Research Article

The Impact of Teaching Strategies on Critical Thinking in Mathematics Education: A Systematic Literature Review

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Abstract.
Critical Thinking (CT) is an important skill for students and is one of the most significant indicators of the quality of learning. In the context of mathematics education, CT plays a crucial role as an essential form of thinking. The use of appropriate teaching strategies is essential to develop students' CT in solving mathematical problems. This research aims to provide a comprehensive overview of the impact of teaching strategies on CT abilities in mathematics education. The research method used is a Systematic Literature Review (SLR) following the PRISMA protocol, which includes reputable databases including Scopus, Eric, Science Direct, and Google Scholar. A total of 916 journal articles have been classified in the identification stage, followed by the screening and eligibility stages, using inclusion and exclusion criteria, as a result, 13 articles were selected for publication in the final stage of the review. The publications considered were between the years 2019 and 2023. The findings of the SLR show that the majority of teaching strategies to enhance CT in mathematics education utilize the problem-based learning (PBL) approach. Furthermore, it can be demonstrated that the majority of the collected studies were conducted at the junior high school level, followed by higher education, senior high school, and primary education levels. Most of the employed teaching strategies have shown significant positive impacts on the development of students' CT abilities.

Keywords: critical thinking, mathematics education, systematic literature review, teaching strategies

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1. INTRODUCTION

Critical Thinking (CT) is an essential skill for students to face the global competition of the 21st century (1). In many countries, CT is considered a crucial educational goal (2). CT is one of the life skills that students must have, particularly in the field of education, as it involves thinking, communication, and problem-solving in their daily lives (3). Mathematics education is one of the subjects that can lead students to adopt

a critical and analytical mindset. Current studies indicate various research on CT in mathematics education (4–6).

CT is the process of organizing, remembering, evaluating, and interpreting information based on logical reasoning. It involves analytical and reflective thinking, including skills like reading comprehension, recognizing essential and non-essential information, drawing accurate conclusions from a set of data, and identifying contradictions and inconsistencies (7). CT is a cognitive process that involves active comprehension, application, analysis, synthesis, observation, experience interpretation, introspection, reasoning, and communication abilities. Mathematics education emphasizes all of these thinking processes (3). CT abilities can be taught and strengthened by appropriately adapting educational strategies or models (8). The following are seven aspects to measure critical thinking abilities, which include seeking truth, being open-minded, analytical, systematic, confident, curious, and mature (3).

According to the results of the Programme for International Student Assessment (PISA) study, Indonesia received a score of 379, much below the average score of 489 (9). This indicates that the mathematical abilities of Indonesian students, including mathematical communication, problem-solving, and reasoning skills, are still not optimal (10). PISA questions emphasize problem-solving and CT abilities (11). The skill of CT can be observed in students who can apply their knowledge in unfamiliar situations, suggesting that the CT abilities of students in Indonesia are still low. Students with low levels of CT abilities exhibit several characteristics, including (1) being less meticulous in analyzing a problem; (2) difficulty in solving higher-level problems (C4-C6); (3) passivity during group work; (4) difficulty in connecting concepts and problems; and (5) difficulty expressing their opinions during discussions. The results show that the aspects of thinking skills in terms of evaluation are at 78%, self-regulation at 66%, interpretation at 52%, analysis at 56%, conclusion at 52%, and explanation at 42% (12). The low CT abilities of students are a problem that needs to be addressed. One of the primary goals of mathematics education is to enhance students' CT skills in solving mathematical problems. As a result, research into effective teaching strategies to develop students' CT abilities in mathematics is crucial.

Research related to teaching strategies aimed at improving CT abilities has been extensively conducted in the past, such as the study by Apriliana (13) on an interactive teaching strategy using the Problem Center Learning (PCL) approach. The research results of Arifin (14) on the Problem-Based Learning strategy demonstrate its ability to enhance problem solving skills through CT compared to the traditional direct instruction

model. Teaching strategies from other research studies, such as the Concept Attention Model (CAM) learning model (15). Flipped Classroom Strategy using E-Learning Systems(16), DAPIC Problem Solving with the RME approach(17), and the implementation of the Reciprocal teaching strategy (18) has demonstrated enhancements in students' CT skills.

