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Investigation of students' mathematical mindset in solving mathematical literacy problems

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Abstract
Mathematical literacy is a crucial competency for university students, yet research indicates that many students struggle to apply it effectively. This study aims to analyze students' mathematical mindsets in addressing mathematical literacy challenges and their implications for mathematics education in higher education. The research employs a descriptive qualitative design, involving three second-semester students selected through purposive sampling. Data collection methods include observation, in-depth interviews, and analysis of mathematical literacy tests, focusing on indicators such as the ability to formulate mathematical situations, apply mathematical concepts and procedures, and interpret mathematical results. Data analysis was conducted through several stages: data reduction, data presentation, drawing conclusions, identifying students' mindsets in solving mathematical problems, and source triangulation. The findings reveal that students' mathematical thinking is influenced by cognitive development, cognitive style, and problem-solving strategies. While some students successfully solve mathematical literacy problems, they still make errors in several concepts and often exhibit carelessness in reading the questions. This research has significant implications for mathematics education in higher education, including the need to emphasize conceptual understanding, balance procedures, and concepts, and utilize visual representations. The development of teaching materials and mathematical literacy questions should be designed to accommodate diverse student mindsets and be grounded in realistic contexts.

Keywords: Higher education, Mathematics education, Mathematical literacy, Mathematical mindset

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Introduction

Mathematics plays a crucial role in daily life and the advancement of science. In an increasingly complex era of globalization, mathematical literacy has emerged as an essential competency that every individual must possess, particularly students who represent the next generation of society. Mathematical literacy encompasses not only the ability to perform basic calculations but also the capability to comprehend, analyze (OECD, 2022a) , apply mathematical concepts, and utilize this knowledge to solve problems in real-life contexts (Lange, 2006).

In higher education, mathematical literacy serves as the foundation for developing critical, analytical, and logical thinking skills essential across various fields of study (Maass et al., 2019; Maslihah, 2020). Students with strong mathematical literacy are generally more adept at facing academic and professional challenges in the future. Those who grasp the content and procedures of mathematics in solving contextual tasks and can effectively apply their knowledge are more likely to succeed in addressing given problems.

However, research indicates that many students still face difficulties (Kolar & Hodnik, 2021) in applying their mathematical knowledge across different contexts. Various studies reveal that the mathematical literacy skills of Indonesian students are still not optimal. As illustrated in Figure 1, the acquisition of Indonesian mathematical literacy scores across different periods reflects this ongoing challenge.

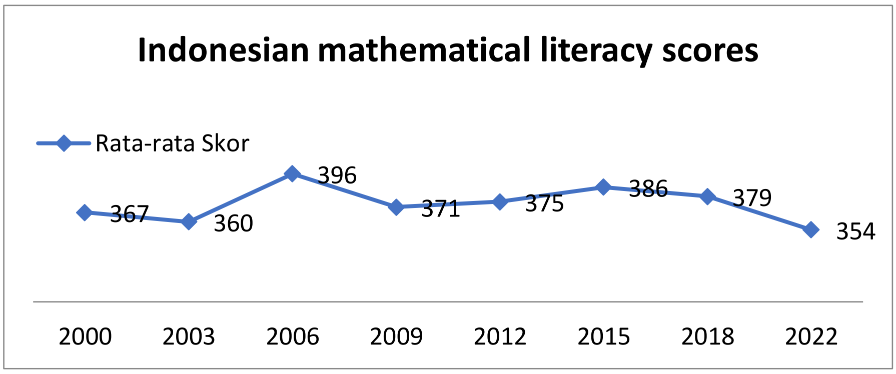

Figure 1. Indonesian Mathematical Literacy Scores

According to the OECD report from 2000-2022, Indonesia's mathematical literacy skills have shown a tendency to decline, as illustrated in Figure 1. This decline is influenced by several factors, including inappropriate learning models (Sholihah & Susanti, 2023), the crucial role of teachers (Manggala & Yuniawatika, 2021), students' affective characteristics (Thien et al., 2015), resource availability (Aisyah & Juandi, 2022), and the nature of teaching materials (Nugraha & Suparman, 2021). Furthermore, previous studies have indicated that many students continue to face difficulties in solving mathematical literacy problems (Hignasari et al., 2023). Additionally, students with excellent academic performance tend to exhibit better mathematical literacy (Al-Fayez, 2023).

One of the key factors influencing mathematical literacy is a mathematical mindset. A mathematical mindset encompasses how an individual perceives, understands, and approaches mathematical problems (Dweck, 2006). Students' mindsets significantly affect their approach to solving mathematical literacy problems. Strong habits of mind and a growth mindset are associated with better problem-solving abilities and persistence (Hakim & Nurlaelah, 2018; Shen et al., 2016). Educational interventions that promote a growth mindset and redesign problem questions to enhance sense-making can improve students' mathematical literacy (Kirkland & McNeil, 2021). Additionally, tailoring teaching methods to students' cognitive development and prior knowledge is crucial for effective problem-solving (Melisa & Utami, 2023) .

Mathematical thinking patterns are diverse and evolve with education and age. Key types include algebraic and fractional thinking (Eriksson & Sumpter, 2021), pattern generalization strategies (Nurwidiyanto & Zhang, 2020), geometric thinking (Mulligan & Mitchelmore, 2009), algorithmic thinking (Stephens, 2019), and advanced mathematical thinking (Edwards et al., 2005). Early awareness and development of these patterns are crucial for mathematical competence and problem-solving abilities. Integrating these patterns into educational practices can significantly enhance students' overall mathematical understanding and performance.

