25 (4), 2024, 1925-1938

Jurnal Pendidikan MIPA

e-ISSN: 2685-5488 | p-ISSN: 1411-2531

http://jurnal.fkip.unila.ac.id/index.php/jpmipa/

Enhancing Students' Critical Thinking in Mathematics Education: A Systematic Literature Review

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Abstract: Students' critical thinking abilities are one of the goals of 21st-century learning. Critical thinking abilities enable students to think in a realistic and logical way, assist in understanding and solving problems, and build effective communication skills in facing future challenges. Therefore, the aim of this Systematic Literature Review (SLR) is to identify effective methods for enhancing students' critical thinking abilities, especially in the study of mathematics education. Microsoft Excel and Publish or Perish were used to examine a total of 14 papers from 2014 to 2024 found using Google Scholar and Scopus. The results of the analysis show that teaching approaches, subject matter, and teacher attitudes are some of the methods used to improve critical thinking skills. The most popular and successful teaching method in mathematics education is problem-based learning (PBL). Additionally, research conducted between 2020 and 2022 shows a greater focus on critical thinking skills, with quantitative and qualitative research methodologies taking center stage. Teachers can use these insights to provide more imaginative and significant mathematics instruction. It is recommended that teachers develop modules and frameworks that are integrated with ICT to improve critical thinking skills, especially for teaching in the early grades. This can contribute to a more imaginative and meaningful mathematics learning process.

Keywords: critical thinking, SLR, learning methods.

▪ INTRODUCTION

The ability to think critically is an essential skill in mathematics education that is needed in the 21st century (Chai & Kong, 2017; Hujjatusnaini et al., 2022; (Bayasut, 2019). In mathematics learning, critical thinking is the core of the process of connecting various concepts, developing problem-solving strategies, and evaluating results logically and systematically (Aizikovitsh & Amit, 2011). Students not only understand mathematical concepts but also solve problems effectively and face real-world challenges (Hafni et al., 2019). Critical thinking trains students to analyze information, develop problem-solving strategies, and evaluate results logically and systematically. In addition, this ability encourages student creativity by enabling the exploration of various problem-solving approaches, which are very relevant in various life contexts (Ayu, 2023; Basri & As'ari, 2019; Ulfa, 2020;).

Facione (1990) defines critical thinking as the ability to express concepts, criteria, evidence, methodology, or contextual considerations as a basis for decision-making as well as organize and produce evaluations, interpretations, analyses, and conclusions. Meanwhile, according to Ennis (2011), critical thinking is a reasoning and reflective thinking skill that is focused on what is believed. Choy and Cheah (2009) also explain that critical thinking is a skill needed to process cognitive information at a high level and to define complex processes. Ennis (1993) formulated indicators of critical thinking skills abbreviated as FRISCO (Focus, Reason, Inference, Situation, Clarity, Overview). Furthermore, Watson & Glaser (2012) provide five indicators as selection tools in the

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DOI: http://dx.doi.org/10.23960/jpmipa/v25i4.pp1925-1938
Received: 13 January 2025
Accepted: 24 January 2025
Published: 26 January 2025

academic field, namely interpretation, deduction, evaluation, inference, and introduction of assumptions.

Critical thinking skills are very important to build students' thinking to face everyday problems (Mahanal et al., 2019; Matthee & Turpin, 2019; Weng et al., 2022). Critical thinking skills make students careful in solving problems so that they make reasonable and appropriate decisions. Critical thinking also allows students to face challenges in an organized manner, create creative questions, study problems systematically, and find new solutions (Ramírez-Montoya et al., 2022). Critical thinking includes having an open mind, getting along with other people, and using abstract ideas to find relevant information (Aini et al., 2021). To become critical thinkers, students must be able to gather and evaluate relevant information, formulate clear hypotheses and problems, evaluate and analyze data, and generate important questions and problems.

Critical thinking skills will increase if there are efforts to manage learning by providing opportunities for students to be actively involved in learning. In order to accomplish these goals, mathematics education must be innovative, for instance, by utilizing models, techniques, and strategies in addition to renewable learning resources (Darmayanti et al., 2022). Therefore, this research is needed to explain the strategies used by researchers over the last ten years to enhance students' critical thinking abilities in mathematics education. To achieve the research objectives, four research questions (RQ) guided the conduct of this systematic review.

