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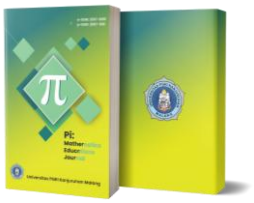

Critical Thinking Of Students In Solving Ill-Structured Mathematical Problems: A Scoping Review

Sheren Nursyafiqoh Undarestaa[a,1,*], Ros Maliah Ahmad[a,2], Aida Nur Aini[a,3], Yudhi Hanggara[a,4], Hermansah[a,5], Suryo Hartanto[a,6], Shalehoddin[a,7]
[a]Universitas Riau Kepulauan, Batam, Indonesia
[1]sherenundaresta@gmail.com
[2]rosmalia271102@gmail.com
[3]aidanuraini363@gmail.com
[4]yudhi@fkip.unrika..ac.id
[5]hermansah@fkip.unrika.ac.id
[6]suryo@fkip.unrika.ac.id
[7]shalehoddin@fkip.unrika.ac.id
[*]Corresponding Author

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ABSTRACT
This study highlights the importance of developing critical thinking skills in modern mathematics, particularly when students face ill-structured problems. Using a scoping review method, the research followed five stages: formulating research questions, identifying relevant articles, removing duplicates, mapping data, and summarizing findings. Data were collected from Google Scholar, Publish or Perish, and Connected Papers, covering publications from 2015 to 2025. Based on the PRISMA selection process, 20 relevant articles were analyzed. The findings reveal that students' critical thinking and mathematical problem-solving abilities in ill-structured contexts are still relatively low. Many students struggle with key aspects of critical thinking, such as verifying information, conducting in-depth analysis, and reflecting on their solutions. These limitations indicate that students are not yet fully equipped to handle complex, open-ended mathematical problems. Thematic analysis shows a shift in research focus over time. Between 2015 and 2020, studies primarily identified students' difficulties and barriers. However, from 2021 to 2025, research has increasingly emphasized the development of higher-order thinking skills (HOTS), numeracy literacy, and preparedness for the Industrial Revolution 4.0. The study recommends future research to explore innovative learning interventions that integrate creativity, critical thinking, and ill-structured problem-solving.

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1. Introduction

Critical thinking is an essential skill that must be developed in modern mathematics, especially when dealing with ill-structured problems [1]. Research emphasizes that critical thinking skills are necessary to deal with rapid change and uncertainty, while [2] shows that critical thinking skills and

the ability to deal with ambiguity can help students become more resilient in uncertain or ambiguous learning environments. The results of the literature review show that ill-structured mathematics is a type of problem that does not have a single solution and reflects complex and ambiguous real-world situations. These conditions encourage students to be creative, flexible in their thinking, and thorough when considering alternative solutions [3]. These findings are consistent with the characteristics of mathematics learning, which requires students to actively participate in constructing models, solving problems, and reflecting on the results [4]. This shows variation in critical thinking processes, with students who have better analytical skills tending to be more flexible in finding solutions. Solving problems that are not mathematically ill-structured requires critical thinking, which includes finding hypotheses, evaluating relationships between cross-topic concepts, calculating logical deductions, and drawing conclusions [5]. [6] found that critical thinking in mathematics involves making logical arguments and analyzing complex data, both of which are important for making good decisions in everyday life. [7] adding that a learning approach involving ill-structured problem exploration can help students improve the variety of critical thinking processes, depending on the students' ability to analyze and draw conclusions. The ways in which students think critically vary, and to date, there has been no comprehensive review available to describe the breadth of this research. Based on the research objective, which is to describe students' critical thinking processes in solving ill-structured mathematical problems, the research questions in this study focus on two main aspects: first, what are the current conditions and directions of research on students' critical thinking abilities in solving ill-structured problems? Second, what themes emerge in research related to students' critical thinking processes in solving ill-structured mathematical problems?.