Regarding the systematic literature review (SLR) on students' CT abilities in mathematics learning, several SLRs have been conducted [19,20,21,22,23]. For example, a systematic literature review (SLR) conducted by Sukma and Priatna (22) investigated how blended learning impacts students' CT. The research by Nor & Sihes (21) provided a systematic review of CT in the classroom and compared its development globally. However, there are some limitations in the previous SLR, as none of them have specifically focused on the impact of teaching strategies on students' CT abilities in mathematics education.

This research employs the SLR method with the aim of providing a comprehensive overview of the impact of teaching strategies on CT skills in mathematics education. This SLR offers a profound understanding of the relationship between mathematics teaching strategies and students' CT abilities. This review is crucial because critical thinking skills are a key aspect of mathematics education. By understanding the impact of teaching strategies, educators can improve the quality of mathematics learning, facilitate the development of students' CT skills, and identify potential gaps for future research in this field. Here are the research questions for this study: i) What are the teaching strategies associated with the ability to think critically in learning mathematics? ii) How is the distribution of research on the impact of teaching strategies on the ability to think critically in mathematical education at the elementary school, junior high school, senior high school and college levels? (iii) What is the impact of teaching strategies on improving CT skills in learning mathematics?

1.1. Critical Thinking

Critical Thinking (CT) is defined by Dewey as a process that begins with the presence of a problem and concludes with a solution and self-interpretation (24). Bean (25) elaborates on this idea by arguing that the problem should naturally pique students' interest and inspire critical learning and thinking. CT is defined by Ennis (26) as reasonable and serious thinking centered on deciding what to believe and do. Good discussion abilities

should not be disregarded because they help to lay the groundwork for sound decision-making. In general, the word "critical thinking" refers to argumentation abilities. Although CT is considered a foundational ability in this respect, data suggests that it is frequently under-taught in schools(27). CT encompasses a range of skills, intellectual abilities, and emotional inclinations that encompass various advanced cognitive capabilities (28). As a result, CT becomes one of the most important talents in the twenty-first century. CT is a necessary component of modern education (29). A critical competency in student performance achievement and the most crucial real-life skill [30,31,32]. These are crucial skills that students must have in order to solve problems and make accurate judgments [33], so that what we believe to be the truth can be attained and executed appropriately. By providing students with opportunities to think critically, education can help them improve their CT skills.

1.2. Critical Thinking in Mathematics Education

In the context of mathematics education, CT plays a crucial role as a highly important form of thinking (34). CT serves as a cognitive tool for logically and deductively solving mathematical problems. CT refers to a problem-solving process that focuses on assessment to develop knowledge (23). It entails achieving and validating solutions during the problem-solving process (35). CT is intimately tied to mathematical skills such logical thinking, questioning, and analysis, all of which are essential components of mathematics education (23,36). In mathematics, CT involves a critical assessment of thinking processes and arguments. It imparts skills to learners to make independent decisions and confront significant questions about personal life and society. Thus, the relevance of developing critical thinking abilities through math education is closely tied to personal life and the decisions individuals make (37). Literature research indicates that CT is positively correlated with mathematical achievement (35,38) Furthermore, relevant literature also shows that CT enhances mathematical skills (36,39,40). Therefore, it is crucial to focus on enhancing students' CT, especially in mathematics learning. Students' CT can be taught using teaching strategies that facilitate critical thinking training.