RQ1: How has the development of students' critical thinking abilities in mathematics education progressed, according to the year of publication?

RQ2: What research methodology-based strategies can be used to improve students' critical thinking skills in math classes?

RQ3: Which educational level is involved in helping pupils develop their critical thinking abilities in mathematics classes?

RQ4: What tools are most widely used in mathematics teaching to help students develop their critical thinking skills?

RQ5: Which country has carried out the most research on teaching mathematical critical thinking skills?

Critical thinking skills can be learned and taught (Ennis, 2011). Therefore, teachers have a very important role in this improvement. Teachers need to help students develop critical thinking skills in solving mathematical problems through the mathematics learning process (Fitriani et al., 2019; Putri & Irwan, 2019). Teachers also need to have critical thinking skills in order to design effective learning and support maximum student development (Afriansyah et al., 2020)This can be done by using learning methods that suit the needs of students in the field. Research shows that learning methods such as problem-based learning (PBL) and Realistic Mathematics Education (RME) can significantly improve students' critical thinking abilities (Wahyuni & Angraini, 2019; Hidayati & Kurniati, 2018). One of the main supporting factors in the success of these two methods is the use of technology. Technology, such as web-based learning platforms, interactive applications, and computer simulations, makes it easier for students to access a variety of resources and expands the scope of their learning. In PBL, technology supports collaboration between students to solve problems more efficiently and helps visualize complex mathematical concepts so that students can better understand and apply them in different situations. Technology also provides opportunities in RME to increase

students' interactions with real-world contexts and enrich their learning experiences through interactive digital media (Sweeney & Hight, 2019; Trinidad & Esteban, 2020).

Although there is a lot of research discussing the development of critical thinking in mathematics education, there are still gaps in the literature regarding several aspects. First, there has been no comprehensive systematization of research to summarize various approaches, effectiveness of methods, and supporting factors in developing critical thinking skills at various levels of education. Second, there are limitations in exploring learning contexts in different environments, such as differences in culture, technology, and educational policies. Third, many studies tend to focus on the effectiveness of one particular method but do not provide a holistic picture of the combination of approaches that can be implemented optimally. Therefore, research is important to fill this gap. This research aims to compile a systematic review of existing studies, identify effective approaches, explore the challenges faced, and provide recommendations for developing more comprehensive learning strategies in improving critical thinking skills in the field of mathematics education.

▪ METHOD

Research Design

The aim of this study is to identify a successful strategy for enhancing students' critical thinking abilities, particularly with regard to learning mathematics. To find, assess, and interpret all of the previous research, a systematic literature review (SLR) was employed in this study. SLR is also relevant to the problem formulation and topic area studied. In a systematic literature review, a research question is developed first, followed by a conceptual framework, selection criteria, search strategy, study selection, coding, study quality assessment, synthesis of individual results to address research questions, and reporting of findings or analysis results (Zawacki-Richter et al., 2020).

The PRISMA (Item Reporting Preferred for Systematic Review and Meta-Analysis) approach, which has a well-defined research methodology, was used to gather the data for this investigation (Stovold et al., 2014). Identification, screening, eligibility, and integration or inclusion are the four phases that make up PRISMA. PRISMA consists of four steps: identification, screening, eligibility, and integration or inclusion. PRISMA has three important advantages. First, create appropriate research questions that enable systematic research; second, establish standards for inclusion and exclusion; and third, try to analyze large scientific database publications over a certain period of time. Finally, the PRISMA statement makes it easier to find innovative words in teaching (Sierra-Correa & Cantera, 2015).

Identification

The article search process was obtained from the Google Scholar and Scopus databases using the Publish or Perish 8 application. Search limits were carried out to obtain the data needed for further information on a particular search and to avoid filtering too large a number. Search string for this study: "critical thinking" AND "mathematics education".

Screening

The first step in the selection process is to assess the article's title and abstract to see if the research is pertinent (Zawacki-Richter et al., 2020). The chosen articles were

also divided according to inclusion-exclusion standards. This study's inclusion-exclusion criteria are shown in the table 1.

