requirements for inclusion will be reviewed (Juandi, 2021). Articles that do not fit the requirement for inclusion are

not moved on to the next phase. Depending on the theme relevance, journals and articles that fit the inclusion requirement are then categorized and sorted for additional assessment.

Presenting the investigation's results in the last stage. This step provides a logical and comprehensible summary of the research findings. The procedure is seen in Figure 2.

Figure 2

PRISMA Diagram Flow



2.6. Stage 5: data extraction

The relevant data were extracted to evaluate the articles' quality after the studies had been identified in the systematic review. Gast, Schildkemp, and Van der Veen's (2017) suggested criteria for the data to be extracted from each article were as follows:

i. General information: Title, author and year of publication, research context, and journals.
ii. Topic: Improving students' mathematical critical thinking abilities.
iii. Research design: Research questions or research objectives, description of the study, and research design.
iv. Overall results: Findings related to the research questions.

2.7. Stage 6: data analysis

To answer the objectives, the results and findings derived from all empirical research were compiled using organized summaries. To ensure a detailed depiction of the results, the findings and discussion sections of all papers that fit the requirements were analyzed in greater depth after extracting the articles' total results. A thematic analysis was used to analyze all of the articles in this systematic literature review. Thematic analysis aided in the examination of large amounts of data by categorizing them into specific topics.

3. Results

3.1. Publishing year

Between 2019 and 2023, numerous papers on strengthening students' mathematical critical thinking abilities were released. 25 papers were chosen based on inclusion and exclusion criteria. Figure 3 displays the annual distribution of article numbers.

Figure 3

Database on Publishing Year

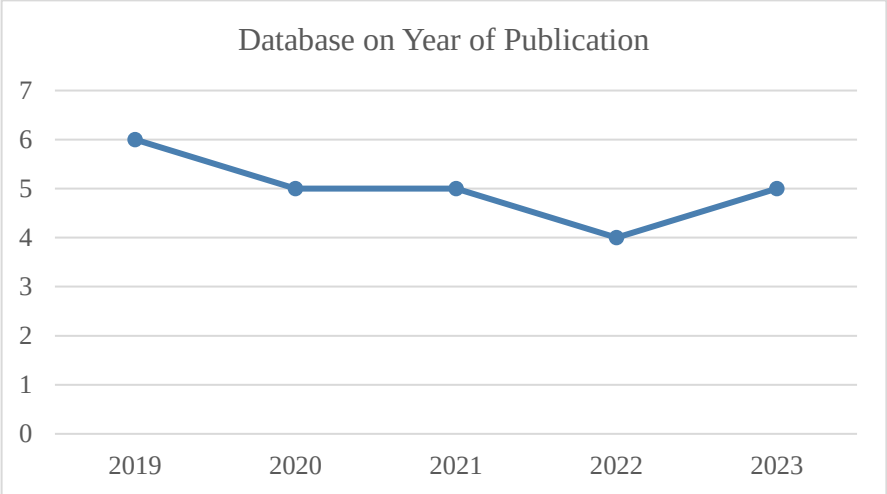


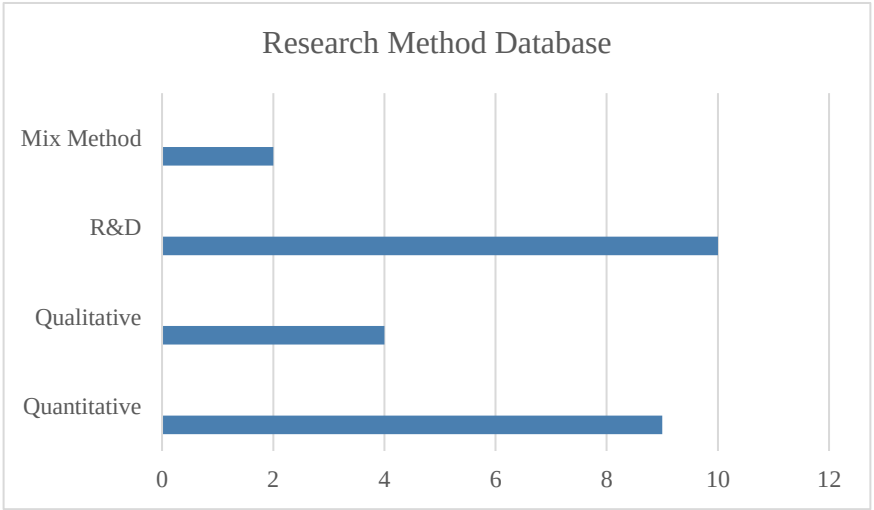
Figure 3 demonstrates that between 2019 and 2022, there were fewer papers about improving students' mathematical critical thinking abilities. However, between 2022 and 2023, there was a modest increase in the number of papers on improving students' mathematical critical thinking abilities.

