Pedagogy Review

ISSN: 3025-6771 | Journal's DOI: 10.61436/pedrev

Homepage: https://imrecsjournal.com/journals/index.php/pedrev

Analysis of High School Students' Critical Mathematical Thinking Processes Reviewed From The Perspective of Students' Self-Efficacy

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ARTICLE INFO

Article History:

Received: 01 July 2026

Accepted: 15 September 2026

Published: 01 November 2026

Keywords:

Mathematical Critical Thinking;
Self-Efficacy;
Mathematical Problem Solving;
Critical Thinking Processes;
Arithmetic Sequences and Series

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ABSTRACT

Critical thinking is an essential competency in twenty-first-century mathematics education because it enables students to analyze, evaluate, and solve mathematical problems systematically. This study aimed to analyze the mathematical critical-thinking processes of high school students across different self-efficacy levels. The study used a qualitative descriptive approach and purposively selected three Grade 10 students representing high, medium, and low self-efficacy from an initial group of 36 students. Data were collected through a mathematical critical thinking test, a self-efficacy questionnaire, and semi-structured interviews, and were analyzed using the interactive model of data reduction, data display, and conclusion drawing. The findings revealed distinct critical thinking processes across the three self-efficacy levels. The participant representing the high self-efficacy category demonstrated systematic analysis, independent inference, reflective evaluation, coherent explanation, and effective self-regulation. Likewise, participants in the medium and low self-efficacy categories exhibited distinct critical thinking processes with different reasoning patterns. Theoretically, these findings suggest that self-efficacy is reflected in the progression of mathematical critical thinking across problem-solving stages. Higher self-efficacy was associated with more independent, reflective engagement across analysis and inference, evaluation, explanation, and self-regulation. In contrast, lower self-efficacy was associated with greater procedural dependence and less sustained reasoning and self-monitoring. Given the qualitative nature of the study and the use of three case participants, these findings describe observed patterns rather than generalizable differences among students with different levels of self-efficacy.

To cite this article:

Rahayu, R., & Jauharoh, I. N. (2026). Analysis of high school students' critical mathematical thinking processes reviewed from the perspective of students' self-efficacy. *Pedagogy Review*, *5*(4), 605-620. doi: https://doi.org/10.61436/pedrev/v5i4.pp605-620

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■ INTRODUCTION

Education is a process that can change mindsets through teaching and training, broaden students' horizons, and encourage them to actively develop their thinking. One subject that can develop students' thinking is mathematics. Mathematics is a core subject taught in elementary school and plays a key role in shaping students' thinking skills (Ati & Setiawan, 2020). Mathematics not only improves quantitative calculation skills but also plays a crucial role in developing logical, analytical, systematic, and critical thinking (Zulaeha et al., 2021). One of the skills that needs to be developed in students is critical thinking skills, because this ability is included in higher-order thinking skills.

The concept of critical thinking has evolved from the ideas of thought in Ancient Greece, pioneered by Socrates, to the understanding of critical thinking in the modern era today (Rahardhian, 2022). Critical thinking is very important in life because it allows a person to carefully filter information, determine the feasibility of a need, and question the truth that sometimes contains elements of lies or other things that have the potential to endanger life (Siskandi et al., 2020). When someone thinks well, it becomes a foundation for making decisions carefully and rationally. Structured and critical thinking help individuals analyze various information received, assess the potential impact of each choice, and determine the most appropriate decision based on logical and responsible considerations (Pratiwi et al., 2025).

Critical thinking skills involve identifying assumptions by linking them to existing knowledge, gaining relevant understanding, and reflecting on and generalizing mathematical situations. This process includes problem-solving activities, drawing conclusions, calculating possibilities, and making decisions (Kusumawati et al., 2022). Students' critical

thinking skills in mathematics learning are necessary to understand and solve problems that require the ability to reason, analyze, evaluate, and interpret (Rahmaini & Chandra, 2024). Therefore, these skills are important to develop in students and should be integrated into the educational curriculum. Critical thinking skills are very important to have because critical thinking can be used to solve problems and as a consideration in making the right decisions (Jiran Dores et al., 2020).

Although critical thinking skills play a crucial role in mathematics learning, their development is inseparable from internal factors that shape students' readiness and confidence to face mathematical problems. One important factor influencing critical mathematical thinking skills is student self-efficacy.

Self-efficacy is an individual's belief in their capacity to complete a specific task. Self-efficacy can be understood as an individual's belief in their capacity to carry out a specific task or role (Aziz et al., 2023). An individual who can predict their actions and plan steps for the future tends to reduce the possibility of errors. This ability reflects a good level of self-efficacy. Thus, it can be said that one of the important factors in achieving success is having a strong self-efficacy (Yuliana & Miatun, 2023). Therefore, in solving mathematical problems, critical thinking skills and self-efficacy are two important aspects because the process requires systematic steps to obtain the correct answer.

Self-efficacy is the belief in one's ability to identify, organize, and execute tasks to achieve goals. Self-confidence helps people deal with everyday challenges. Self-efficacy makes it easier for students to solve problems or assignments and can even improve academic achievement (Afifah & Kusuma, 2021). The importance of self-efficacy becomes even more evident in mathematics learning, which demands self-confidence, perseverance, and the ability to choose appropriate problem-solving strategies. In mathematics, students with high self-efficacy tend to be more confident, choose appropriate problem-solving strategies, and not give up easily when faced with difficulties. These findings are supported by research by Geovani & Waluya (2025), which shows that self-efficacy is positively and significantly related to mathematical critical thinking skills.