2. Methods

This type of research is qualitative, using the Scoping Review method. Scoping review is a type of knowledge synthesis that aims to describe the breadth and depth of research that has been conducted on a particular topic by identifying themes, key concepts, sources of evidence, and variations in the literature [8], [9]. Unlike systematic reviews or meta-analyses, scoping reviews offer greater flexibility and can combine various research designs, methodologies, and data sources to provide a comprehensive overview without overly strict inclusion criteria [10], [11]. This scoping review uses five main stages, namely: (1) identifying research questions, (2) identifying relevant articles, (3) eliminating duplicate articles, (4) recording and mapping data, and (5) compiling, summarizing, and reporting research results. The first step in conducting a scoping review is to formulate research questions that will serve as the basis for determining the direction of the study, the focus of the analysis, and the inclusion criteria for the articles to be reviewed. Based on the research objective, which is to describe students' critical thinking processes in solving ill-structured mathematical problems, the research questions in this study focus on two main aspects: first, what are the current conditions and directions of research on students' critical thinking abilities in solving ill-structured problems? Second, what themes emerge in research related to students' critical thinking processes in solving ill-structured mathematical problems? The second stage focuses on identifying relevant studies. After the research questions were formulated, the next step was to create a list of keywords to find elements related to students' critical thinking in solving ill-structured mathematical problems, as shown in Table 1. Several types of keywords and data collection were carried out on three interdisciplinary academic databases to refine the search phrases, namely Google Scholar, Publish or Perish, and Connected Papers. The third stage focused on filtering and removing duplicate or irrelevant articles.

Table 1. Search Keywords

Data Search Keywords	
Google Scholar	All fields “critical thinking in mathematics” AND

Data Search Keywords	
Publish or Perish	"mathematical problem solving" AND "ill-structured mathematics" "ill-structured mathematical problems" AND "critical thinking in mathematics"
Conneted Papers	Search for related works using the keywords: critical thinking in mathematics, mathematical problem solving, ill-structured mathematical problems

Table 2. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Articles indexed in SINTA 4-1 and international journals	Books, book chapters, theses, dissertations, seminar proceedings, project reports, and popular/non-academic articles
Speaks Indonesian and English	Articles in languages other than Indonesian and English
2015–2025 (the last 10 years)	Articles published before 2015
Focus on critical thinking, mathematical problem solving, ill-structured problems, or the interrelationship between these concepts.	Articles that do not discuss critical thinking, mathematical problem solving, ill-structured problem

Only research articles were selected because this type of article generally provides a more in-depth and systematic analysis of the topic under review, while most other studies are only published in the form of proceedings. On the other hand, articles in the form of systematic reviews, meta-analyses, non-academic reports, proceedings, book chapters, and popular articles (such as news or editorials) were not included in this study. Regarding language and publication period, this study only involved articles in Indonesian and English published between 2015 and 2025, to ensure that the research remained relevant and up-to-date. Screening was carried out carefully to prevent duplication of articles from various sources such as Google Scholar, Publish or Perish, and Connected Papers, while ensuring that each study specifically selected contributed to the understanding of students' critical thinking in the context of ill-structured mathematical problem solving. The fourth stage involves data extraction or specific data mapping. Microsoft Excel is used to combine the collected data to support the thematic and comparative analysis process. The fifth stage involves collecting, summarizing, and reporting the findings. At this stage, common themes and conclusions from the various publications reviewed are identified and formulated.

3. Result and Discussion

The article selection process consists of four main stages: 1) Identification: Collecting articles based on keywords from various databases. 2) Screening: Eliminating duplicates and reading abstracts for initial selection. 3) Eligibility: Evaluating full articles based on inclusion/exclusion criteria. 4) Inclusion: Determining the final articles to be analyzed. This process is visualized in the PRISMA flow diagram. See Figure 1.

