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MATHEMATICAL REASONING CHARACTERISTICS ACROSS ABILITY LEVELS IN METACOGNITIVE-BASED DEEP LEARNING

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ABSTRACT
Mathematical reasoning ability is an essential competency in mathematics learning; however, many students still experience difficulties in constructing arguments, applying concepts, and drawing logical conclusions. Metacognitive-based deep learning is expected to support reasoning development by encouraging students to plan, monitor, and evaluate their thinking processes. This study aimed to describe the characteristics and levels of junior high school students' mathematical reasoning ability in a metacognitive-based deep learning environment. A descriptive quantitative approach was employed involving 31 seventh-grade students of SMP Yos Sudarso Karawang. Data were collected through a mathematical reasoning test consisting of two essay items based on four indicators: making conjectures, applying mathematical concepts, carrying out logical procedures, and drawing conclusions. The instrument met the criteria of validity, reliability, discrimination index, and difficulty index. The results showed that 6.45% of students were categorized as high, 70.97% as medium, and 22.58% as low. High-level students fulfilled all reasoning indicators, medium-level students showed weaknesses in procedures and conclusions, and low-level students experienced difficulties in concepts, procedures, and conclusions. These findings provide a deeper understanding of students' mathematical reasoning characteristics across ability levels and may inform more reflective mathematics instruction.
Keywords: ability levels; characteristics of mathematical reasoning; mathematical reasoning ability; metacognitive-based deep learning.

ABSTRAK
Kemampuan penalaran matematis merupakan kompetensi penting dalam pembelajaran matematika, namun masih banyak peserta didik yang mengalami kesulitan dalam menyusun argumen, menerapkan konsep, dan menarik kesimpulan secara logis. Deep learning berbasis metakognitif diharapkan dapat mendukung pengembangan penalaran melalui kegiatan merencanakan, memantau, dan mengevaluasi proses berpikir. Penelitian ini bertujuan untuk mendeskripsikan karakteristik dan level kemampuan penalaran matematis peserta didik SMP dalam pembelajaran deep learning berbasis metakognitif. Penelitian menggunakan pendekatan deskriptif kuantitatif dengan melibatkan 31 peserta didik kelas VII SMP Yos Sudarso Karawang. Data dikumpulkan melalui tes kemampuan penalaran matematis yang terdiri atas dua soal uraian berdasarkan empat indikator. Instrumen telah memenuhi kriteria validitas, reliabilitas, daya pembeda, dan indeks kesukaran. Hasil penelitian menunjukkan bahwa 6,45% peserta didik berada pada level tinggi, 70,97% pada level sedang, dan 22,58% pada level rendah. Peserta didik pada level tinggi memenuhi seluruh indikator penalaran, peserta didik pada level sedang masih menunjukkan kelemahan pada prosedur dan kesimpulan, sedangkan peserta didik pada level rendah mengalami kesulitan dalam konsep, prosedur, dan kesimpulan. Temuan ini memberikan pemahaman yang lebih mendalam mengenai karakteristik penalaran matematis pada setiap level kemampuan dan dapat menjadi pertimbangan dalam pembelajaran matematika yang lebih reflektif.
Kata kunci: deep learning berbasis metakognitif, karakteristik penalaran matematis, kemampuan penalaran matematis, level kemampuan.
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Introduction

Mathematics is a discipline characterized by objective truth and plays an important role in developing critical thinking and problem-solving skills (Safari & Nurhida, 2024). Therefore, mathematics is often regarded as the foundation of various fields of knowledge because of its contribution to the development of logical, systematic, and analytical thinking skills. In mathematics learning, reasoning ability is one of the essential competencies that need to be developed in students (Arif et al., 2021). This ability helps students understand concepts, construct arguments, solve problems, and draw logical conclusions.

Mathematical reasoning is commonly understood as a thinking process used to draw conclusions based on known facts, patterns, or information (Rosyidah et al., 2021). Furthermore, Wau (2022) explained that mathematical reasoning involves students' ability to analyze patterns, understand concepts, and apply mathematical ideas when solving mathematical problems. Despite its importance, recent evidence indicates that students' mathematical reasoning ability remains a challenge in mathematics education. Results from PISA (2022) showed that Indonesian students obtained an average mathematics score of 366, which remained below the OECD average and reflected persistent difficulties in mathematical literacy and reasoning. Similarly, Anggoro (2023) reported that low mathematical reasoning ability contributes to students' difficulties in solving mathematical problems. These findings suggest that strengthening students' mathematical reasoning ability remains an important issue that requires further attention in mathematics learning.