Many studies have been conducted to measure critical thinking skills, one of which is research by Wahyuningtiyas et al. (2024), which shows differences in critical thinking skills between female and male students when solving mathematical problems. Female students tend to be more detailed and meet all critical thinking indicators. In contrast, male students focus more on practicality and the final result and meet only some critical thinking indicators. Further research was conducted by Aini & Amelia (2023), This shows that subjects with high self-concept meet all critical thinking indicators. Subjects with moderate self-concept meet critical thinking indicators, but are still less accurate in determining strategies and drawing conclusions. Meanwhile, subjects with low self-concept do not meet all critical thinking indicators, especially in determining strategies and performing arithmetic operations. Another study conducted by Thoyyibah et al. (2024) shows that critical thinking skills differ based on the level of self-regulated learning. Students with high self-regulated learning have excellent critical thinking skills; those with moderate levels show less than optimal abilities, while those with low self-regulated learning have low critical thinking skills. This understanding is expected to inform the development of more appropriate learning strategies to improve the quality of mathematics learning in schools.

Building on this background, although previous studies have shown that self-efficacy is associated with students' mathematical critical thinking skills, most studies have examined the relationship between these variables or compared students' performance across categories. Few studies have explored in depth how students with different levels of self-efficacy engage in mathematical critical thinking while solving mathematical problems. This understanding matters because it offers deeper insight into students' reasoning, decision-making, and self-regulation during mathematical problem-solving.

Therefore, this study aims to analyze high school students' mathematical critical thinking processes based on their self-efficacy levels. Specifically, this study asks the following research question: How do high school students' mathematical critical thinking processes differ across high, medium, and low levels of self-efficacy when solving mathematical problems?

By addressing this question, the study is expected to provide a more comprehensive understanding of the relationship between self-efficacy and mathematical critical thinking processes. Furthermore, the findings are expected to contribute to the development of mathematics learning strategies that strengthen both students' self-efficacy and their mathematical critical thinking skills.

■ METHOD

Research Design and Procedures

This study employed a qualitative descriptive approach to provide an in-depth description of high school students' mathematical critical thinking processes in

relation to their self-efficacy levels. This approach was selected because it focused on understanding and describing students' thinking processes when solving mathematical problems rather than quantitatively measuring differences. The research was conducted in three main stages. First, a self-efficacy questionnaire was administered to identify students' self-efficacy levels. Second, all students completed a mathematical critical thinking test on arithmetic sequences and series. Third, selected participants were interviewed in depth to explore and clarify their reasoning processes while solving the problems. The written responses and interview data were subsequently analyzed to identify characteristics of mathematical critical thinking across the three self-efficacy categories.

Participants

This study was conducted at SMA 2 Bae Kudus, Central Java, Indonesia, in November 2025. The initial participants were 36 Grade X E4 students, classified into three self-efficacy levels based on the questionnaire results: high (5 students), medium (29 students), and low (2 students). Because the study aimed to examine mathematical critical thinking processes in depth rather than statistically compare the three groups, one participant from each self-efficacy category was purposively selected for further analysis. The selection considered the participant's self-efficacy questionnaire score, mathematical critical thinking test performance, and ability to articulate their reasoning process during the initial assessment. Accordingly, S1 was selected from the high self-efficacy category, S2 from the medium category, and S3 from the low category. The unequal distribution of students across the three categories, particularly the predominance of the medium category, therefore did not determine the number of participants selected for in-depth analysis. Instead, the three participants were selected based on the relevance and richness of the data they could provide for examining mathematical critical thinking processes within their respective self-efficacy categories.

Research Instruments

Data were collected using three instruments: a mathematical critical thinking test, a self-efficacy questionnaire, and semi-structured interviews. The mathematical critical thinking test was adapted from previous studies on mathematical critical thinking and constructed based on Facione's (2015) critical thinking indicators: analysis, inference, evaluation, explanation, and self-regulation. The self-efficacy questionnaire was adapted from Bandura's self-efficacy framework and modified to suit the context of mathematics learning. Before implementation, experts in mathematics education reviewed both instruments to ensure content validity. Furthermore, a pilot study was conducted to examine the validity and reliability of the instruments. The questionnaire demonstrated good internal consistency, with a Cronbach's alpha of 0.88, and all test items met the predetermined validity criteria. Semi-structured interviews were conducted to better understand students' mathematical critical thinking processes and to triangulate results from the written test.

Data Analysis

Data analysis followed the interactive model proposed by Miles et al. (2014), consisting of data reduction, data display, and conclusion drawing. During the data reduction stage, students' written responses and interview transcripts were transcribed, organized, and carefully reviewed. Relevant segments of data were selected based on the research objective, namely to identify students' mathematical critical thinking processes according to the five critical thinking indicators: analysis, inference, evaluation, explanation, and self-regulation.

Subsequently, the selected data were coded deductively using these predefined indicators as the analytical framework. Each segment of students' written responses and interview statements was examined to determine how participants demonstrated the characteristics of each indicator during mathematical problem-solving. After the coding process, data from the written tests and interviews were compared to identify recurring patterns and similarities within each self-efficacy category.

In the data display stage, the coded data were organized into narrative descriptions that illustrated each participant's mathematical critical thinking processes. Finally, conclusions were drawn by interpreting the relationships between students' levels of self-efficacy and their mathematical critical thinking processes across the five indicators. To strengthen the trustworthiness of the findings, the study employed methodological triangulation by comparing evidence from the mathematical critical thinking test, the self-efficacy questionnaire, and the interview data. In addition, the consistency of the interpretations was verified by continuously comparing the findings across these three data sources before final conclusions were established.

■ RESULT AND DISCUSSION

A self-efficacy questionnaire and a critical thinking test were used to categorize students' ability levels. The data were then analyzed and categorized by self-efficacy and critical thinking

skills to determine which subjects would be interviewed. The results of the self-efficacy questionnaire completed by 36 students showed a lowest score of 62,1 and a highest score of 87,8. These scores were obtained by aggregating students' answers according to the established indicators and assessment guidelines. Based on these results, 5 students were categorized as high self-efficacy, 29 as medium self-efficacy, and 2 as low self-efficacy. Details of this data are presented in Table 1.