1.3. Teaching Strategies

In the 21st century, both domestic and international education systems strongly emphasize teaching strategies. This is due to the fact that excellent teaching strategies are

critical to the advancement of the educational system (41). Teaching strategies are well-structured instructional plans that take into account both the objectives and participants of the teaching-learning process, as well as educational experiences and activities. According to Nilsen and Albertalli (42) teaching is a process in which a teacher assists students or a group of students in acquiring new knowledge or skills. Teaching, in this context, is defined as the active involvement of students in efforts to understand and apply knowledge, concepts, and methodologies. The teaching process involves steps such as planning, material selection, delivery, evaluation, and reflection.

Strategies are action plans to achieve educational goals and enhance learning activities. Teachers have the responsibility to develop strategies for efficient and successful teaching and learning activities after lesson plans are made. The term used to describe this procedure is teaching strategy (43). Teaching strategy is a general overview for a lesson that includes the context, expected behaviors from students, and a description of specific methods needed to implement it (44). When applied in the context of learning mathematics, teaching strategies can serve as tools that enable teachers to create an environment that stimulates critical thinking, strengthens student engagement, and effectively achieves educational goals.

2. METHOD

2.1. Research Design

This research design utilizes Systematic Literature Review (SLR). SLR is a data collection method that is appropriate for a specific topic and meets predetermined eligibility criteria (45). The SLR in this study was conducted using the PRISMA method (Preferred Reporting Items for Systematic Reviews and Meta-Analyses). Figure 1 shows the PRISMA flow chart in this study. The selection process follows the four stages in PRISMA, namely identification, screening, eligibility, and inclusion (46). This research only considers journal publications from the years 2019 to 2023, with keywords being (“Critical Thinking” OR “Teaching Strategies”) AND (“Mathematics” OR “Mathematics Education” OR “Mathematics Learning”). Next, the articles are sorted based on inclusion criteria, and only relevant articles that meet the criteria will be examined.

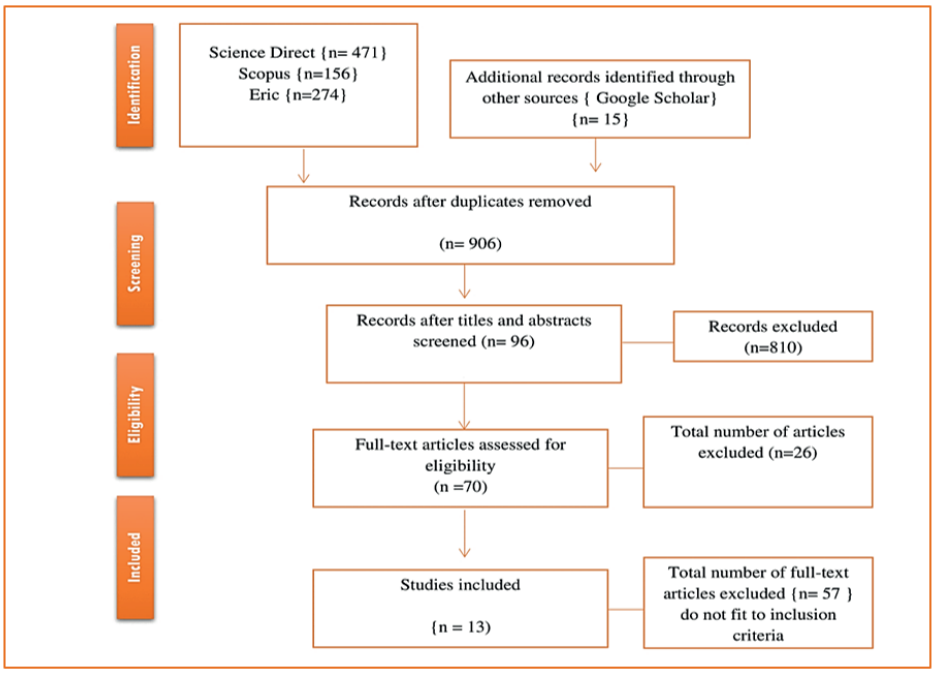

Figure 1: the PRISMA flowchart in this study.