Various studies have indicated that students' mathematical reasoning ability remains a significant challenge in mathematics education. Oktaviana & Aini (2021) found that junior high school students experienced difficulties in constructing mathematical arguments and drawing logical conclusions when solving mathematical problems. Similar findings were reported by Astriani & Dhana (2024), who revealed that students' mathematical reasoning abilities had not yet developed optimally, indicating the need for instructional approaches that encourage deeper engagement in mathematical thinking. These findings suggest that strengthening students' mathematical reasoning ability remains an important issue that requires continuous attention in mathematics learning.

According to Haryanti (2024), many students have not yet demonstrated satisfactory mathematical reasoning performance, particularly when dealing with mathematical problems situated in real-life contexts. These difficulties are often associated with students' reliance on procedural knowledge and formula memorization rather than conceptual understanding, making it challenging for them to represent contextual problems mathematically. Such findings indicate that students need learning experiences that encourage deeper understanding, reflective thinking, and meaningful engagement in mathematical problem solving.

Prior to conducting the study, the researcher carried out a preliminary investigation through communication with mathematics teachers and the administration of an initial mathematics ability test. This preliminary study was

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conducted to obtain an overview of students' mathematical reasoning ability. The results of the initial test indicated that students' mathematical reasoning ability had not yet reached an optimal level. Students still experienced difficulties in systematically organizing solution procedures, drawing conclusions, and providing logical justifications for their answers. In addition, communication with teachers revealed that some students still struggled to solve problems requiring reasoning skills. During the learning process, students also tended to rely on memorizing formulas without understanding the underlying concepts. These conditions indicate the need for learning approaches that encourage students to think more deeply, reflectively, and meaningfully.

One learning approach that can support the development of mathematical reasoning ability is the deep learning approach. In education, the deep learning approach emphasizes the development of deep, critical, and applicable understanding rather than merely memorizing facts (Diputera et al., 2024). Students are encouraged to understand that the learning process is as important as learning outcomes, so attention is not solely directed toward the final result (Syafi'i & Darnaningsih, 2025). Furthermore, deep learning encourages students to develop a more comprehensive and integrated understanding, enabling them to apply their knowledge in various situations and contexts (Dewi et al., 2025). Therefore, deep learning creates learning experiences that encourage students to think reflectively, evaluate their understanding, and employ reasoning processes more effectively when solving mathematical problems.

The deep learning approach is closely related to metacognition because both emphasize deep thinking processes and students' awareness of their own learning processes. Students' ability to solve problems is not only determined by their mastery of the subject matter but also by their ability to monitor and evaluate the thinking processes they employ while seeking solutions (Ningsih, 2023). The implementation of deep learning integrated with metacognition can help students understand learning materials in a more meaningful, critical, and reflective manner. According to Flavell, as cited in Purba et al. (2026), metacognition refers to an individual's ability to understand, direct, and regulate their own thinking processes through activities such as planning, monitoring, and evaluating their thinking. Deep learning not only emphasizes surface-level understanding but also encourages students to understand concepts deeply, establish connections among ideas, and apply knowledge in various contexts (Mulyanto et al., 2025). Therefore, metacognitive activities can strengthen deep and meaningful learning.

Metacognition also has a close relationship with mathematical reasoning ability. According to Hignasari (2026), without adequate metacognition, the process of reflecting on one's thinking and problem-solving strategies cannot be carried out effectively, thereby hindering the development of higher-order reasoning skills. Syaripuddin, as cited in Sompa et al. (2025), stated that a metacognitive approach can help improve students' mathematical reasoning ability through activities of planning, monitoring, and evaluating problem-solving strategies. Furthermore, metacognitive skills can promote the development of self-regulation, enabling students to become more active, independent, and confident in constructing their own knowledge (Nasir & Khadijah, 2026). Based on these perspectives, a metacognitive-based deep learning approach is considered capable of assisting

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students in developing mathematical reasoning ability through more directed, reflective, and meaningful thinking processes.