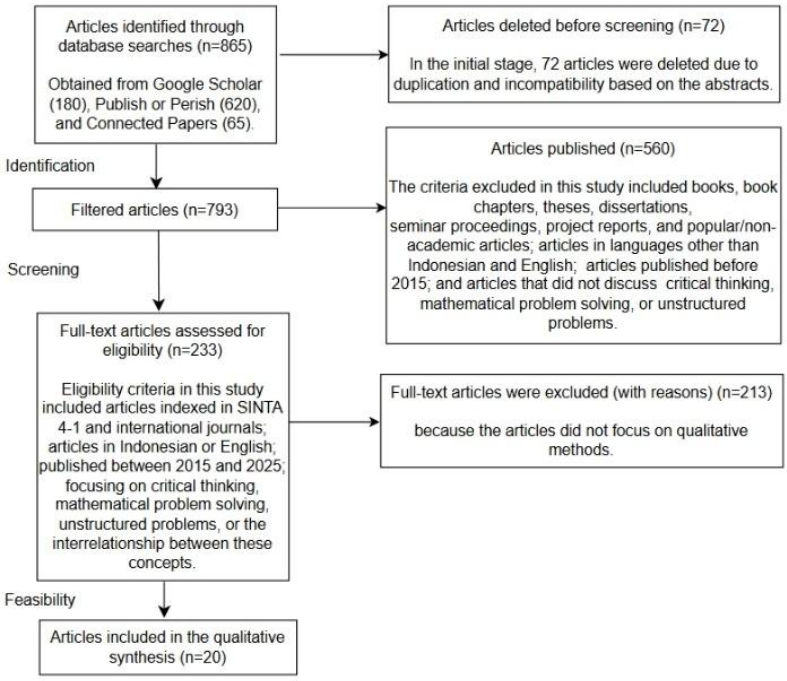

Figure 1. PRISMA Diagram of the Article Selection Process

Based on Figure 1, a total of 865 articles were identified, including 180 articles indexed in Google Scholar, 620 articles indexed in Publish or Perish, and 65 articles indexed in Connected Papers. Before the initial screening, 72 articles were removed from the list due to duplication and incompatibility based on the abstract, resulting in 793 articles for the screening stage. 560 articles were excluded from this study, including books, book chapters, theses, dissertations, seminar proceedings, project reports, and popular/non-academic articles; articles in languages other than Indonesian and English; articles published before 2015; and articles that did not discuss critical thinking, mathematical problem solving, or ill-structured mathematical problems. Next, in the eligibility stage, 233 articles were included in this study, comprising articles indexed in SINTA 4-1 and international journals; articles in Indonesian and English; published between 2015 and 2025; focusing on critical thinking, problem solving, ill-structured problems, or related concepts. 213 articles were excluded because they did not focus on qualitative methods. In the final stage, 20 articles met all eligibility criteria and were included in the qualitative synthesis. In addition, the selected articles were only empirical studies using qualitative approaches published in national journals over the past ten years (2015–2025). First, conference proceedings were rejected because they were considered unsystematic and non-transparent due to the conventional evaluation process [12]. Second, studies examining a particular issue for at least six years showed that the research subjects were consistent [13].

Table 3. Distribution of Research Methods in Reviewed Articles

Types of Research Methods	Number of Articles	Reference Code
Qualitative descriptive	12	[14], [16], [18], [19], [20], [22], [23], [25], [26], [31], [32], [33]
Qualitative Case Study	4	[15], [17], [25], [28]
Quasi-experiment	2	[21], [27]
Exploratory qualitative	1	[24]
Qualitative Study	1	[30]

Table 4. Data Mapping Form

Publication	Method	Constructs or Variables Studied	Key Findings	Emerging Themes
Hanggara et al. (2025) [14]	Descriptive-exploratory qualitative study	A disposition for mathematical critical thinking, particularly seeking truth and analytics in solving ill-structured mathematical problems	Most students demonstrated a low disposition for critical thinking. Students did not verify information, did not identify missing information, were unable to construct strong arguments, and did not reflect on solutions. Only 2 of the 117 students showed a tendency to seek truth and be analytical, but even this was limited	Low critical thinking disposition among students. Difficulty understanding ill-structured problems. Lack of information verification. Weak analytical and reflective skills, need for learning that trains critical thinking through ill-structured problems
Umbara et al. (2025) [15]	Qualitative case study	Mathematical critical thinking ability (MCTA) of ninth grade students in solving ill-structured problems	Students failed to meet the MCTA indicators due to a lack of practice in solving contextual and ill-structured problems; it is recommended to use separate instruments for MCTA and ill-structured problem-solving skills	Lack of student practice in contextual problems. The difference between convergent thinking (MCTA) and divergent thinking (ill-structured problems)
Tika Anjasari et al. (2022) [16]	Qualitative descriptive	The effect of math anxiety on students' problem-solving abilities in ill-structured problems	Students with low and moderate anxiety are able to achieve the stages of understanding, planning, and review; students with high anxiety fail at all stages; it is recommended that teachers pay attention to math anxiety	The effect of math anxiety on problem solving. Stages of problem solving. The role of teachers in overcoming math anxiety
Ninik Mutianingsih et al. (2022) [17]	Qualitative case study	The failure of st udents (RZ) in solving ill-structured problems about rectangles	Students failed to develop solutions due to their mastery of partial quadrilateral concepts; used trial and error; failed in monitoring and evaluation; it is recommended that teachers teach the relationship between concepts	Partial mastery of concepts as a cause of failure. Trial and error. The importance of relationships between mathematical concepts