3.2. Research methodologies

Researchers employ several study approaches to improve students' mathematical critical thinking abilities. Figure 4 depicts the study methodology utilized by various studies to improve students' mathematical critical thinking abilities.

Figure 4

Database on Research Method



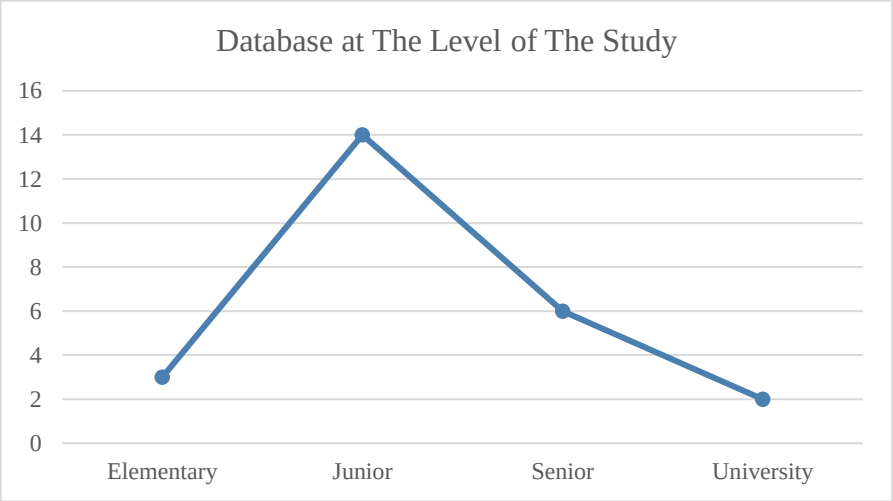
According to Figure 4, the researchers' most popular design for improving students' mathematical critical thinking abilities is research and development. ADDIE models (Analysis, Design, Development, Implementation, and Evaluation) are the most popular kind of research and development.

3.3. Study level

Students enrolled in schools or universities are one of the designated inclusion criteria. The research subjects of the 25 papers that were analyzed are shown in Figure 5 below.

Figure 5

The Level of The Study Database



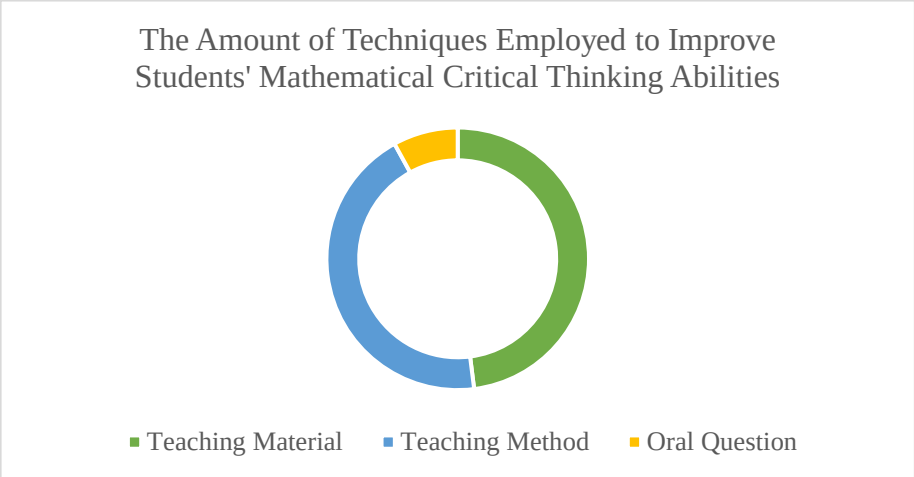
According to Figure 5, the majority of the research subjects were Junior High School students, followed by college or university students, Senior High School students, and Elementary School students.