Mathematical reasoning develops differently among students, resulting in variations in the quality of reasoning demonstrated during mathematical activities. Putri et al. (2022) argued that the development of mathematical reasoning is closely related to students' cognitive growth and individual characteristics. Similarly, previous studies have consistently emphasized the importance of mathematical reasoning and metacognitive processes in mathematics learning. While studies such as Oktaviana and Aini (2021) and Rohati et al. (2023) focused on students' reasoning performance and reasoning behavior, Halidin et al. examined students' mathematical reasoning ability based on mathematical literacy levels and found differences in reasoning characteristics among students with different levels of ability. These studies collectively indicate that mathematical reasoning can be enhanced through learning environments that encourage reflection, problem solving, and self-regulation.

However, most previous studies have primarily focused on students' reasoning achievement or the effectiveness of instructional approaches, with limited attention given to understanding how mathematical reasoning is demonstrated across varying levels of ability. In addition, studies that specifically examine the characteristics of students' mathematical reasoning within metacognitive-based deep learning environments remain scarce. As a result, a comprehensive understanding of students' reasoning profiles across different ability levels is still limited. Unlike previous studies, this study focuses on identifying the characteristics of students' mathematical reasoning at different ability levels within a metacognitive-based deep learning context. Therefore, this study aims to describe the characteristics and levels of junior high school students' mathematical reasoning ability in metacognitive-based deep learning. The findings are expected to contribute to mathematics education and metacognitive learning research by providing a deeper understanding of students' reasoning profiles in deep learning contexts, as well as offering practical insights for teachers in designing more reflective and differentiated mathematics instruction that accommodates different levels of mathematical reasoning ability.

Research Methods

This study employed a descriptive quantitative approach. A descriptive quantitative approach was selected because the study aimed to systematically describe students' mathematical reasoning abilities based on numerical data obtained from a mathematical reasoning test, without examining causal relationships or testing the effectiveness of an intervention. Through this approach, students' mathematical reasoning abilities could be classified into different ability levels and analyzed based on the achievement of each reasoning indicator. Although the study employed a descriptive quantitative approach, qualitative descriptions of students' responses were used to support the interpretation of the quantitative findings at each ability level. The purpose of this study was to describe students' mathematical reasoning ability at each ability level in learning through a metacognitive-based deep learning approach.

The study was conducted at SMP Yos Sudarso Karawang during the second semester of the 2025/2026 academic year. The research subjects consisted of 31 seventh-grade students who received instruction through a metacognitive-based deep learning approach. The research data were obtained through a mathematical reasoning test administered after the completion of the learning process.

Data for this study were obtained from a mathematical reasoning assessment conducted after the completion of the learning activities. The assessment was designed to examine students' capacity to solve mathematical tasks involving reasoning processes. The instrument was constructed around four dimensions of mathematical reasoning, namely making conjectures, applying appropriate mathematical concepts, carrying out logical mathematical procedures, and formulating valid mathematical conclusions. Students' responses were then evaluated according to their performance on these dimensions.

Data for this study were obtained from a mathematical reasoning assessment conducted after the completion of the learning activities. The assessment was designed to examine students' capacity to solve mathematical tasks involving reasoning processes. The instrument consisted of two essay items developed based on four dimensions of mathematical reasoning, namely making conjectures, applying appropriate mathematical concepts, carrying out logical mathematical procedures, and formulating valid mathematical conclusions. Each test item was designed to encompass all four reasoning indicators, allowing students' mathematical reasoning abilities to be assessed comprehensively. Students' responses were then evaluated according to their performance on these dimensions.

Prior to its implementation, the instrument was tested to determine its quality. The instrument analysis included validity, reliability, discrimination index, and difficulty index tests. The results indicated that both essay items met the established criteria and were considered suitable for use in the study. Therefore, the instrument was deemed capable of measuring students' mathematical reasoning abilities appropriately and consistently.

Data collection was conducted by administering the mathematical reasoning test to all research subjects. The test results were then scored according to the achievement of each indicator. The scores obtained by the students were used to determine their levels of mathematical reasoning ability, namely high, medium, and low levels. The classification of ability levels was determined using the mean score ($\bar{x}$) and standard deviation (SD). The criteria for grouping mathematical reasoning ability levels are presented in Table 1.