Table 1. Student categories based on self -efficacy (Samsuddin & Retnawati, 2022)

Value Criteria	Category	Total
$x > 75.6$	High	5
$63.3 < x < 75.6$	Medium	29
$x < 63.3$	Low	2

The details of each research subject selected based on the results of grouping levels of self-efficacy are presented in full in Table 2.

Table 2. Selected subjects

Subject	Self-efficacy category	Test Score
S1	High	87.5
S2	Medium	75.0
S3	Low	62.5

Overview of Participants' Mathematical Critical Thinking

To provide a comprehensive overview before presenting findings for each critical thinking indicator, the study synthesized the three participants' mathematical critical thinking performance based on the written test and interview data. The participants represented three self-efficacy levels: high (S1), medium (S2), and low (S3). The synthesis highlights the distinguishing characteristics of each participant's mathematical critical thinking process and serves as the basis for the subsequent indicator-based analysis. The summary is presented in Table 3.

Table 3. Overview of Mathematical Critical Thinking Characteristics Across Self-Efficacy Levels

Critical Thinking Indicator	High Self-Efficacy (S1)	Medium Self-Efficacy (S2)	Low Self-Efficacy (S3)
Analysis	Identified relevant information accurately and interpreted the mathematical context before selecting a solution strategy.	Identified only part of the relevant information and relied on familiar examples to understand the problem.	Experienced difficulty understanding the problem context and focused primarily on numerical information.
Inference	Formulated logical conclusions and selected solution strategies independently based on mathematical reasoning.	Applied solution procedures by recalling previously learned examples without considering alternative strategies.	Was unable to formulate appropriate conclusions and depended heavily on memorized procedures.
Evaluation	Verified the correctness of solutions by rechecking calculations and comparing alternative methods.	Evaluated answers mainly by comparing them with classmates' solutions.	Rarely evaluated the solution process and assumed correctness based on external confirmation.
Explanation	Clearly explained each step of the mathematical reasoning using appropriate arguments.	Provided limited explanations and focused mainly on procedural steps rather than mathematical justification.	Encountered difficulties explaining the reasoning underlying the solution process.

Critical Thinking Indicator	High Self-Efficacy (S1)	Medium Self-Efficacy (S2)	Low Self-Efficacy (S3)
Self-regulation	Continuously monitored, revised, and reflected on the solution process independently.	Performed limited self-monitoring and corrected errors only after receiving external feedback.	Demonstrated minimal self-monitoring and tended to stop working when encountering difficulties.

Overall, the synthesis presented in Table 3 indicates that students with different levels of self-efficacy demonstrated distinct patterns of mathematical critical thinking. Rather than representing isolated characteristics of individual participants, these patterns reflect recurring behaviors identified consistently from the written tests and semi-structured interviews. To better represent these findings conceptually, we synthesized the recurring behaviors into a thematic map (Figure 1). The thematic map shows how different self-efficacy levels are associated with distinct critical thinking behaviors, including careful analysis, independent reasoning, following teachers' examples, peer confirmation, self-checking, initial confusion, and giving up when encountering difficulties. This visual synthesis provides an integrated overview of the qualitative findings and serves as a conceptual foundation for the subsequent discussion of each critical thinking indicator.

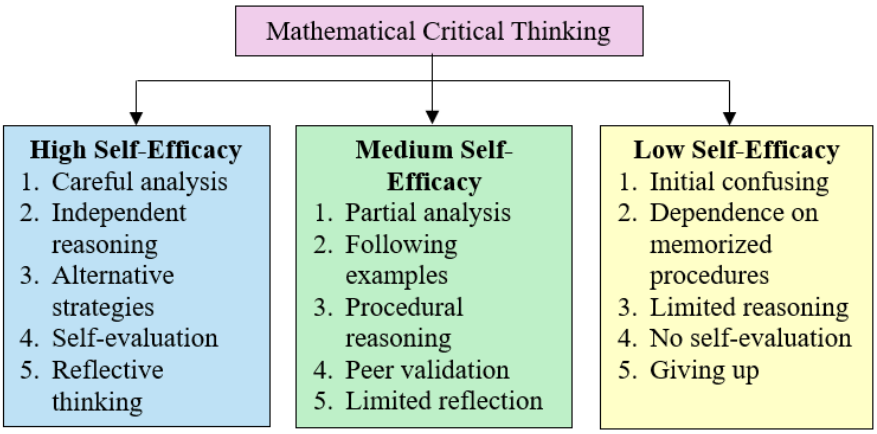


Figure 1. Thematic Map of Critical Thinking Behaviors Across Self-Efficacy Levels

Analysis of Mathematical Critical Thinking

Analysis is the first indicator of mathematical critical thinking and refers to students' ability to identify relevant information, distinguish known and unknown elements, interpret the mathematical context, and determine an appropriate strategy before solving a problem. Analysis of the written test and interview data revealed noticeable differences among participants with high, medium, and low self-efficacy.

The analysis of the written test and interview data revealed noticeable differences among participants with high, medium, and low levels of self-efficacy. The participant in the high self-efficacy category (S1) demonstrated a more systematic, reflective analytical process. In contrast, students with medium and low self-efficacy showed increasing dependence on external guidance and experienced greater difficulty interpreting the mathematical situation.

Subject S1 demonstrated strong analytical ability by accurately identifying the known information, the problem requirements, and the mathematical relationships presented in the task before selecting a solution strategy. During the interview, S1 explained that identifying important information was the first step undertaken before solving the problem.

Researcher: How do you understand what is asked in the question? S1: I look for important information and ensure that what is important is identified as the main question of the problem. Researcher: After understanding the question, what is the first step you take? S1: Determine what is known, what is asked, and possible methods that can be used.