3.4. The most common techniques

Figure 6 depicts the percentage of approaches employed to improve students' mathematical critical thinking abilities. This report provides a complete study of the most common strategies utilized to improve students' mathematical critical thinking abilities.

Figure 6

The number of Techniques Employed to Improve Students' Mathematical Critical Thinking Abilities



According to the graph, one of the most popular techniques for improving students' mathematical critical thinking abilities is teaching materials. The application of new instructional tools is believed to boost students' interest and ability in mathematics. Less inventive teaching methods and teaching materials cause students to lose interest in lessons and become bored with the lesson (Alp Christ et al., 2024). The teachers then shift their perspectives by not being dubious of additional change and progress to become inventive and professional teachers in the classroom behavior learning process.

Table 2 provides an additional explanation.

Table 2

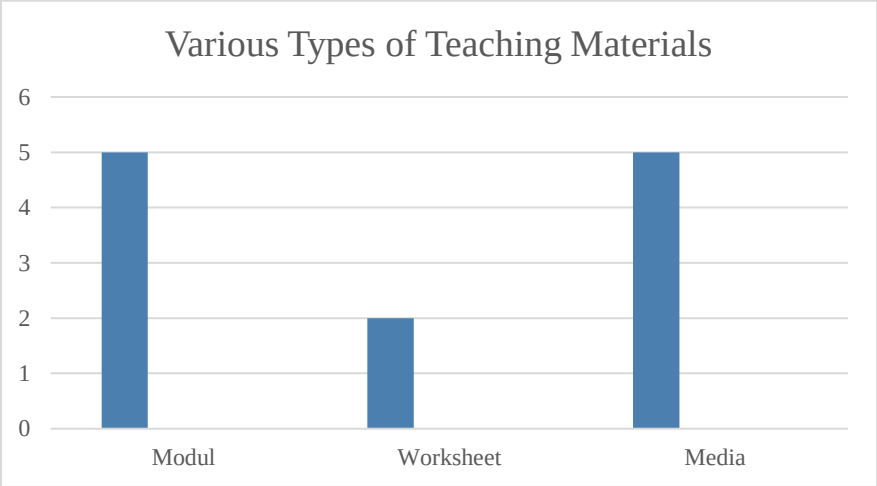
The Findings of The Techniques Utilized to Improve Students' Mathematical Critical Thinking Abilities

No	Authors	Techniques		
		Teaching Material	Teaching Method	Oral Questions
1	Setambah et al., (2019)		✓	
2	Hairun et al., (2020)		✓	
3	Solihati and Suparman (2019)	✓		
4	Andriani and Suparman (2019)	✓		
5	Hikayat et al., (2020)	✓		
6	Kusumaningrum and Suparman (2020)	✓		
7	Buchori and Puspitasari (2023)	✓		
8	Sayekti and Suparman (2020)	✓		
9	Metpattarahiran (2019)		✓	
10	Tsng et al., (2021)		✓	
11	Pramasdyahsari et al., (2023)	✓		
12	Hidayat et al., (2023)	✓		
13	Basri et al., (2021)			✓
14	Mahmud et al., (2021)		✓	
15	Mangwiro and Machaba (2022)			✓
16	Priyadi and Kuswanto (2023)	✓		
17	Alfayez et al., (2022)		✓	
18	Sydawy and Hassan (2019)		✓	
19	Mater et al., (2022)		✓	
20	Dewi and Kuswanto (2023)	✓		
21	Rahayu and Kuswanto (2021)	✓		
22	Hebebci and Usta (2022)		✓	
23	Lestari et al., (2021)	✓		

It is evident from Figure 6 and Table 2 that the most popular method for improving students' mathematical critical thinking abilities is the employment of instructional materials. The following is an example of applied kind of instructional material:

Figure 7

Different kinds of teaching materials



The figure demonstrated how the researchers most frequently employ two types of teaching materials – modules and media – to help students develop their mathematical critical thinking abilities.