Table 1. The criteria for inclusion and exclusion

Criterion	Inclusion Criteria	Exclusion Criteria
Literature Type	Journal (research article) or conference proceeding	Book, book series and chapters, or systematic literature review articles
Language	English or Indonesia	Non-English or Non- Indonesia
Timeline	Between 2014-2024	Before 2014

To ensure that the selected literature is relevant and meets research requirements, the literature screening process is carried out by setting inclusion and exclusion standards (Kraus et al., 2022). First, only research journal articles or conference proceedings were included, considering that these two types of publications generally present the latest research findings that have gone through a peer-review process, while books, book series, book chapters, or "systematic literature review" articles were excluded. Second, the selected literature must be written in English or Indonesian to ensure good understanding and wider coverage, both at the local and international levels, and literature written in other languages will be rejected from the analysis. Third, the literature included in this study is limited to the period 2014 to 2024, so that the study results remain relevant to the latest developments in the field of mathematics education. This time period was chosen considering that the development of theory and practice in mathematics education, especially those related to improving students' critical thinking, has experienced significant changes in the last decade. Various new approaches, learning innovations, and educational policies that focus more on developing critical thinking skills have been introduced in this time span. Therefore, articles published in the 2014-2024 period are believed to be better able to reflect the current dynamics in mathematics education research that are relevant to the objectives of this research. So all works published before 2014 are automatically rejected from the selection process. By using this method, the literature examined becomes more relevant and more focused on the research objectives.

Article selection was carried out manually, namely considering the suitability of the title and topic with the main focus of this research regarding improving students' critical thinking skills in mathematics education. Articles that have relevant titles and discuss this topic in depth are preferred. In terms of quality, the selected articles must go through a peer review process, demonstrate a clear and valid methodology, and make a significant contribution to the field of developing critical thinking in mathematics education.

Eligibility

The screening approach is followed by the eligibility process. Researchers checked the extracted articles to guarantee that all other articles met the requirements. The article filtering process begins by identifying database sources, including Scopus with 191 articles and Google Scholar with 999 articles, and then using the "Publish or Perish" application to filter the information. This is achieved by carefully examining the title, abstract, and contents of the paper. After this step, 173 articles were removed from the study because they were published as book chapters and literature reviews and did not

focus on improving students' critical thinking skills in mathematics education. In the end, only 14 articles met the inclusion criteria.

Included

Methods for enhancing students' critical thinking abilities in mathematics education are the focus of this systematic review. The Google Scholar and Scopus databases were used to select 14 articles, primarily due to the quality of the databases and the type of publications published in the field of mathematics education; only relevant papers that meet the inclusion criteria will be analyzed; journals and articles that do not meet these criteria will not be considered further. The journals and articles that met the inclusion criteria were then rearranged and classified in the review based on how well they fit the theme. Communicating the research findings is the last phase. At this point, the PRISMA approach is used to provide a concise and methodical summary of the research findings. The steps involved in this process are:

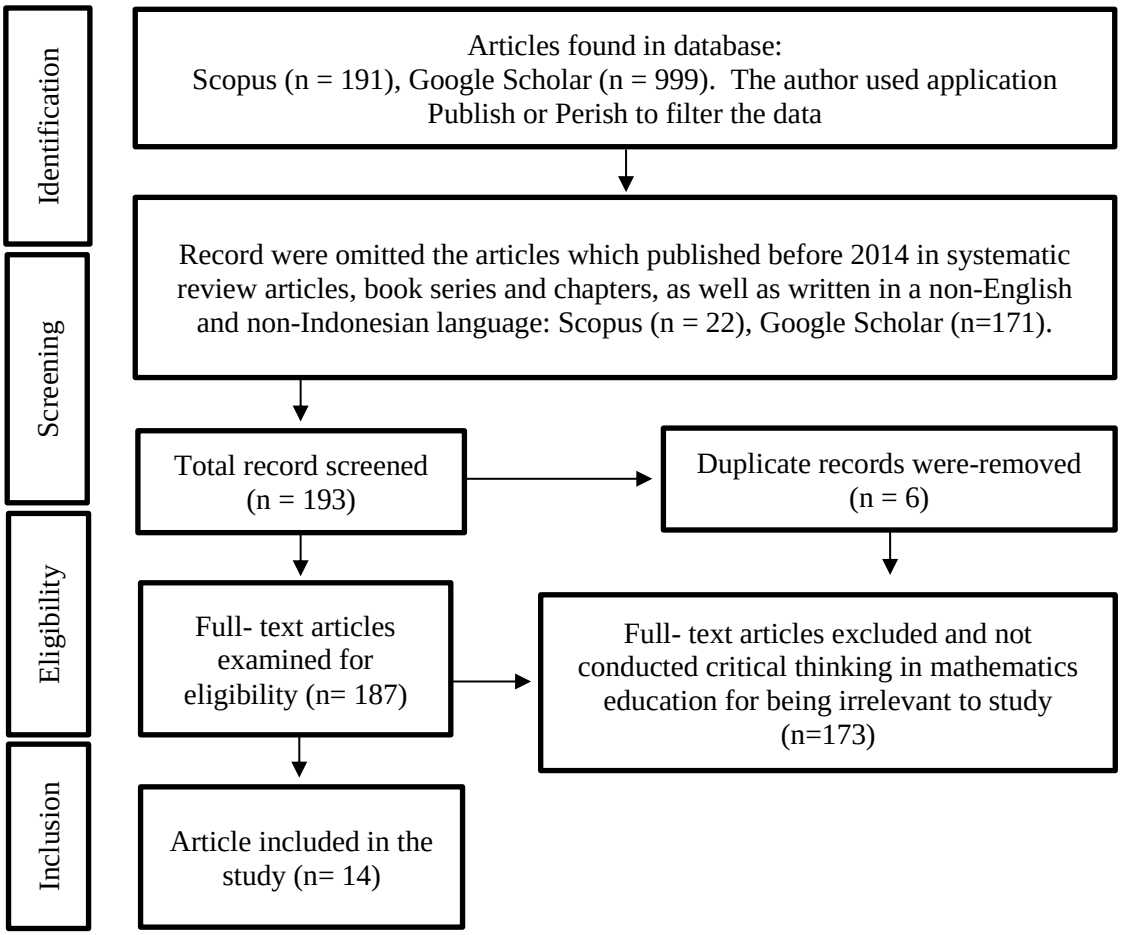

Figure 1. PRISMA systematic review adapted from (Page et al., 2021)

▪ RESULT AND DISSCUSSION

Year of Publication

There were numerous articles published between 2014 and 2024 about enhancing students' critical thinking abilities in mathematics classes. Only 14 articles, nevertheless,

were chosen using the inclusion-exclusion criteria. The distribution of the quantity of articles by year is shown in Figure 2.

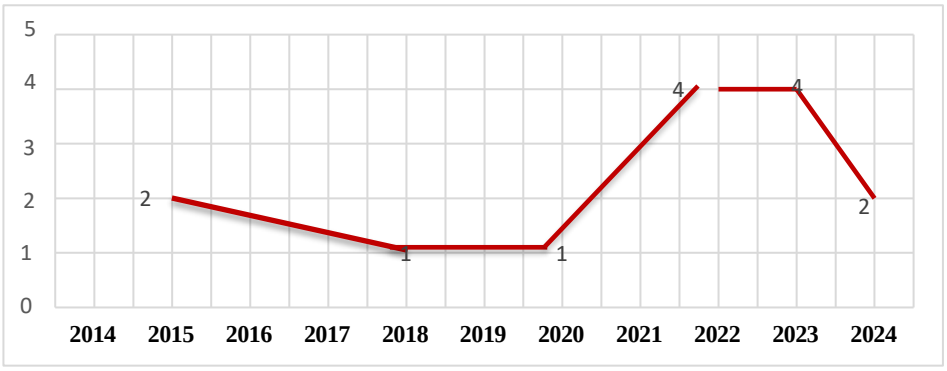

Figure 2. Year of publication database

According to Figure 2, there was a minor increase in the quantity of publications in mathematics education research concerning the development of students' critical thinking abilities between 2020 and 2022. It did, however, decline between 2023 and 2024.

Research Methodologies

To improve pupils' critical mathematical thinking skills, researchers used a range of study techniques. Figure 3 shows the study methodology used in many studies to improve students' critical thinking abilities.