The interview findings are supported by S1's written response, which shows that the participant systematically organized the known information, identified the required information, and planned an appropriate solution strategy before performing mathematical calculations.

In contrast, S2 demonstrated only partial analytical ability. Although S2 was able to identify information relevant to the problem, the analytical process relied mainly on previously learned examples rather than an independent interpretation of the mathematical context. During the interview, S2 explained:

> *Researcher: From the information available, how would you structure the steps? S2: I immediately used the formula that is usually used because it is similar to the example that was ever taught.*

The written response confirms that S2 applied familiar procedures directly without explicitly organizing known and unknown information. This indicates that S2's analytical process remained procedural and was strongly influenced by previous classroom instruction.

The weakest analytical performance was observed in S3. During the interview, S3 admitted that they felt confused immediately after reading the mathematical problem.

> *Researcher: When you first read a math problem, what do you think? S3: I immediately felt confused when I read the question. The problem seemed difficult.*

This finding aligns with S3's written response, which shows limited identification of relevant information and difficulty interpreting the problem's mathematical relationships. Rather than analyzing the mathematical context, S3 focused primarily on numerical values and tried to recall memorized procedures, making it difficult to choose an appropriate solution strategy.

Overall, these findings show that students' analytical processes varied with their levels of self-efficacy. S1, who represented the high self-efficacy category, analyzed mathematical situations systematically by independently identifying relevant information and planning solution strategies. Students with medium self-efficacy showed adequate analytical skills. However, they remained dependent on familiar examples, whereas students with low self-efficacy struggled to comprehend problems from the start and demonstrated fragmented analytical thinking.

These findings support Bandura's social cognitive theory, which posits that self-efficacy influences individuals' cognitive engagement, persistence, and confidence when performing challenging tasks. Students with stronger self-efficacy are more likely to invest cognitive effort in understanding problems before selecting solution strategies. In contrast, students with lower self-efficacy tend to rely on familiar procedures and avoid situations they perceive as difficult. This finding is also consistent with previous studies reporting that students with high self-efficacy demonstrate stronger mathematical critical thinking skills than those with lower self-efficacy. However, unlike previous studies that primarily reported quantitative relationships between self-efficacy and critical thinking, the present study provides qualitative evidence showing how different self-efficacy levels shape students' analytical behaviors during mathematical problem solving.

The findings indicate that students' analytical abilities vary with their self-efficacy levels. Subject S1 demonstrated a systematic analytical process by identifying relevant information, interpreting the mathematical context, and planning an appropriate solution strategy before performing calculations. In contrast, S2 showed only partial analytical ability, relying primarily on previously learned examples rather than independently interpreting the problem. Meanwhile, S3 struggled from the start of problem comprehension, resulting in fragmented analysis and an inability to determine an appropriate solution strategy. These findings suggest that self-efficacy influences not only students' confidence but also the quality of their cognitive engagement during the initial stage of mathematical problem solving.

The superior analytical performance demonstrated by S1 supports Bandura's social cognitive theory, which states that individuals with high self-efficacy are more likely to invest greater cognitive effort, persist when facing challenges, and employ effective strategies to accomplish complex tasks. Students with strong self-efficacy tend to approach mathematical problems with greater confidence, enabling them to interpret information systematically and select appropriate solution strategies before carrying out mathematical procedures. Conversely, students with lower self-efficacy often perceive mathematical tasks as difficult, leading to uncertainty during problem analysis and greater reliance on memorized procedures or external assistance.

These findings align with Susanti et al. (2023), who found that students with high self-efficacy met the indicators of mathematical critical thinking more fully than those with moderate or low self-efficacy. Similarly, Hidayat & Noer (2021) reported that students with

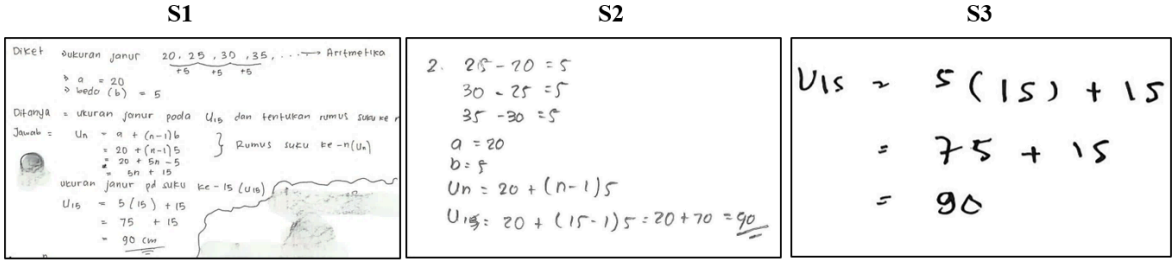


Figure 2. Comparison of Students' Written Responses on the Analysis Indicator Across Self-Efficacy Levels

low self-efficacy experienced considerable difficulty in analyzing mathematical problems and tended to rely on incomplete reasoning processes. The present study extends these findings by providing qualitative evidence of how differences in self-efficacy are reflected in students' analytical behaviors during mathematical problem solving. Rather than merely showing statistical differences, this study reveals the cognitive characteristics associated with each self-efficacy level during the analysis stage.

From a pedagogical perspective, these findings imply that mathematics instruction should not focus solely on procedural mastery but should also strengthen students' self-efficacy through learning environments that encourage independent problem analysis, exploration of multiple solution strategies, and reflective thinking. By building students' confidence alongside their analytical skills, teachers can support more meaningful mathematical problem-solving.

Inference of Mathematical Critical Thinking

Inference is the second indicator of mathematical critical thinking. It refers to students' ability to formulate logical conclusions and determine an appropriate mathematical strategy based on the information identified during the analysis stage. In this study, inference was reflected in how students connected the identified arithmetic sequence pattern with the appropriate general formula before determining the fifteenth term.