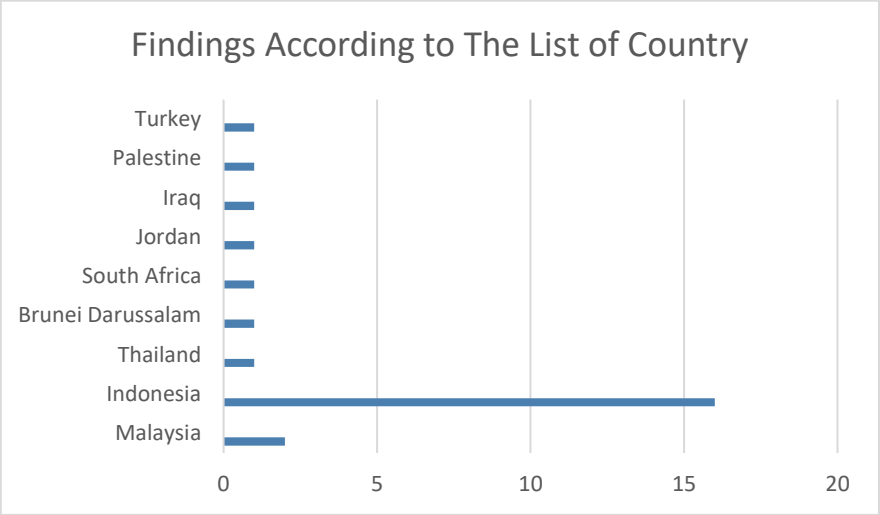
The results show that media that was once employed to help kids develop their mathematical critical thinking abilities, MathCityMap App, Android-based Comic Media, Android-based Carom Games Comic, Android-based Learning Media, and Mathematics Comic that contains Pancasila Values. On another side, there are 11 research on teaching methods with their classification, which include Science, Technology, Engineering, and Mathematics (STEM), Problem-Based Learning (PBL), Game-Based Learning, ICT-based Learning, Appleton Model, Academic Constructive Controversy Learning, Contextual Learning and Problem Posing, Adventure Based Learning, and Flipped Classroom.

3.5. The country with the most research

This review involves nine different countries. The majority of mathematical critical thinking abilities research, according to the findings of this study, is carried out in Indonesia. In terms of number, sixteen researches have been undertaken in Indonesia. In addition, two researches were undertaken in Malaysia. In the meantime, only one study has been undertaken in seven nations to improve students' mathematical critical thinking abilities: Thailand, Brunei Darussalam, South Africa, Jordan, Iraq, Palestine, and Turkey.

Figure 8

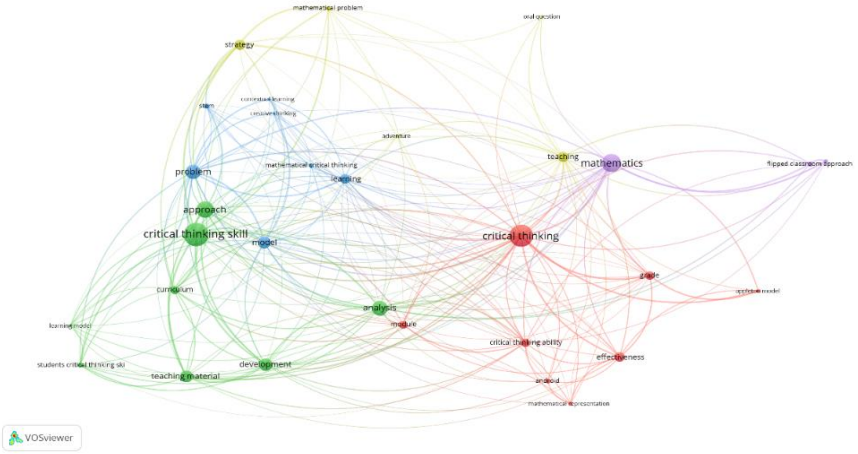
Findings on improving students' mathematical critical thinking ability research according to the list of countries