Publication	Method	Constructs or Variables Studied	Key Findings	Emerging Themes
Anggita Auni et al. (2024) [18]	Qualitative descriptive	Students' problem-solving abilities on ill-structured problems reviewed from mathematical abilities (high, medium, low)	High and medium students are able to analyze problems well; low students are less capable; problem-solving categories: good (high), fairly good (medium), poor (low)	Differences in mathematical ability affect problem solving. Problem analysis based on Polya's stages. Evaluation of learning to improve ability
Muzayyanatun Munawwarah et al. (2020) [19]	Qualitative descriptive	Students' critical thinking skills in solving mathematical problems based on 21st-century skills	Improvement in critical thinking skills from "non-critical" (pre-test) to "sufficiently critical" (post-test); the Analyze stage showed the highest improvement; HOTS learning development is recommended	Improving critical thinking through 21st century learning. Facione's stages of critical thinking (IDEALS). The role of HOTS learning in the era of the 4.0 industrial revolution
Siti Nurjanah et al. (2019) [20]	Qualitative descriptive	The thought process of students with logical-mathematical intelligence in solving ill-structured problems	Students use the following steps: break down the problem, connect information, add/change information; further research is recomended	Mathematical-logical intelligence in problem solving. Stages of ill-structured problem solving. Use of think aloud and interviews
Asfi Yuhani et al. (2018) [21]	Experiment	The effect of problem-based learning on junior high school students' mathematical problem-solving skills	The experimental class (PBM) performed performed better than the control class; N-Gain for the experimental class was 0.52 (moderate), while for the control class it was 0.42; implementation of PBM is recommended	The effectiveness of PBM in improving problem solving. Comparison of experimental vs. control classes. Polya's problem solving indicators
Abdillah (2018) [22]	Qualitative descriptive	The emergence of student creativity as a result of solving ill-structured mathematical problems	Creativity emerges through fluency, flexibility, novelty; students reveal the process through deep thinking; more extensive research is recommended	Creativity components (fluency, flexibility, novelty). Ill-structured problems as triggers for creativity. Use of

Publication	Method	Constructs or Variables Studied	Key Findings	Emerging Themes
				think aloud and interview methods between problem solving and critical thinking
Illyuna Rizki Ardianingtyas et al. (2020) [23]	Qualitative descriptive	The critical thinking skills of junior high school students as seen from their mathematical problem-solving abilities	Students are lacking in inference, situation, clarity; low-performing students do not meet expectations; critical thinking learning is recommended	
Mohamad Salam (2022) [24]	Exploratory qualitative	Mathematical representation in solving ill-structured problems	Verbal and symbolic representations were used by both subjects; visual representations were not used; both subjects had different methods of using representations; the solutions were different but correct; further research is recommended	Use of verbal and symbolic representations. Lack of visual representations. Differences in solution methods. Different solutions to open-ended problems
Nissa Risma Mulyanti et al. (2018) [25]	Qualitative descriptive	Students' difficulties in solving mathematical problems involsing the pythagorean theorem	Junior high school students' problem-solving skills are still low; main difficulties: lack of understanding of the problem, lack of mastery of concepts, lack of thoroughness in calculations; contextual learning is recommended lack of understanding of the problem, lack of mastery of concepts, lack of thoroughness in calculations; contextual learning is recommended	Poor problem-solving skills. Difficulty understanding story problems. Lack of mastery of the Pythagorean theorem. The importance of contextual learning
Hendryawan et al., (2017) [26]	Qualitative descriptive	Middle school students' mathematical critical thinking skills through problem-based learning with the Green Motivation Strategy	Students with low initial abilities mastered 5 critical thinking indicators; students with moderate abilities mastered 6 indicators. Green's strategy helped increase motivation, confidence, and comfort in learn	Problem-based learning. Green's motivational strategy. Improvement of mathematical critical thinking. The role of motivation and learning environment