2.2. Systematic Review Process

Identification. In the identification stage, researchers collected as many articles as possible from reputable databases, including Scopus, Eric, and Science Direct, using the keywords ("Critical Thinking" OR "Teaching Strategies") AND ("Mathematics" OR "Mathematics Education" OR "Mathematics Learning"). The researchers generated a list of synonyms and alternative terms based on the most common search terms, so broadening the search terms and tactics to include as many relevant articles as feasible. The search method yielded 901 hits from Scopus, Science Direct, and Eric, with an additional 15 papers found from other sources. As a result, 916 journal articles were classified at this level.

Screening. In the screening stage, the researchers removed articles identified as duplicates. The next step involved filtering based on titles and abstracts. Various inclusion and exclusion criteria were used in this approach. The researchers only focused on English-language journal articles published within the last five years. There were no exceptions based on specific countries or regions. Finally, the researchers focused on articles that contained at least one mathematical reference.

Eligibility. At this stage, a strict selection of articles is carried out. Each paper title, abstract, methodology, outcome, and discussion is extensively examined to verify that

all articles meet the research selection criteria and objectives. Most articles have been rejected at this point because they do not properly demonstrate critical thinking skills or do not thoroughly explain and comment on the findings in the study findings section. As a result, 13 articles were selected for publication after undergoing the review process.

Inclusion and Exclusion Criteria. Following the collection of all findings from all identified sources, the researchers employed selection criteria such as publication year, document type, language, and subject area to eliminate papers that were not relevant to this study. It is critical that the studies selected are related to the core research goal. The inclusion and exclusion criteria have been explicitly stated to guarantee that the studies chosen are in line with the primary study objectives. This study's inclusion and exclusion criteria are shown in Table 1.

TABLE 1: Inclusion and Exclusion Criteria.

Inclusion criteria	Exclusion criteria
Published between 2019 and 2023	<2019
Indexed jurnal	Non-indexed journals, chapter in book,conference proceeding,master dissertation,prefaces and opinion
English languange	Non-English
Subject area of mathematics or mathematics education	Subject area in general

3. RESULTS AND DISCUSSIONS

3.1. Teaching Strategies Related to CT in Mathematics Learning

Based on the results of a systematic search related to teaching strategies associated with critical thinking skills in mathematics learning, several significant findings were identified. As seen in Figure 2, the majority of teaching strategies found are through a learning approach, namely Problem-Based Learning (PBL) (46%, n=6) Arifin (14), Aini (47), Darhim (48), Maulidiya and Nurlaelah (49), Rahman(50) and Susilo(51). Other teaching strategies found include the use of PBL-based Module learning media (52), RME-based Module (53), PBL-based Worksheets (54), and the use of mathematical comics to enhance CT skills (55), each found once (n=1). In addition, teaching strategies with a Contextual Teaching and Learning (CTL) approach (56), Cooperative Learning (57), and the Problem Solving DAPIC (Define, Assess, Plan, Implement, and Communicate) approach with Realistic Mathematics Education (RME) (17) were also identified.