High self-efficacy (S1)

The written response indicates that S1 successfully identified the mathematical pattern, formulated the general formula, and correctly determined the fifteenth term. The interview further illustrates that the participant developed the solution by organizing the available information before applying the mathematical formula.

> *Researcher: From the available information, how did you organize your solution? S1: "I wrote the solution step by step, starting from identifying the given information until obtaining the final answer." Researcher: How did you know that your answer was appropriate? S1: "I checked whether my answer matched the context of the problem and whether the reasoning was logically consistent." Researcher: How did you determine the formula and the fifteenth term? S1: "I identified the first term and the common difference, applied them to the general formula for the nth term, and then substituted n = 15 into the formula."*

These interview excerpts indicate that S1 organized the solution by identifying relevant information, checking the consistency of the reasoning, and applying the appropriate mathematical concept. The participant's inference process therefore reflected independent mathematical reasoning rather than merely recalling memorized procedures.

Medium self-efficacy (S2)

Although S2 successfully obtained the correct answer, the written response suggests that the participant relied mainly on familiar procedures. The interview supports this observation.

> *Researcher: How did you organize your solution? S2: "I followed the example that the teacher had explained." Researcher: How did you know that your answer was correct? S2: "I usually asked my classmates whether my answer was correct." Researcher: How did you determine the formula? S2: "I used the same method as the example given by the teacher and followed the example problem."*

The interview indicates that S2's inference process depended largely on reproducing previously learned examples and seeking external confirmation. Although the participant reached the correct mathematical conclusion, the reasoning process remained predominantly procedural.

Low self-efficacy (S3)

S3 demonstrated the weakest inference performance among the three participants. The written response contained limited intermediate reasoning, and the interview further explains this pattern.

> *Researcher: How did you organize your solution? S3: "I followed the steps from the example that the teacher had previously explained." Researcher: How did you know that your answer was correct? S3: "I usually asked my classmates to check my answer." Researcher: How did you determine the formula? S3: "I followed the steps that the teacher had taught and used the example problem."*

The interview suggests that S3 relied almost entirely on recalling previously demonstrated procedures and obtaining confirmation from peers. Little evidence showed that the participant independently connected the given information to the mathematical concepts needed to construct the solution.

The findings indicate that self-efficacy plays an important role in students' inference processes during mathematical problem solving. Students with high self-efficacy connected the analysis-stage information to the appropriate mathematical concepts before determining a solution strategy. Their written responses showed a logical sequence of reasoning, starting with identifying the common difference, selecting the appropriate arithmetic sequence formula, and drawing a mathematically justified conclusion. In contrast, students with medium self-efficacy tended to use familiar classroom procedures. Students with low self-efficacy focused primarily on obtaining the final answer without explicitly demonstrating the reasoning that supported their conclusions.

These findings align with Bandura's Social Cognitive Theory, which explains that individuals with stronger self-efficacy are more willing to engage in complex cognitive processes, persist in challenging situations, and regulate their thinking during problem solving (Bandura, 1997). Students who believe in their capabilities tend to evaluate available information more carefully before choosing an appropriate mathematical strategy. In contrast, students with lower self-efficacy are more likely to rely on familiar procedures and avoid uncertainty.

The present findings are further supported by the recent scoping review conducted by Street et al. (2024), which concluded that mathematics self-efficacy is consistently associated with students' cognitive engagement, persistence, mathematical performance, and strategic decision-making during problem solving. Students with higher mathematics self-efficacy tend to invest greater cognitive effort and are more willing to explore alternative solution strategies when confronted with mathematical challenges.

Kohen et al. (2022) reported a similar conclusion, finding that students with higher mathematics self-efficacy demonstrated significantly better problem-solving skills and conceptual understanding than students with lower self-efficacy. Their study also showed that students with stronger self-efficacy were better able to select appropriate mathematical strategies and adapt them when solving unfamiliar problems. In contrast, students with lower self-efficacy relied more heavily on procedural approaches. These findings align closely with the present study: S1 demonstrated independent mathematical inference, S2 relied primarily on familiar classroom procedures, and S3 showed limited evidence of logical reasoning before arriving at the final answer.

Unlike previous studies that primarily examined the statistical relationship between self-efficacy and mathematical performance, the present study provides qualitative evidence showing how self-efficacy shapes students' inference processes during mathematical problem solving. Specifically, the findings reveal that differences in self-efficacy are reflected not only in the correctness of students' solutions but also in the quality of their reasoning, strategy selection, and justification of mathematical conclusions. These findings suggest that mathematics instruction should encourage students to explain why a particular strategy is appropriate and justify their conclusions, thereby fostering both mathematical inference and mathematics self-efficacy.

Evaluation of Mathematical Critical Thinking

Evaluation is the third indicator of mathematical critical thinking and refers to students' ability to assess the correctness of mathematical procedures, examine the consistency of reasoning, and verify whether the obtained solution appropriately addresses the given problem. In mathematical problem solving, evaluation reflects students' awareness of the validity of their reasoning rather than merely obtaining the correct final answer.

High self-efficacy (S1)

The written response indicates that S1 presented a complete and coherent solution process. The participant systematically identified the arithmetic sequence, determined the common

difference, applied the appropriate formula, and verified the obtained solution before reaching the final answer. The interview further confirms that S1 continuously evaluated whether each solution step was appropriate.