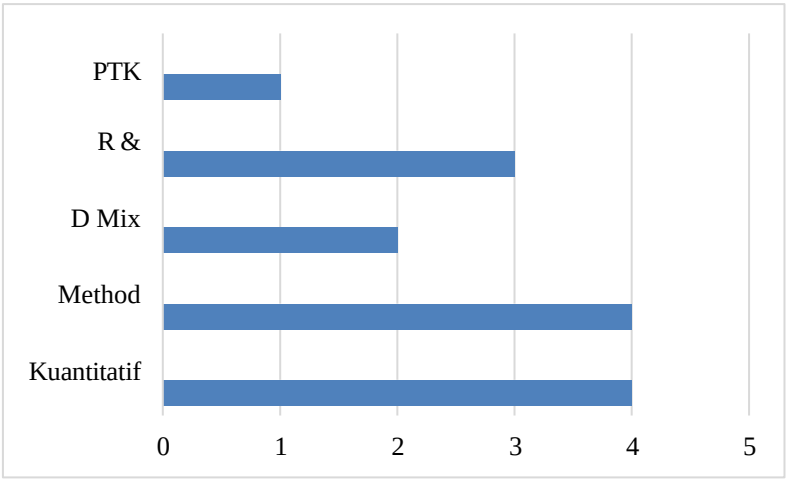

Figure 3. Research methods database

The two most common research designs employed by researchers to enhance students' critical thinking abilities are qualitative and quantitative, as shown in Figure 3. While quasi-experimental research is the type of quantitative research, case studies are the most popular form of qualitative research.

Study Level

The research subjects must be students enrolled in school or a university, according to one of the stated inclusion requirements. The research subjects of the 14 examined publications are shown in Figure 4.

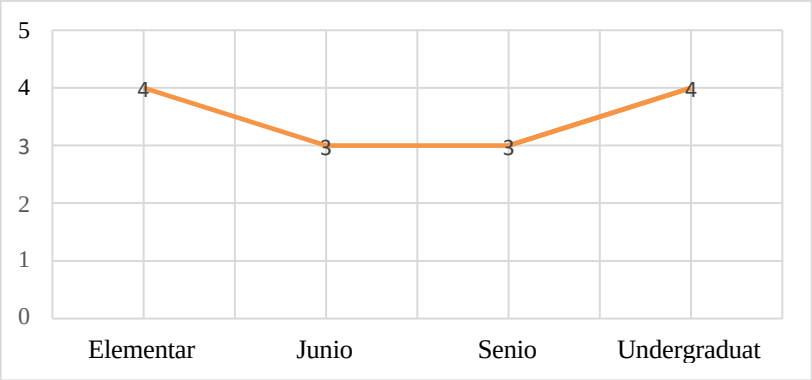

Figure 4. The study level database

Undergraduate and elementary school students were chosen as the research subjects, followed by middle and high school students, as shown in Figure 4.

The Most Popular Techniques

Figure 5 shows the proportion of methods utilized to enhance students' critical thinking skills in mathematics instruction. These findings offer a thorough examination of the most widely used resources for enhancing students' critical thinking abilities in mathematics instruction.

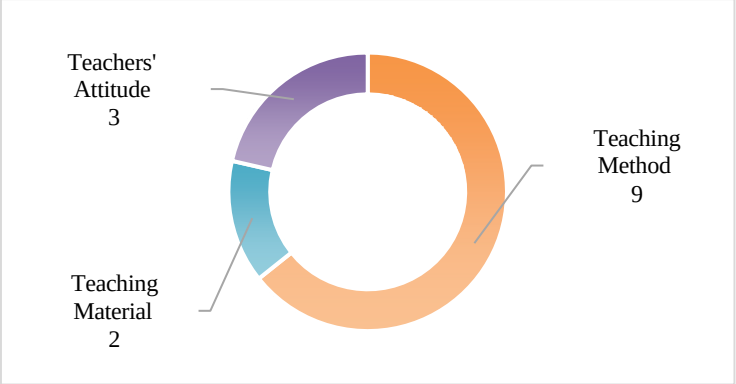

Figure 5. The percentage of strategies used to improve students' critical thinking skills

Teaching methods are the most widely used strategies for enhancing students' critical thinking abilities, as the figure illustrates. This is consistent with (Nurullaevna, 2021), assertion that the use of diverse teaching strategies is anticipated to boost students' mathematical aptitude and interest. Students become bored with lessons and lose interest in them when teachers utilize fewer creative teaching strategies. After overcoming their skepticism about change, educators become more competent and creative in their

implementation of the learning process in the classroom (Amrina et al., 2024). More details are shown in Table 2.