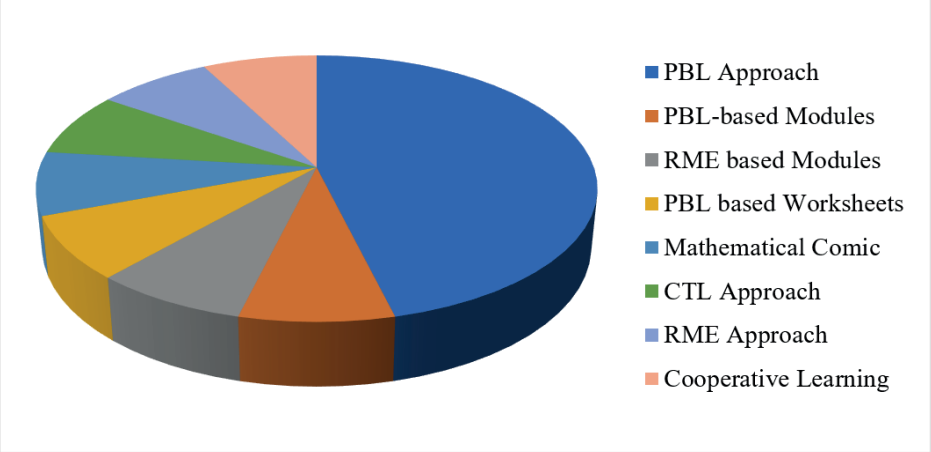

Figure 2: Teaching Strategies Related to CT in Mathematics Learning.

PBL teaching strategy has proven to be the most popular in mathematics education compared to other approaches such as the CTL approach, Cooperative Learning, and the Problem Solving DAPIC and RME approaches. This finding aligns with research conducted by Amin et al. (58), stating that PBL is generally more effective in improving students' CT abilities. This finding is also supported by research indicating that PBL supports students' critical thinking through the provision of relevant real-world contexts in solving mathematical problems (43). Other research has demonstrated that good PBL implementation can improve students' CT skills (59).

Furthermore, the paradigm shift in the curriculum towards more student-centered and active learning has made PBL increasingly relevant. As expressed by Jamal et al (41) learning approaches emphasizing active student participation are currently a major trend. PBL, as defined by Balim et al (60) involves real-life problem scenarios that guide students through an active learning process, enabling them to independently solve problems. This approach begins with teachers presenting students with scenario problems drawn from everyday life, encouraging them to identify and solve these problems using their existing knowledge(61). Involving students in solving real-life problems not only provides deep and contextual learning experiences but also allows them to develop CT skills holistically through the application of PBL models, guiding them through the stages of the learning process (62).

In addition to the PBL approach, there are various other teaching strategies through learning media, such as PBL-based modules. During learning, students actively argue, generate ideas, and build their knowledge with explanations in the modules. They seek their own problem solutions and analyze the solutions found. Students also

analyze arguments within groups. This process trains students in building knowledge and enhancing CT skills (52). RME-based modules (53) can also improve students' CT abilities because their design follows RME principles that present active learning activities, including problem-solving, argumentation, and data analysis. The evaluation in the modules tests students' CT abilities. RME steps and CT skill indicators are also included. With the right design and a focus on CT development, these modules can help students improve their abilities to analyze, evaluate, and critically solve problems (53). Worksheets developed by Hairun et al. (54) based on PBL with a student worksheet design are intended to facilitate the development of students' CT skills. Additionally, mathematics comic media developed by Lestari et al. (55) can also enhance students' CT abilities.

3.2. Distribution of Research Based on Educational Levels

The distribution of research on learning strategies to enhance CT skills in mathematics education can be visualized through Figure 3. Research in elementary schools is presented by Lestari et al. (55). Meanwhile, at the Junior High School level, several studies have been conducted by Erdogan(57), Hairun et al.(54), Hikayat et al. (53), Toheri et al. (56) and Wulandari (17). At the Senior High School level, research has been carried out by Arifin (14), Maulidiyah and Nurlaelah (49), and Rahman et al. (50). As for the higher education level, some studies include works by Aini et al.(47), Darhim et al.(48), Seruni et al.(52), and Susilo et al.(51).