> *Researcher: How did you evaluate the solution steps that you used? Were they efficient or could they be simplified? S1: "I think my solution steps were already efficient, but I still reviewed them again." Researcher: Did you ever realize that you had made a mistake during the solution process? S1: "Yes. I traced back the mistake from the beginning and corrected it." Researcher: After completing the calculations, how did you check whether your solution was correct? S1: "I compared the procedures and recalculated them to see whether the final result was the same or different." Researcher: What did you do if the result was different from your initial answer? S1: "I validated all the calculations again and made sure that no step had been overlooked." Researcher: Why did you choose that strategy? S1: "Because I considered it the most logical and the simplest approach."*

These interview excerpts indicate that S1 consistently evaluated the validity of the mathematical reasoning throughout the solution process. Rather than accepting the first obtained answer, the participant repeatedly verified the computational procedures, examined the logical consistency of the reasoning, and corrected possible errors before finalizing the solution. This evidence demonstrates a reflective evaluation process supported by independent judgment.

Medium self-efficacy (S2)

Although S2 successfully obtained the correct final answer, the written response provided less evidence of reflective evaluation than S1. The participant focused primarily on completing the required procedures, with limited written justification for each computational step. The interview also indicates that the participant largely based evaluation on external confirmation.

> *Researcher: How did you evaluate the solution steps that you used? S2: "I thought the steps were already correct because they were similar to the teacher's example." Researcher: Did you notice any mistakes during the solution process? S2: "If I was unsure, I asked my classmates." Researcher: How did you check whether your final answer was correct? S2: "I compared my answer with my classmates' answers." Researcher: What did you do if your answer was different? S2: "I followed the answer that I believed was correct after discussing it with my classmates." Researcher: Why did you choose that strategy? S2: "Because I was more confident after comparing my answer with others."*

The interview suggests that S2 evaluated the solution's correctness primarily through peer confirmation rather than independently verifying the mathematical reasoning. Although the participant recognized the need to check the answer, the evaluation process remained procedural and relied heavily on external validation.

Low self-efficacy (S3)

S3 demonstrated the weakest evaluation process among the three participants. Although the written response reached the correct final answer, it provided limited evidence that the participant critically examined the validity of the selected strategy or reflected on the consistency of the reasoning. The interview further supports this finding.

> *Researcher: How did you evaluate the solution steps that you used? S3: "I thought the steps were correct because I followed the teacher's example." Researcher: Did you realize if you had made any mistakes? S3: "Usually I realized them after comparing my answer with my classmates'." Researcher: How did you check whether your answer was correct? S3: "I asked my classmates whether my answer was the same as theirs." Researcher: What did you do if your answer was different? S3: "I corrected my answer based on the discussion." Researcher: Why did you choose that strategy? S3: "Because I was not confident in my own answer."*

The interview indicates that S3 relied heavily on external confirmation rather than independently evaluating the correctness of the mathematical reasoning. Instead of reviewing the logical consistency of each solution step, the participant tended to judge correctness by comparing the final answer with peers. Consequently, the evaluation process reflected limited self-monitoring and weak independent verification of mathematical procedures.

The findings indicate that students' evaluation processes differed by self-efficacy level. Although all three participants obtained the correct final answer, the quality of their evaluation was reflected in the completeness and

coherence of their mathematical reasoning. S1 demonstrated a more systematic solution process, indicating stronger evidence of monitoring the consistency of each solution step. In contrast, S2 focused primarily on completing the required procedures, whereas S3 provided limited evidence that they evaluated the appropriateness of the selected mathematical strategy. These findings suggest that self-efficacy influences not only students' confidence but also how critically they evaluate their own mathematical reasoning during problem solving.

These findings align with Street et al.'s (2024) scoping review, which reported that mathematics self-efficacy is closely associated with students' cognitive engagement, persistence, strategic decision-making, and mathematical performance. Furthermore, Wang et al. (2024) demonstrated that self-efficacy positively influences students' problem-solving disposition through the sequential mediating roles of metacognitive disposition and critical thinking disposition. Their findings indicate that students with higher self-efficacy are more likely to engage in reflective thinking, monitor their reasoning, and critically evaluate solution strategies before reaching conclusions. This evidence supports the present study, in which S1 demonstrated stronger evidence of evaluating mathematical procedures than S2 and S3, suggesting that confidence in one's mathematical ability facilitates more reflective and systematic evaluation during problem solving.

These findings suggest that mathematics instruction should give students more opportunities to justify each step, evaluate alternative strategies, and reflect on the consistency of their reasoning, rather than emphasizing only the correctness of the final answer. Learning environments that encourage reflective questioning, mathematical justification, and self-evaluation are expected to strengthen both students' evaluation skills and their mathematics self-efficacy, thereby supporting the development of higher-order mathematical critical thinking.

Explanation of Mathematical Critical Thinking

Explanation is the fourth indicator of mathematical critical thinking. It refers to students' ability to communicate mathematical reasoning clearly, justify their chosen solution strategy, and explain the relationships between the mathematical concepts used during problem solving. This indicator emphasizes not only solution correctness but also the clarity and logical coherence of the reasoning presented. Based on the written responses in Figure 2, the three participants demonstrated different levels of explanatory ability aligned with their self-efficacy levels.

High self-efficacy (S1)

The written response indicates that S1 presented a complete and logically organized solution. The participant clearly identified the common difference, formulated the general expression for the arithmetic sequence, substituted the appropriate values, and communicated the solution through a coherent sequence of mathematical reasoning. The interview further illustrates how S1 justified each step of the solution.

> *Researcher: Can you explain why you used the arithmetic sequence formula to solve this problem? S1: "Because the pattern showed a constant difference between consecutive terms, I concluded that it was an arithmetic sequence." Researcher: How would you explain your solution to a classmate who did not understand the problem? S1: "I would first explain the given information, then show how to find the common difference, construct the general formula, and finally substitute the required term." Researcher: Why do you think your explanation is correct? S1: "Because every step is connected to the previous one and is consistent with the information given in the problem."*

These interview excerpts indicate that S1 articulated not only the computational procedures but also the mathematical justification for each step. The participant consistently linked the characteristics of the arithmetic sequence to the selected formula and communicated the reasoning coherently and logically. This demonstrates that the the explanation was grounded in conceptual understanding rather than procedural execution alone.