Table 1. Criteria for Grouping Students' Mathematical Reasoning Ability Levels

Ability Level	**Criteria**
High	$X \geq \bar{x} + SD$
Medium	$\bar{x} - SD < X < \bar{x} + SD$
Low	$X \leq \bar{x} - SD$

Based on Table 1. The classification of students' mathematical reasoning ability levels was determined using the mean score ($\bar{x}$) and standard deviation (SD).

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This categorization method is commonly used in educational research to classify students into high, medium, and low ability groups based on the distribution of scores within a sample. According to Arikunto (2018), students whose scores are above the mean plus one standard deviation are categorized as high, those whose scores fall within one standard deviation of the mean are categorized as medium, and those whose scores are below the mean minus one standard deviation are categorized as low.

After the students were classified into three ability levels, their work at each level was analyzed in depth. The analysis was conducted to identify the characteristics of students' mathematical reasoning based on the established indicators. At the high level, the analysis focused on the completeness and accuracy of students in fulfilling all indicators. At the medium level, the analysis focused on the indicators that had been achieved as well as the errors that still appeared during the solution process. Meanwhile, at the low level, the analysis focused on students' difficulties in understanding problems, selecting concepts, performing calculations, and drawing conclusions.

The analysis process followed three interconnected procedures: organizing the data, presenting the findings, and interpreting the results. Initially, students' responses were reviewed and categorized according to their levels of mathematical reasoning ability. The organized data were then presented through percentage summaries of indicator achievement, distributions of reasoning levels, and descriptions of students' response characteristics at each level. Finally, interpretations were made to determine the distinctive features of students' mathematical reasoning based on their performance across the indicators and ability categories.

In addition to qualitative analysis, the percentage achievement of each mathematical reasoning indicator was also calculated. This calculation aimed to provide an overview of the indicators that were most mastered by students and those that still posed difficulties. Therefore, the analysis results were able to reveal not only students' ability levels but also the characteristics of mathematical reasoning at each level within the implementation of metacognitive-based deep learning.

Prior to data collection, permission to conduct the study was obtained from SMP Yos Sudarso Karawang. Participants were informed about the purpose of the study and their involvement was voluntary. The confidentiality of students' identities was maintained throughout the research process, and all data were used solely for academic and research purposes.

Results and Discussion

Results

Students' mathematical reasoning ability was analyzed based on four indicators: making conjectures, applying relevant mathematical concepts, performing logical mathematical processing, and drawing appropriate mathematical conclusions. The percentage achievement of each indicator is presented in Table 2.

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Table 2. Percentage Achievement of Each Indicator

Indicator	**Percentage**
Making conjectures	90.98%
Applying relevant mathematical concepts	79.31%
Performing logical mathematical processing	81.37%
Drawing appropriate mathematical conclusions	53.79%

Based on Table 2, the indicator of making conjectures obtained the highest percentage achievement, reaching 90.98%. This result indicates that most students were able to understand the initial information provided in the problem and predict appropriate solution strategies. The indicator of performing logical mathematical processing achieved 81.37%, while the indicator of applying relevant mathematical concepts achieved 79.31%. These findings indicate that most students were able to select appropriate mathematical concepts and carry out solution procedures, although inaccuracies in procedural steps and calculations were still found.

The indicator of drawing appropriate mathematical conclusions obtained the lowest percentage achievement at 53.79%. This finding indicates that students still experienced difficulties in relating calculation results to the context of the problem. Some students were able to obtain the correct final answer but had not yet written complete and accurate conclusions.

The results of the mathematical reasoning test showed a mean score of 66.71 with a standard deviation of 24.71. Students were then classified into three levels of mathematical reasoning ability: high, medium, and low. The distribution of students' mathematical reasoning ability levels is presented in Table 3.

Table 3. Distribution of Mathematical Reasoning Ability Levels

Level	**Number of Students**	**Percentage**
High	2	6.45%
Medium	22	70.97%
Low	7	22.58%

Based on Table 3, 2 students 6.45% were classified as having a high level of mathematical reasoning ability, 22 students 70.97% were classified as having a medium level, and 7 students 22.58% were classified as having a low level. After the classification process, students' responses at each ability level were analyzed in depth.

An example of a student response categorized as high-level mathematical reasoning on Item 1 is presented in Figure 1.