3.6. The trend of five-year publication in improving mathematical critical thinking abilities

Figure 9 depicts trends over the last five years based on data from VOSviewer-processed bibliographies. The same-colored circles represent the same group, while the size of each circle denotes keyword prevalence. The wider the circle, the more often the topic of discussion was mentioned in the 25 articles. VOSviewer simulates that 31 significant keywords achieve the 5 cluster requirements. Critical thinking, critical thinking skills, mathematics, problem, and strategy had the highest score frequency in each group, indicating that the four keywords are mostly concentrated and significantly closely connected.

Figure 9
The keyword network visualization



The colors in Figure 10 show research topic tendencies. The lighter the color, the more current the study. Recent papers that include many keywords such as STEM, strategy, mathematical critical thinking, android, and mathematical representation are highlighted in yellow as trending. Researchers need information on the topic's uniqueness is critical in describing the present state of investigations completed over many periods.

Figure 10
The keyword overlay visualization

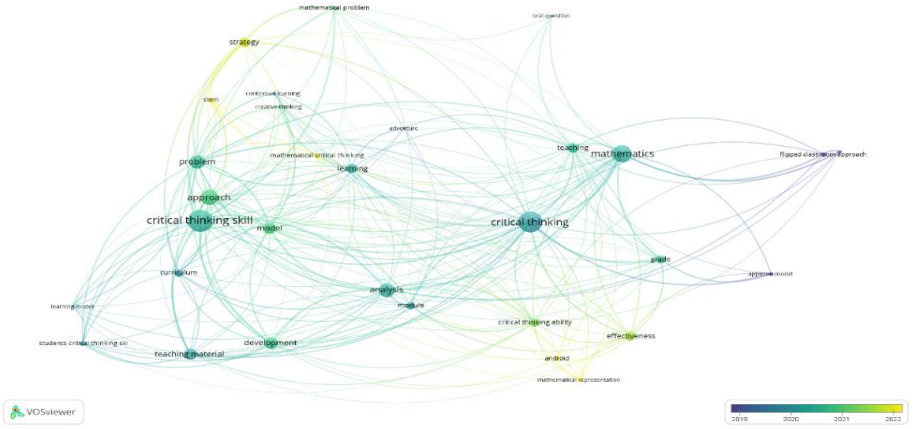
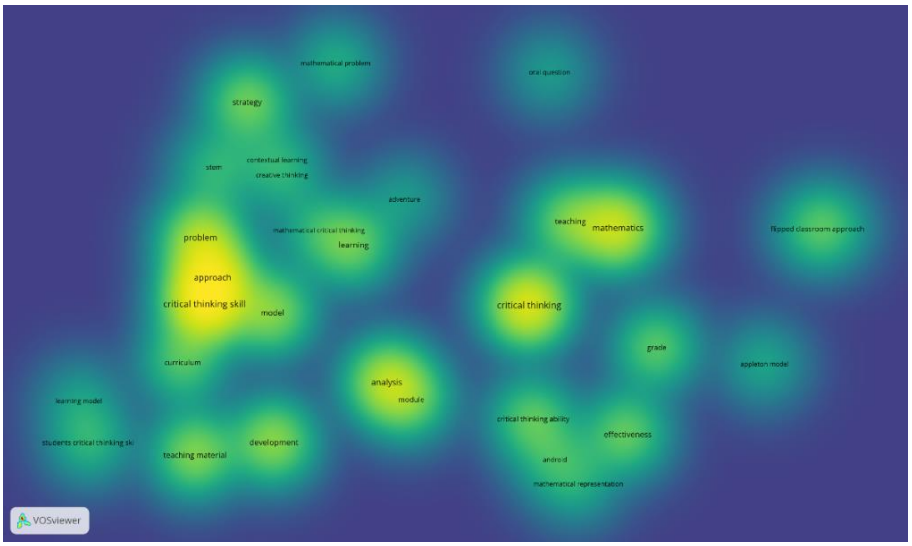


Figure 11 depicts the brightest colors as critical thinking, critical thinking skill, approach, and mathematics. This demonstrates that these themes are frequently employed in studies on critical thinking skills in mathematics learning. Other topics, such as adventure, the Appleton model, the flipped classroom approach, strategy, effectiveness, oral questions, android, and mathematical representation, remain understudied. These themes can be expanded into more studies to help students enhance their mathematical critical thinking abilities.