Medium self-efficacy (S2)

S2 also obtained the correct solution; however, the written response contained fewer explanations than S1. Although the participant completed the required calculations correctly, the written work emphasized procedural execution rather than explaining why the selected strategy was appropriate. The interview further reflects this tendency.

> *Researcher: Why did you choose that formula? S2: "Because it was the same formula that the teacher had explained before." Researcher: If your friend asked you to explain the solution, what would you say? S2: "I would show the calculation steps first*

because that was how I learned to solve this type of problem." Researcher: Why do you think those steps are appropriate? S2: "Because they follow the example that I learned in class."

The interview indicates that S2 communicated the solution mainly by describing the computational procedures rather than explaining the mathematical relationships that justified those procedures. Although the explanation was sufficient to reproduce the solution, it provided limited conceptual justification linking the sequence's characteristics to the chosen mathematical strategy.

Low self-efficacy (S3)

S3 demonstrated the weakest ability to explain among the three participants. As shown in Figure 2, the written response consisted primarily of numerical substitutions with minimal written justification. The interview provides additional evidence of the participant's limited ability to explain the reasoning behind the selected strategy.

Researcher: Why did you use that formula? S3: "Because that was the formula I remembered from the teacher." Researcher: Could you explain why the formula worked for this problem? S3: "I am not really sure. I just followed the example." Researcher: How would you explain your answer to someone else? S3: "I would show the formula and the calculations because I do not know how to explain it differently."

The interview findings indicate that S3 experienced considerable difficulty communicating the reasoning underlying the selected mathematical strategy. Rather than explaining the conceptual relationship between the problem information and the arithmetic sequence formula, the participant focused primarily on recalling and reproducing previously learned procedures. Consequently, the explanation emphasized procedural completion rather than mathematical justification.

The findings indicate that students' explanation abilities differed by self-efficacy level. S1 not only applied the appropriate mathematical formula but also presented a coherent sequence of reasoning that clearly demonstrated the relationship between the given information and the selected solution strategy. In contrast, S2 emphasized procedural calculations with limited mathematical justification, whereas S3 provided only brief numerical substitutions without adequately explaining the reasoning underlying the solution. These findings suggest that self-efficacy contributes to students' confidence in communicating and justifying mathematical ideas during problem solving.

These findings align with Jäder et al. (2020), who reported that students with stronger mathematical reasoning can better explain and justify their solution strategies when solving non-routine mathematical problems. Similarly, Widjaja et al. (2021) emphasized that mathematical communication plays a central role in developing students' reasoning because it enables learners to articulate, justify, and refine their mathematical thinking. The present study extends these findings by showing that differences in mathematics self-efficacy are reflected in the quality of students' written explanations, particularly in their ability to communicate logical reasoning rather than merely presenting computational procedures.

These findings suggest that mathematics learning should encourage students not only to produce correct answers but also to communicate the reasoning behind their solutions through written and oral explanations. Classroom activities involving mathematical discussion, justification, and argumentation may strengthen students' explanation skills while simultaneously enhancing their confidence in expressing mathematical ideas during problem solving.

The findings indicate that students' explanation abilities differed by self-efficacy level. Based on the written responses presented in Figure 2, S1 communicated mathematical reasoning more systematically than S2 and S3. S1 not only selected an appropriate solution strategy but also presented a coherent sequence of mathematical procedures that clearly connected the given information with the final solution. In contrast, S2 focused primarily on procedural calculations with limited justification, whereas S3 provided only brief numerical substitutions without sufficiently explaining the reasoning underlying the selected strategy. These findings suggest that self-efficacy contributes to students' confidence in communicating and justifying mathematical ideas during problem solving.

These findings align with Mukuka et al. (2021), who reported that mathematics self-efficacy significantly mediates students' mathematical reasoning. Their study showed that students with stronger self-efficacy demonstrate better reasoning because they are more confident in constructing and communicating mathematical arguments. Similarly, Smit et al. (2023) found that self-efficacy mediates students' mathematical reasoning, as students who received formative feedback developed stronger reasoning practices by becoming more confident in expressing and defending their

mathematical ideas. These findings support the present study, in which students with higher self-efficacy provided more coherent, logically connected explanations than those with medium or low self-efficacy.

These findings suggest that mathematics instruction should give students more opportunities to explain and justify their reasoning rather than focusing solely on correct answers. Classroom activities involving mathematical argumentation, reflective questioning, and formative feedback can encourage students to communicate their reasoning more explicitly while simultaneously strengthening mathematics self-efficacy. Such learning experiences are expected to promote deeper mathematical understanding and support the development of students' mathematical critical thinking skills.

Self-regulation of Mathematical Critical Thinking

Self-regulation is the fifth indicator of mathematical critical thinking and refers to students' ability to monitor, control, and reflect on their own thinking processes while solving mathematical problems. This indicator reflects how students evaluate the effectiveness of their chosen strategies, recognize possible errors, and adjust their work to improve solution accuracy. Based on the written responses in Figure 2, the three participants demonstrated different levels of self-regulation aligned with their self-efficacy levels.

High self-efficacy (S1)

The written response shows that S1 presented a complete, organized, and consistent solution process. Each computational step followed a logical sequence, suggesting that the participant continuously monitored the solution before proceeding to the next stage. The interview further demonstrates how S1 regulated the problem-solving process.