Publication	Method	Constructs or Variables Studied	Key Findings	Emerging Themes
Kairuddin (2018) [27]	Quasi-experiment	Analysis of student response processes related to problem-solving skills in contextual learning versus problem-based learning classes	Contextual learning classes were better than problem-based classes; the contextual answer process was better; the application of contextual learning was recommended	Comparison of learning models. The advantages of contextual learning. The process of student responses. Improvement of problem-solving skills.
Indah Luthfiyah et al. (2024) [28]	Qualitative case study	Exploring the problem-solving process of eighth-grade students in solving story problems	The process includes understanding the problem, solving strategies, and verifying answers; additional themes: student attention and problem perception; strengthening problem-solving learning is recommended	Polya's problem-solving steps. Student attention and perception. Student difficulties with story problems. The importance of student self-regulation
Muhammad Rifqi Mahmud et al. (2019) [25]	Qualitative case study	Numeracy literacy, ill-structured problem solving	Students are able to solve ill-structured problems in everyday life; students are able to analyze information and draw conclusions. Difficulties: understanding questions, material prerequisites, strategies, solutions, drawing conclusions	Numeracy literacy. Problem solving. Ill-structured. Number material
Fitri Pujiasih (2018) [30]	Qualitative	Mathematical critical thinking skills, SPLDV problem solving, mathematical ability	High-achieving students are proficient in all categories; moderate- and low-achieving students are not yet proficient in inference and strategy	Critical thinking, creativity, problem solving, mathematical ability
Anggun Gestiani el al. (2025) (31)	Qualitative descriptive	Mathematical literacy, ill-structured problems, extroverted personality	Subjects are proficient at the formulate stage, but not yet proficient at the employ and interpret stages in mathematical literacy	Mathematical literacy. Ill-structured problems. Extroverted personality type
A. Sri Mardiyanti Syam (2020) [32]	Qualitative descriptive	Critical thinking, creative thinking, mathematical problem solving, mathematical ability	High-achieving students meet 4 critical indicators and 3 creative indicators; low-achieving students meet 3 critical indicators	Critical thinking, creativity, problem solving

Publication	Method	Constructs or Variables Studied	Key Findings	Emerging Themes
			but lack flexibility and originality	
Jaelani el al. (2023) [33]	Qualitative descriptive	Critical thinking process, mathematics education students, ill-structured problems, mathematical ability	Subjects engage in critical thinking through 6 stages: Analyzing, Exploring, Creating, Deciding, Evaluating	Critical thinking, mathematics education students, ill-structured problems

3.1 Research Conditions & Direction

Based on the results of the scoping review, students have not demonstrated critical thinking skills, particularly in terms of seeking the truth, conducting analysis, verifying information, and reflecting on the solutions obtained. Most students do not have strong critical thinking skills when faced with ill-structured mathematical problems, so they tend not to verify data, identify missing information, or evaluate the solutions obtained [14]. This condition is also influenced by students' lack of experience in solving contextual and non-routine problems. As a result, students fail to meet the standards of mathematical critical thinking skills [15]. Students with low and moderate levels of math anxiety are able to complete the problem-solving stages better than students with high anxiety who face difficulties at every stage of problem solving [16]. Students who have a partial understanding of concepts tend to use trial and error strategies without evaluating the solutions obtained [17]. Students with high and moderate math skills are able to analyze problems better than students with low skills [18]. In addition, critical thinking skills can also be improved through the application of 21st-century skills-oriented learning and HOTS-based learning, which have been proven to improve students' critical thinking skills from non-critical to fairly critical [19]. Students with mathematical-logical intelligence tend to break problems down into smaller parts, connect various pieces of available information, and add or modify information to arrive at the correct solution [20].

From a learning strategy perspective, the application of problem-based learning has been proven to have a positive effect on improving students' mathematical problem-solving skills compared to conventional learning [21]. In addition, ill-structured problems can also encourage students' creativity, as demonstrated by fluency, flexibility, and novelty in generating solutions [22]. Students with moderate or low problem-solving abilities still experience difficulties in inference, clarification, and determining solution strategies [23]. In addition, when solving ill-structured problems, students generally use verbal and symbolic representations more, while the use of visual representations is still rarely found [24]. Poor mathematical problem-solving skills are often caused by difficulty understanding problems, lack of conceptual mastery, and carelessness in performing calculations [25]. One approach that can be used is problem-based learning combined with motivational strategies, which have been proven to increase student motivation, self-confidence, and critical thinking skills [26]. In addition, contextual learning has also been proven to be more effective than problem-based learning in improving students' response processes and problem-solving abilitie [27]. The importance of understanding the student problem-solving process, which includes the stages of understanding the problem, planning a solution strategy, and verifying the answers obtained [28]. In the context of numeracy literacy, students are actually capable of solving ill-structured problems in everyday life, but still have difficulty understanding questions, determining solution strategies, and drawing the right conclusions [25]. In addition, mathematical ability also influences critical thinking and problem-