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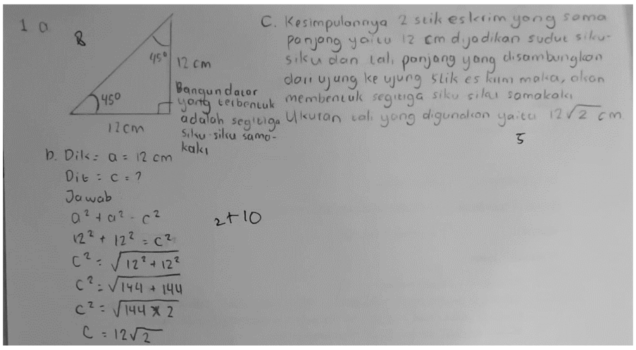

Figure 1. Example of a High-Level Student's Response to Item 1.

Based on Figure 1, students at the high level demonstrated strong mathematical reasoning ability by fulfilling all mathematical reasoning indicators. They were able to formulate appropriate conjectures, apply the Pythagorean Theorem to determine the length of the rope, and perform calculations systematically until obtaining the result of $12\sqrt{2}$ cm. In addition, they were able to draw accurate mathematical conclusions according to the context of the problem, indicating conceptual understanding and a well-structured problem-solving process.

An example of a student response categorized as having a medium level of mathematical reasoning ability on Item 1 is presented in Figure 2.

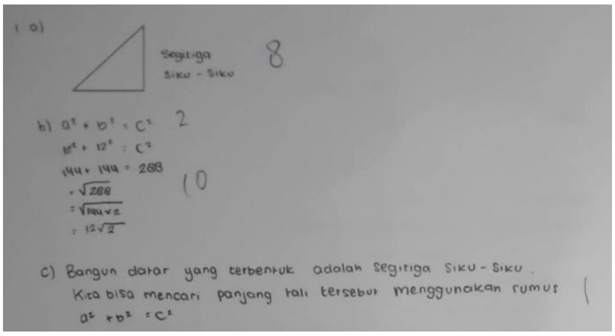

Figure 2. Example of a Medium-Level Student's Response to Item 1.

As presented in Figure 2, students classified at the medium level exhibited relatively adequate mathematical reasoning skills, as they were able to achieve most of the mathematical reasoning indicators. These students demonstrated the ability to formulate conjectures and apply the Pythagorean Theorem to determine unknown side lengths. During the problem-solving process, they generally followed appropriate procedures however, several inaccuracies in calculations and solution steps were still identified. Although students attempted to provide conclusions, some of them were not fully aligned with the problem context. Accordingly, these students were categorized as having a moderate level of mathematical reasoning ability.

An example of a student response categorized as having a low level of mathematical reasoning ability on Item 1 is presented in Figure 3.

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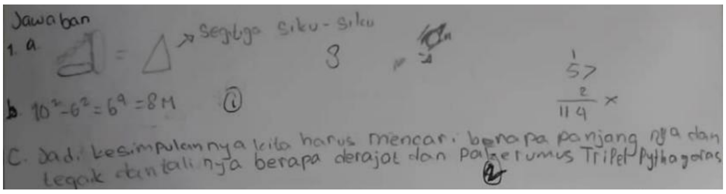

Figure 3. Example of a Low-Level Student's Response to Item 1.

As illustrated in Figure 3, students categorized at the low level showed limited mathematical reasoning abilities, as they achieved only a few of the expected reasoning indicators. Although these students were capable of making conjectures by recognizing the figure as a right triangle, the reasoning they presented remained relatively basic. They attempted to use the Pythagorean Theorem; however, errors in calculation procedures led to inaccurate results. Furthermore, the solution steps presented lacked completeness and logical consistency, while the conclusions drawn were often not fully relevant to the problem context. Consequently, these students were classified as possessing a low level of mathematical reasoning ability due to challenges encountered throughout the problem-solving process.

Discussion

The findings revealed distinct characteristics of mathematical reasoning across ability levels within a metacognitive-based deep learning environment. Students at the high ability level were able to fulfill all mathematical reasoning indicators, including making conjectures, applying relevant mathematical concepts, performing logical mathematical procedures, and drawing appropriate conclusions. In contrast, students at the medium and low ability levels showed incomplete fulfillment of these indicators, particularly in carrying out procedures accurately and formulating conclusions. These differences indicate that students demonstrated varying qualities of reasoning during the problem-solving process. Such findings support Rohati et al. (2023), who argued that mathematical reasoning can be identified through students' ability to understand problems, select strategies, construct arguments, and formulate conclusions.