Table 2. The methods employed to enhance students' critical thinking capabilities

No.	Author	Techniques		
		Teaching Method	**Teaching Material**	**Teachers' Attitude**
1	Aizikovitsh-Udi, E., & Cheng, D. (2015)	√		
2	Assi et al. (2022)			√
3	Belecina, Rene R. & Jose M. Ocampo, Jr. (2018)	√		
4	Benedicto et al. (2022)	√		
5	Dolapcioglu et al. (2022)			√
6	Firdaus et al. (2024)	√		
7	Geiger et al. (2023)	√		
8	Gek et al. (2020)	√		
9	Lestari et al. (2023)	√		
10	Maričića, S. & Špijunovićb, K. (2015)	√		
11	Muliawan et al. (2024)		√	
12	Monteleone et al. (2023)	√		
13	Tazkia et al. (2022)			√
14	Wijaya et al. (2023)		√	

The most popular strategies for enhancing students' critical thinking skills include educational approaches, as shown in Figure 5 and Table 2. Here are some examples of the many teaching approaches used:

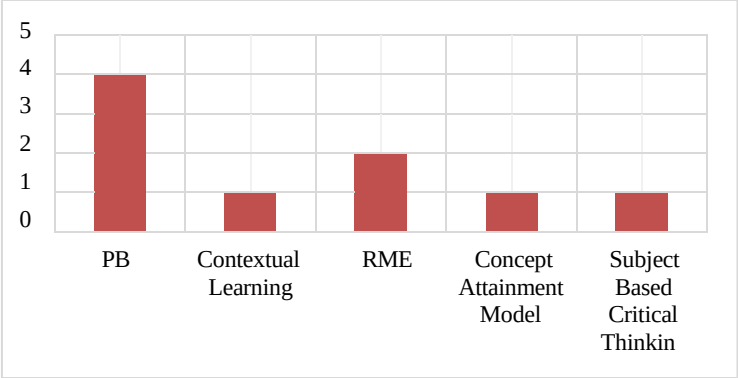

Figure 6. Various type of teaching methods

This figure indicates that the PBL approach is most commonly used by researchers to assist students in honing their critical thinking abilities. The development of educational materials, the use of technology-based learning media, and teacher-prepared learning strategies such as the development of modules to improve students' critical

thinking skills, authentic learning models, the provision of scaffolding at the start of learning, and the choice of planned content have also been the subject of three studies.

The Country with The Most Research

The results of studies on enhancing students' critical thinking abilities in mathematics instruction are shown by nation in Figure 7. The majority of the study on mathematical critical thinking abilities was carried out in Indonesia, with five studies and two in Australia, according to the analysis of the nine nations that participated in this review. However, in six countries Malaysia, Turkey, the Philippines, Singapore, the United States, the United Kingdom, and China only one study was conducted that enhanced students' critical thinking abilities in mathematics education.

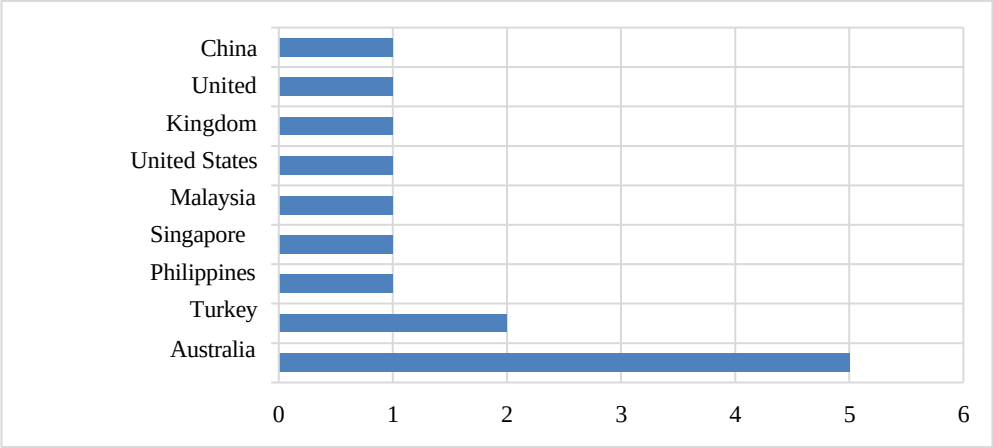

Figure 7. Research findings by list countries on enhancing students' critical thinking in mathematics education