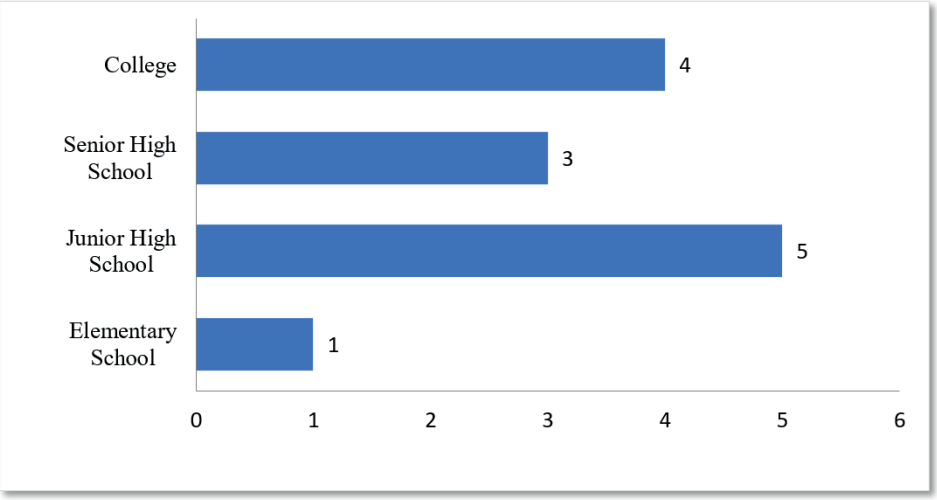

Figure 3: Distribution of Research Based on Educational Levels.

It is important to note that these findings indicate a greater concentration of research at the Junior High School level. Nevertheless, it is acknowledged that research has also been conducted at the primary education level, Senior High School, and even at the College level. Each educational level has different needs and focuses on the development of students' CT skills. Therefore, research at each level provides a more comprehensive understanding of effective and relevant teaching strategies to enhance students' CT skills in the context of mathematics education. Thus, this distribution of research reflects coordinated efforts to understand and enrich learning approaches at various education levels.

3.3. The Impact of Teaching Strategies on Critical Thinking in Mathematics Education

The results of this SLR indicate that various teaching strategies in mathematics education play a crucial role in developing students' CT skills. The primary focus of this discussion is on PBL, a strategy proven effective in enhancing students' CT skills. PBL as evidenced by several studies [14,47,48,49,50] has shown a significant positive impact on the development of students' CT skills.

The PBL approach significantly improves students' CT skills in the context of mathematics learning. Aini et al. (47) emphasize the critical stages of PBL, such as controversial issues and active debates, as an excellent alternative for developing students' CT skills. Arifin's (14) research adds an important dimension by demonstrating significant differences in CT skills between students with Field Dependent and Field Independent cognitive styles. PBL continues to gain support from research concluding that students' CT skills improve after the PBL model is implemented (49). Student activities during the implementation of the PBL model on enumeration rule material fall into the active category. Teacher's ability to enumerate rules is well assessed when using the PBL model. Other aspects such as suitable facilities, students' ability levels, and teachers' competence levels in implementing the model assist the implementation of teaching models or approaches. Rahman (50) offers something new by illustrating how technology, such as the PBL approach supported by GeoGebra software, can improve students' CT abilities.

Furthermore, the importance of mathematical disposition in moderating PBL outcomes is found in Susilo (51) research, demonstrating that mathematical disposition has a positive influence on student achievement and the improvement of CT skills in the

context of PBL. Students with positive mathematical dispositions, such as confidence and high interest, great perseverance, and a positive assessment of mathematics, assist students in overcoming numerous problems. This is because mathematical inclination has a good effect on kids' problem-solving ability (63). Positive mathematical dispositions assist students in overcoming hurdles and improving CT skills, allowing them to solve problems.