Figure 11
The keyword density visualization



4. Discussion

According to research findings, research papers on improving students' mathematical critical thinking abilities increased from 2022 to 2023 with the majority of authors being from Indonesia. Next, based on Figure 3, the most common design employed by study authors to evaluate critical thinking abilities is research and development. Furthermore, the research findings revealed that the majority of the research subjects were Junior High School students. At this level, learners begin to face more sophisticated mathematical content that necessitates deeper knowledge. The process of developing critical thinking abilities in mathematics at the Junior High School level can have a substantial impact on their abilities in mathematics at higher levels as well as critical thinking in general.

There are 12 studies out of 25 that focus on teaching materials to improve students' mathematical critical thinking abilities. Teaching materials account for 48% of the total in promoting mathematical critical thinking abilities. This systematic literature review offers light on numerous teaching resources used to develop students' mathematical critical thinking abilities such as modules, students' worksheets, and media. Based on the teaching strategy, the most common teaching resources are modules and media. According to the findings, media such as the MathCityMap App, Android-based Comic Media, Android-based Carom Games Comic, Android-based Learning Media, and Mathematics Comics that feature Pancasila Values are utilized to increase students' mathematical critical thinking abilities.

As many as 44% of research focuses on teaching methods used to increase critical thinking skills. Based on the outcomes of this research, the teaching methods used to improve critical thinking abilities are Science, Technology, Engineering, and Mathematics (STEM), Problem-Based Learning (PBL), Game-Based Learning, ICT-based Learning, Appleton Model, Academic Constructive Controversy Learning, Contextual Learning and Problem Posing, Adventure Based Learning, and Flipped Classroom. The most common methodologies are PBL and STEM. This is consistent with research outcomes (Aswan et al., 2018; Amin et al., 2020) implementing PBL enables students to think critically by asking questions, addressing challenges, and developing solutions (Narmaditya et al., 2018). On the one hand, Morrison (Hafni et al., 2020) claims that STEM teaches students to think critically. Therefore, to prepare students for the fast-evolving industry 4.0, STEM can help them develop abilities like critical thinking and an industrial attitude. The STEM approach to teaching sharpens students' critical thinking abilities (Yulianti et al., 2020; Ardianti et al., 2020; Prasadi et al., 2020; Hacioglu & Gulhan, 2021).

The research's oral questions employed in this study were the kinds of questions teacher ask while they converse with their students about mathematics. Effective oral questions in mathematics can

stimulate students' mathematical critical thinking and encourage them to think critically. Developing a skeptical mindset to study a mathematical subject in a classroom setting should improve one's capacity to critically assess mathematics. Many techniques of studying mathematics, such as questions on Olympics, and High Order Thinking Skills (HOTS) are utilized to stimulate efforts to improve the level of mathematical critical thinking abilities. It revealed that understanding the material of mathematics requires a higher level of cognitive ability. It is also because the questions under consideration have medium to challenging degrees of difficulty in the Bloom Cognitive domain.

5. Conclusions

Based on the findings and discussions above, the study was conducted on students' critical thinking abilities and this research experienced an increase from 2022 to 2023. The most commonly utilized research method is Research and Development, and the majority of study subjects are Junior High School students. According to the findings of this study, the most common approaches utilized to develop students' mathematical critical thinking abilities are teaching materials, based on a comprehensive literature evaluation.

Aside from that, modules and media are the most commonly used by researchers. Future researchers can use the modules and media based on learning models to help students develop their critical thinking abilities. Furthermore, according to research trends utilizing VOSviewer, the application of the STEM adventure model, Appleton model, flipped classroom approach, oral questions, android, and mathematical representation in mathematics learning are new with few studies on it.in mathematics learning is new with little studies on it.

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