The differences in reasoning characteristics found in this study suggest that students do not demonstrate mathematical reasoning in the same way. While some students were able to complete the entire reasoning process successfully, others still experienced difficulties in several reasoning indicators. This finding is in line with Putri et al. (2022), who stated that the development of mathematical reasoning is closely related to students' cognitive growth and individual characteristics.

Students at the medium and low ability levels frequently encountered difficulties in providing logical justifications and drawing conclusions that were consistent with the problem context. Similar findings were reported by Oktaviana and Aini (2021), who found that students often experience difficulties in constructing mathematical arguments and drawing logical conclusions when solving mathematical problems.

The results of this study are in line with previous findings by Ramlah et al. (2024), which highlighted the significant role of metacognitive activities in mathematical problem solving through processes such as awareness, regulation, and evaluation of thinking. In this study, students who actively monitored and reflected on their problem-solving strategies tended to demonstrate greater accuracy in applying mathematical concepts and formulating conclusions. In contrast, students with limited reflective engagement still showed weaknesses in procedural accuracy and the interpretation of problem-solving outcomes.

Furthermore, Tay et al. (2024) stated that metacognitive experiences in mathematics learning help students understand their own thinking processes when solving problems. This finding suggests that metacognitive-based deep learning can support students not only in obtaining correct answers but also in understanding the rationale behind the strategies they use. Subba et al. (2025) also reported that constructivist-based learning models can improve metacognition and mathematical problem-solving skills. Therefore, learning environments that provide opportunities for students to plan, monitor, and evaluate their problem-solving processes can strengthen mathematical reasoning ability.

Hidayat et al. (2025), through a meta-analysis study, demonstrated that metacognitive instruction has a positive effect on mathematics achievement. These findings support the results of the present study, indicating that a metacognitive-based deep learning approach is relevant for developing students' mathematical reasoning ability. Hoang et al. (2024) also emphasized that metacognition has become an important focus in mathematics education research because it is closely associated with the development of higher-order thinking skills.

Susanna et al. (2026) showed that reflective activities in problem solving can activate various metacognitive skills in students. This finding reinforces the results of the present study, particularly regarding the indicator of drawing appropriate mathematical conclusions, which still requires improvement through reflective practices, answer verification, and the habit of writing conclusions that align with the problem context. Sari et al. (2025) also reported that representational models in number problem solving can help students build stronger conceptual understanding. Therefore, the use of representations, reflection, and metacognitive strategies is important for strengthening students' mathematical reasoning ability.

In general, the findings of this research suggest that metacognitive-based deep learning contributes positively to the improvement of students' mathematical reasoning skills, particularly in understanding problems, developing conjectures, and utilizing relevant mathematical concepts. Nevertheless, students still require further support in formulating accurate mathematical conclusions. Therefore, teachers are encouraged to design learning experiences that promote reasoning activities, such as explaining problem-solving strategies, reflecting on solution processes, employing suitable mathematical representations, and formulating conclusions that align with the problem context.

Conclusion and Suggestion

The findings of this study indicate that students' mathematical reasoning abilities in metacognitive-based deep learning varied according to their ability levels. The majority of students were classified within the moderate category, whereas only a limited number belonged to the high and low categories. Students in the high-ability group demonstrated competence in achieving all mathematical reasoning indicators, such as formulating conjectures, utilizing appropriate mathematical concepts, carrying out logical mathematical operations, and making accurate conclusions. In contrast, students in the moderate category were generally able to meet most of the indicators, although some errors remained evident in mathematical procedures and the formulation of conclusions. On the other hand, students in the low-ability category encountered challenges in applying mathematical concepts, structuring solution steps in a systematic manner, and connecting computational outcomes to the given problem context.

The findings also revealed that making conjectures was the indicator most successfully achieved by students, whereas drawing appropriate mathematical conclusions was the least achieved indicator. These results indicate that students were generally able to understand problems and determine solution strategies, but they still required greater practice in reflection and in formulating conclusions based on the results obtained.

Overall, metacognitive-based deep learning can support the development of students' mathematical reasoning ability through activities involving planning, monitoring, and evaluating thinking processes during problem solving. The findings provide an overview of the characteristics of mathematical reasoning ability at each level and may serve as a reference for teachers in designing mathematics instruction that is more reflective, meaningful, and responsive to students' learning needs.

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