PBL provides an opportunity for students to actively engage in problem-solving, analytical thinking, evaluation, and formulation of strategies. Through PBL, collaboration and discussion among students are also facilitated, building communication, cooperation, and problem-solving skills within groups (14,47–50). Five phases in the PBL learning process begin with the orientation phase, where students deeply understand the problem to be solved (62). This procedure necessitates a planned and methodical approach in which students are encouraged to present difficulties in a constructive and orderly manner (64). The second phase, organizing students for learning, involves arranging the learning structure so that students can effectively explore information. Following that, the phase of directing individual and group investigations include actively encouraging students to discover solutions and discuss them in small groups. The fourth phase, developing and presenting works, emphasizes the importance of organizing solutions systematically and clearly. Presenting discussion results is a crucial step in learning. Widiana and Jampel (65) state that effective student interaction can be achieved when they are provided with the chance to collaborate and engage in discussions. Finally, the phase of assessing and evaluating the work's results. This stage is critical for increasing CT skills. Students respond to feedback by reflecting, evaluating, and improving their solutions, encouraging critical questions and reflection. This helps develop students' critical thinking skills, broaden their perspectives, and enable deep learning.

Within the application of the PBL approach, students are prompted to consistently participate in analytical thinking, assessment, drawing conclusions, and developing strategies to address problems. These actions serve as indicators of the presence of CT skills(66). This thought process has a substantial impact on pupils' CT abilities development. Thus, PBL-based teaching strategies can have a positive impact on students in enhancing CT skills, problem-solving skills, self-directed learning, collaboration, and making learning more meaningful and relevant to them.

In this context, other teaching strategies such as the use of instructional media, RME approach, Cooperative Learning, and the Problem Solving DAPIC approach also contribute positively to the development of students' CT skills. The use of e-modules

in PBL improves CT skills and students' interest in learning (52). Using PBL-based electronic modules enhances student engagement, enabling them to be more active in participating, expressing opinions, and developing critical ideas. The utilization of electronic modules also strengthens students' interest and motivation in learning, creating an engaging and effective learning experience. The RME approach through RME-based modules improves mathematical understanding with greater relevance (53). Learning strategies using mathematical comics can improve critical thinking skills, learning achievements, interest in learning, motivation, understanding of material, and student engagement in critical thinking (55). Through the integration of CT, students can develop the CT skills needed to analyze problems, find solutions, and make informed decisions.

Contextual learning has a positive impact, expanding concept understanding and developing collaboration skills (56). Cooperative Learning has a positive impact on organizing thinking, understanding mathematical concepts, self-efficacy, and student motivation (57). This strategy also enhances social interaction and student cooperation. The Problem Solving DAPIC approach with the RME approach has a positive impact on improving critical thinking skills, conceptual understanding, motivation, and student engagement (17). This strategy has proven effective in improving the stages in this approach help students develop logical, analytical, and reflective thinking skills systematically. This approach also strengthens the connection of mathematics with everyday life through the application of relevant problems.

With a focus on the positive impact of PBL on improving students' CT skills, there is a need for further emphasis on PBL in the curriculum and mathematics teaching strategies at various levels of education. Therefore, intensive training for teachers in designing and implementing PBL can be an effective step in improving the effectiveness of learning. Overall, integrated teaching strategies can prepare students to be independent, creative learners, ready to face complex challenges in the 21st century. The limitation of this research lies in the breadth and search strategies, which may result in the neglect of some relevant publications, although efforts have been made to analyze most of the existing literature.

4. CONCLUSION

Based on the presentation of the results and previous discussions, it can be concluded that the teaching strategy related to CT abilities in mathematics education through the Problem-Based Learning (PBL) approach has been the most extensively researched

compared to other approaches such as Contextual Teaching and Learning (CTL), Cooperative Learning, Problem Solving DAPIC, Realistic Mathematics Education (RME), as well as teaching strategies using media like module and mathematics comics.Studies on teaching strategies in mathematics education have been conducted at various educational levels, and although more research has been done at the junior high school level, it is important to acknowledge that studies have also been conducted at the primary school, senior high school, and college levels. Each educational level has different needs and focuses on developing students' critical thinking abilities.PBL and other approaches such as CTL, Cooperative Learning, Problem Solving DAPIC, RME, and the use of media like module and mathematics comics have positive impacts on improving critical thinking skills, conceptual understanding, motivation, and student engagement. These learning strategies help students become independent, creative learners, and prepare them to face challenges in the 21st century.

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