solving skills, where students with high abilities are able to meet most critical thinking indicators compared to students with moderate and low abilities [30]. Students with certain personality types are able to perform the formulation stage in mathematical literacy, but still experience difficulties in the application and interpretation stages [31]. In addition, critical and creative thinking skills are also closely related to mathematical problem-solving skills, where students with high mathematical abilities tend to be able to fulfill more indicators of critical and creative thinking than students with low abilities [32]. The critical thinking process in solving ill-structured problems involves several stages, such as analyzing the problem, exploring possible solutions, making decisions, and evaluating the results obtained [5].

3.2 Emerging Themes

a. The 2015–2020 period

From 2015 to 2020, research was dominated by efforts to identify fundamental obstacles in students' mathematical problem solving. The theme that emerged during this period was mastery of the stages of problem solving. Many articles focused on analyzing students' errors at each stage, from understanding the problem to verifying the solution. In addition, the main issues that were often discussed included a lack of critical thinking and difficulty understanding ill-structured problems. Affective factors were also a significant concern during this period. Mathematical anxiety was identified as a variable that affected students' performance in problem solving. The role of teachers in overcoming this anxiety and the importance of mastering partial concepts were identified as causes of failure in problem solving. The use of trial and error methods and the difference between convergent and divergent thinking were analyzed to understand students' problem-solving strategies.

b. The 2015–2020 period

Entering the period from 2021 to 2025, there has been a significant thematic shift towards the integration of higher-order thinking skills (HOTS) and numeracy literacy. The themes that emerge during this period are closely related to the demands of the Industrial Revolution 4.0 era. Research no longer focuses solely on Polya's stages, but expands the analysis into a more comprehensive critical thinking framework, such as the IDEALS model proposed by Facione. Ill-structured problems are increasingly used as triggers for students' creativity and critical thinking skills. Creativity components, including fluency, flexibility, and originality, have become important indicators in learning evaluation. In addition, the effectiveness of problem-based learning and contextual learning is evaluated more deeply to improve numeracy literacy. The use of think-aloud methods and interviews has also become more intensive to explore students' thinking processes in greater depth. This period also shows greater attention to differences in student personalities, such as extroverted personality types, as well as the relationship between problem solving and numeracy literacy in the context of more complex number material.

4. Conclusion

Based on the results of the scoping review, students' critical thinking and mathematical problem-solving abilities, especially in the context of ill-structured problems, are still at a low level. Most students have a weak critical thinking disposition, characterized by an inability to verify information, analyze thoroughly, and reflect on the solutions obtained. This condition is exacerbated by effective factors, such as math anxiety, as well as cognitive factors in the form of partial concept mastery, which encourages the use of trial and error strategies without adequate evaluation. The results of the theme analysis show that the focus of research has shifted from the 2015–2020 period to the 2021–2025 period. In the early period, research focused more on identifying basic obstacles, or problem-solving stages, and the role of affective factors such as anxiety. In contrast to the previous period, recent research has placed greater emphasis on the development of higher-order thinking skills (HOTS), numeracy literacy, and readiness to face the challenges of the Fourth Industrial Revolution. Researchers are increasingly focusing on the use of ill-structured problems as triggers for student creativity, the application of comprehensive critical thinking frameworks such as the IDEALS model, and testing the

effectiveness of problem-based and contextual learning. This research shows that mathematics teaching methods need to be changed. Moving away from conventional approaches that focus on procedures, teachers must shift to learning designs that challenge students' creativity, verify information, and solve unstructured problems. Strengthening the basic concepts that are important for higher-order thinking skills and controlling math anxiety also requires greater attention. To prepare students for the challenges of the 21st century, further research is needed to investigate specific learning interventions that combine creativity, critical thinking, and ill-structured math problems.

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