The results of a systematic literature review show that research publications on improving students' critical thinking skills in mathematics education experienced a slight increase between 2020 and 2022, as the response to the COVID-19 pandemic forced a large-scale transition to online learning. In this period, there has been increasing awareness of the importance of critical thinking skills to support effective online learning, so much research has focused on developing these skills in the context of mathematics education. However, between 2023 and 2024, the number of articles will decrease, which is likely due to a post-pandemic shift in research focus, with many studies focused more on the recovery of face-to-face learning, as well as a shift in funding priorities aimed more at topics such as educational technology and artificial intelligence. In addition, changes in educational policies that focus on educational standards and exam results also influence research trends in this field. The authors of most of the publications in this research come from Indonesia. Furthermore, based on Figure 3, qualitative research is the most dominant design used by researchers to investigate critical thinking skills.

The study's findings also indicate that the majority of the participants were elementary school and college students. This is consistent with (Abayeva et al., 2024), who state that many higher education professionals aim to prepare students' critical thinking abilities because graduates would be the ones to carry out their duty as future teachers. Furthermore, critical thinking is a fundamental learning goal in the general

education curriculum on campus, which will outline the attributes that businesses look for in university graduates (Erdoğan & Kalkan, 2024). Apart from that, it is important for prospective teachers to have good critical thinking skills in order to teach students in an effective way. Research shows that prospective teachers who are trained to identify and analyze mathematical problems can be better prepared to face challenges in teaching (Afriansyah et al., 2020). Applying critical thinking from elementary school is also necessary to encourage mathematical thinking in children and to give them numerous opportunities to explore different approaches to honing their critical thinking abilities. (Kurniati et al., 2015) pointed out that pupils can find it simpler to master mathematics, which necessitates conceptual knowledge and logical reasoning, if they are encouraged to cultivate thinking patterns since elementary school. Critical thinking skills can therefore be cultivated in elementary school mathematics lessons to help students think critically before moving on to the next level.

The main focus of nine of the fourteen studies is on how to improve students' critical thinking skills through instruction. One of the largest percentages in the development of students' critical thinking skills in mathematics education, 64%, is attributed to instructional methods. According to (Umam & Susandi, 2022), creating models and methods for teaching mathematics can help pupils become more adept at critical thinking. Several teaching strategies, including problem-based learning (PBL), contextual learning, realistic mathematics education (RME), subject-based critical thinking education, and concept achievement models, are described in this systematic literature review. These strategies are used to help students develop their critical thinking skills in mathematics classes that are designed at the beginning of the learning process before it starts.

The Problem-Based Learning (PBL) approach is the most popular and widely used method for improving students' critical thinking skills in mathematics education. PBL emphasizes active learning through real problem solving, encouraging students to think deeply, analyze situations, evaluate solutions, and formulate evidence-based answers. This approach develops higher-order thinking skills such as analysis, evaluation, and synthesis, which are important in mathematics and real-world contexts (Hmelo-Silver, 2004; Bransford, Brown, & Cocking, 2000). Constructivism theory supports PBL because students build knowledge actively through direct experience and reflection. The views of Piaget and Vygotsky also reinforce this, emphasizing the importance of challenges and social interactions to stimulate the development of critical thinking (Barrows, 2002). Research shows that PBL encourages students to think critically through asking questions, discussing, and solving problems (Aswan et al., 2018; Fitria et al., 2020; Isti et al., 2017). Additionally, the integration of technology in PBL increases its effectiveness. The use of media such as GeoGebra to visualize mathematical concepts, as well as interactive platforms such as Kahoot! and Quizlet, helps students understand relationships between concepts, improves problem solving, and encourages student engagement (Alyani & Putri, 2022; Andriani et al., 2022;Rahayu et al., 2020).

Teaching materials also play an important role in supporting the success of PBL-based learning. Teachers must be selective in choosing teaching materials that are innovative and suit students' needs. In this research, teaching materials such as PBL worksheets, interactive videos for online learning, and critical thinking development modules are effective media that help students understand the material more deeply (Gökçe, 2024; Nugroho et al., 2017). Well-designed teaching materials can make

mathematics learning more meaningful, increase learning motivation, and result in increased students' cognitive abilities.