> *Researcher: What did you do when you felt uncertain about your answer? S1: "I reviewed each calculation step from the beginning to make sure I had not made any mistakes." Researcher: Did you change your strategy after checking your work? S1: "If I found an error, I corrected it immediately and recalculated the solution." Researcher: How did you decide that your final answer was ready? S1: "After checking all the steps and making sure they were consistent with the problem."*

These interview excerpts indicate that S1 actively monitored the solution process, identified possible errors, and revised the calculations whenever necessary. Rather than accepting the initial answer, the participant continuously reflected on the appropriateness of the selected strategy before finalizing the solution. This evidence suggests that S1 demonstrated strong self-regulation characterized by independent monitoring and reflective control of the mathematical reasoning process.

Medium self-efficacy (S2)

The written response indicates that S2 completed the mathematical procedures correctly but showed fewer signs of independently monitoring the reasoning process. This tendency is also reflected in the interview.

> *Researcher: What did you do when you were unsure about your answer? S2: "I usually asked my classmates first." Researcher: Did you review your own work before asking others? S2: "Sometimes, but I felt more confident after comparing my answer with theirs." Researcher: What made you decide that your answer was correct? S2: "When my answer was the same as my classmates' answer."*

The interview indicates that S2 demonstrated some awareness of the need to verify the solution; however, self-monitoring was still dependent on external confirmation. Instead of independently reflecting on the reasoning process, the participant tended to judge correctness through comparison with peers. Consequently, self-regulation was present but remained limited by procedural dependence and reliance on external feedback.

Low self-efficacy (S3)

Among the three participants, S3 demonstrated the weakest evidence of self-regulation. The written response contained limited intermediate reasoning and little indication that the participant monitored or revised the selected strategy. The interview further supports this finding.

> *Researcher: What did you do when you were unsure about your answer? S3: "I usually stopped and asked my classmates." Researcher: Did you check your own calculations first? S3: "Not really. I was afraid that my answer was wrong." Researcher: How did you know whether your final answer was correct? S3: "If my classmates had the same answer, I thought mine was correct."*

The interview findings indicate that S3 showed minimal independent self-regulation during mathematical problem solving. Rather than reviewing the reasoning process or independently identifying possible errors, the participant relied almost entirely on external confirmation. The responses also suggest limited confidence in evaluating their own work, leading them to stop the problem-solving process when uncertainty arose rather than reflect on alternative strategies.

The findings indicate that students' self-regulation differed by self-efficacy level. Subject S1 demonstrated stronger evidence of monitoring and organizing the solution process than S2 and S3. S1's systematic progression suggests greater awareness of the consistency of each solution step, whereas S2 tended to complete the procedure without substantial evidence of monitoring the reasoning process. In contrast, S3 provided limited intermediate reasoning, making it difficult to determine whether the participant reflected on or evaluated the appropriateness of the selected strategy. These findings indicate that higher self-efficacy is associated with stronger self-regulation during mathematical problem solving.

These findings are supported by Rovan et al. (2024), who showed that motivational beliefs, particularly self-efficacy, play a central role in students' self-regulated learning in mathematics. Their reconceptualized expectancy-value model emphasizes that students with stronger self-efficacy are more likely to monitor, regulate, and adapt their learning strategies when solving mathematical tasks. Similarly, Göller et al. (2026) reported that successful self-regulated learning in university mathematics is characterized by continuous monitoring of learning goals, reflection on progress, and adaptation of learning strategies according to contextual demands. In addition, Paz-Baruch (2025) found that self-efficacy and self-regulated learning strategies jointly contribute to students' achievement in STEM disciplines, suggesting that confidence in one's capabilities encourages students to regulate their cognitive processes more effectively. The present findings reinforce these studies by showing that students with higher self-efficacy demonstrated more organized and reflective mathematical solution processes than students with medium and low self-efficacy.

These findings imply that mathematics instruction should explicitly promote self-regulated learning by encouraging students to monitor their reasoning, evaluate the effectiveness of their strategies, and reflect on the consistency of their mathematical solutions. Classroom practices such as reflective journals, self-assessment, structured feedback, and guided reflection may strengthen students' self-regulation while simultaneously enhancing mathematics self-efficacy and mathematical critical thinking. Such learning environments encourage students not only to solve mathematical problems correctly but also to become more independent and reflective learners.

Overall, the findings show that self-efficacy influences not only students' confidence but also every stage of mathematical critical thinking, from problem analysis through inference, evaluation, explanation, and self-regulation. Students with high self-efficacy consistently exhibited systematic, reflective thinking, whereas the participant in the medium self-efficacy category (S2) relied more on procedural knowledge and external confirmation. Conversely, S3, representing the low self-efficacy category, showed fragmented reasoning and limited self-monitoring, particularly when faced with unfamiliar mathematical situations.

These findings suggest that strengthening students' self-efficacy should become an integral component of mathematics instruction because cognitive performance and affective beliefs develop simultaneously during mathematical problem solving.

■ CONCLUSION

This study shows that participants' mathematical critical thinking processes varied across self-efficacy levels and were reflected differently across the five critical thinking indicators. The participant representing the high self-efficacy category exhibited systematic analysis, independent inference, reflective evaluation, coherent explanation, and effective self-regulation throughout the problem-solving process. The participant in the medium self-efficacy category relied more on familiar procedures and external confirmation, particularly in reasoning and self-monitoring. Meanwhile, the participant in the low self-efficacy category demonstrated fragmented reasoning, limited explanation, and minimal self-monitoring, beginning with difficulty understanding the problem. Theoretically, these findings suggest that self-efficacy shapes the progression of mathematical critical thinking across problem-solving stages: higher self-efficacy was associated with more independent, reflective engagement from analysis and inference through evaluation, explanation, and self-regulation, whereas lower self-efficacy was associated with greater procedural dependence and less sustained reasoning and self-monitoring. Given the qualitative nature of the study and

the use of three case participants, these findings describe observed patterns rather than providing a basis for generalizing differences across all students with different levels of self-efficacy.

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