The implementation of Problem-Based Learning (PBL) in Indonesia has significant differences compared to other countries, especially in terms of infrastructure readiness, educational culture, and policy support. In Indonesia, PBL was introduced through the 2013 Curriculum policy and then strengthened in the Merdeka Curriculum, which emphasizes project-based learning and the development of 21st-century skills, such as critical thinking, creativity, and collaboration. However, the implementation of PBL in Indonesia is still faced with a number of challenges, such as inequality in access to technology between urban and rural areas, limited teacher training, and obstacles to a learning culture that is still oriented towards traditional lecture-based methods (Kemendikbud, 2022).

In developed countries such as Finland, the Netherlands, and Singapore, the implementation of PBL tends to be more systematic and integrated into their educational curriculum. Finland, for example, is known for its cross-disciplinary approach to PBL, where students learn a variety of subjects through problem-based projects that are relevant to real life. The education system in Finland also gives teachers the freedom to design innovative learning methods, which are supported by intensive training and high-quality educational infrastructure (Sahlberg, 2015). In Singapore, PBL is widely implemented, especially in STEM (Science, Technology, Engineering, and Mathematics) education, with the support of advanced technology such as simulation laboratories and interactive software. The Singapore government also consistently encourages the use of technology in learning to strengthen PBL implementation (Tan, 2019). In contrast, the implementation of PBL in Indonesia tends to be limited to superior schools or in urban areas that have better access to technology and teacher training. For example, several schools in Jakarta and other big cities have used applications such as GeoGebra, Kahoot!, or digital modules to support problem-based learning, especially in mathematics and science (Dzulfikar & Turmudi, 2024; Kim & Md-Ali, 2017) . However, in remote areas, limited access to technology and a lack of learning resources often become obstacles. In addition, the traditional teacher-centered approach is still dominant in many schools, so teachers need to adapt further to adopt the role of facilitator in PBL.

Cultural factors also play an important role in implementing PBL. In Indonesia, students are generally accustomed to learning methods that prioritize memorization and following teacher instructions, so PBL often requires further adjustments to build students' collaboration and initiative skills. This is different from countries such as the Netherlands or the United States, where the educational culture supports an inquiry-based approach and students are more accustomed to working independently or in groups (Hmelo-Silver, 2004). However, the Indonesian government has attempted to increase the implementation of PBL through programs such as Sekolah Pengmobil and Guru Pengmobil, which aim to train teachers in designing project-based learning and empower students as active learners. In addition, the integration of educational technology through platforms such as Learning Management Systems (LMS) and digital learning applications is expected to expand the application of PBL throughout Indonesia (Kemendikbud, 2022). The teacher's attitude referred to in this research is using provocative mathematical questions in teaching and assessment. Developing the habit of skeptical thinking to analyze mathematical questions in class should improve the ability to critically analyze

other situations outside mathematics (SKlymchuk & Sangwin, 2021). Students are given a framework related to everyday life so that students will get used to thinking critically wherever they are. Teachers provide different frameworks to support and design how students demonstrate critical mathematical thinking during mathematics learning experiences. This will provide a better understanding of how critical thinking is exhibited in mathematics learning. Teachers can also prepare authentic learning models that suit the context and needs of students and provide scaffolding at the beginning of learning. This can help students gain learning experience in solving complex problems to improve their critical thinking skills.

▪ CONCLUSION

Research on students' and university students' critical thinking abilities has grown between 2020 and 2022, according to the findings and analysis above. Moreover, quantitative and qualitative research methodologies are the most popular. Undergraduate and elementary school students make up the majority of research subjects. According to the results of this study, instructional methods are the most widely employed strategy for enhancing students' critical thinking abilities. This conclusion was reached after a thorough assessment of the literature. Other than that, PBL is the most extensively utilized method and is employed by many researchers. PBL and learning materials combined with ICT can be used by future researchers to help students develop their critical thinking abilities. Furthermore, the development of frameworks and the preparation of modules in initial learning settings before students undertake formal school learning activities are still rarely carried out. So, there is a need for further research regarding the use of modules for students who will be learning in class for the first time.

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