Several previous studies have examined various aspects of mathematical literacy at the college level. Wijaya et al. (2021) investigated the difficulties faced by students in solving contextual problems and found that the majority of students struggled to transform contextual problems into mathematical form. Similarly, Manah et al. (2017) analyzed students' mathematical problem-solving strategies and identified that metacognitive abilities play a crucial role in successful problem-solving. Furthermore, Schoenfeld (2016b) revealed that a growth-oriented mathematical mindset is positively correlated with enhanced mathematical problem-solving abilities. Conversely, Lithner (2003) found that students who favor procedural thinking experience greater difficulties in solving non-routine problems compared to those who develop a conceptual understanding.

Although these studies have provided valuable insights, there remains a need for more in-depth investigations into how mathematical mindsets influence the way students approach and solve mathematical literacy problems. Responding to this urgency, this research aims to examine the mathematical thinking patterns of students in addressing mathematical literacy challenges. A deeper understanding of these patterns will significantly contribute to the development of more effective mathematics learning strategies at the higher education level.

Methods

The research design employed a descriptive qualitative approach, focusing on the depiction and in-depth understanding of a phenomenon or situation (Cohen et al., 2008). In the context of this study, the descriptive qualitative design was utilized to investigate and describe students' mindsets in mathematical literacy at the university level. The researchers aimed to understand the perspectives, experiences and thought processes of students as they engage in mathematical literacy tasks.

Researchers play a key role as the primary instruments in data collection and analysis. The research subjects were selected through purposive sampling, consisting of three second-semester students enrolled in basic mathematics courses. These subjects were chosen due to their varied response patterns. Data collection began with direct observation (Creswell & Creswell, 2018), wherein students were observed while engaged in mathematical literacy tasks. Subsequently, a mathematical literacy test analysis (Bowen, 2009) was conducted by examining students' written work on mathematical literacy problems. To further reinforce the analysis, in-depth interviews were conducted to delve into the students' perspectives, experiences, and thought processes related to mathematical literacy. The indicators and instruments provided are detailed in Table 1. Next, to check student answers, a test assessment rubric for the mathematical literacy questions given is used as in Table 2.

Table 1. Test Indicators and Instruments

<table>
<tr><th>Indicator Test</th><th>Test Instrument</th></tr>
<tr><td>The ability to formulate situations mathematically

The ability to use mathematical concepts, procedures, facts, and tools

The ability to interpret, determine, and evaluate mathematical results</td><td>Santi has 24 dollars in cash. If he wants to exchange it into rupiah and the exchange rate for dollars into rupiah is as in the table below
<table>
<tr><th>Date</th><th>Exchange</th></tr>
<tr><td>May 19, 2024</td><td>15,965</td></tr>
<tr><td>May 20, 2024</td><td>16,040</td></tr>
<tr><td>May 21, 2024</td><td>16.011</td></tr>
<tr><td>May 22, 2024</td><td>16,047</td></tr>
<tr><td>May 23, 2024</td><td>16.102</td></tr>
<tr><td>May 24, 2024</td><td>16,045</td></tr>
<tr><td>May 25, 2024</td><td>16,045</td></tr>
</table>
Determine:
a. If Santi exchanges money on May 21 2024 with a 5% administration fee, then how much money will he receive?
b. What kinds of rupiah denominations might Santi receive on that date?
c. If Santi does not exchange on May 21, 2024, on what date will Santi get a bigger profit? State the reason</td></tr>
</table>

Table 2. Rubric for mathematical literacy

Indicator	Criteria	Score
Ability to Formulate Situations Mathematically	Able to identify relevant mathematical information very well. Able to formulate problems into mathematical models very precisely	4
	Able to identify most of the relevant mathematical information. Able to formulate problems into mathematical models well, even though there are a few small errors	3
	Able to identify some relevant mathematical information, but it is still incomplete. Able to formulate problems into mathematical models quite well, but there are several errors.	2
	Less able to identify relevant mathematical information. Less able to formulate problems into mathematical models correctly	1
Ability to Use Concepts, Procedures, Facts, and Mathematical Tools	Able to use mathematical concepts, procedures, facts, and tools very precisely. Able to implement effective and efficient resolution strategies	4
	Able to use mathematical concepts, procedures, facts, and tools well, even if there are a few small errors. Able to apply quite effective resolution strategies	3
	Able to use some concepts, procedures, facts, and mathematical tools, but there are some errors. Able to apply sufficient settlement strategies, even though they are less efficient	2
	Less able to use mathematical concepts, procedures, facts, and tools correctly. Less able to implement effective resolution strategies.	1
Ability to Interpret, Apply, and Evaluate Mathematics Results	Able to interpret mathematical results very well. Able to apply mathematical results very precisely. Able to evaluate the suitability and logic of mathematical results	4
	Able to interpret mathematical results well, even if there are a few small errors. Able to apply mathematical results well, even though there are a few small errors. Able to evaluate the suitability and logic of mathematical results, even though there are slight shortcomings	3
	Able to interpret mathematical results, but there are several errors. It is possible to apply mathematical results to make decisions or draw conclusions, but there are several errors. Able to evaluate the suitability and logic of mathematical results, but there are several shortcomings	2
	Less able to interpret mathematical results. Less able to apply mathematical results to make decisions or draw conclusions. Less able to evaluate the suitability and logic of mathematical results	1

The data analysis process in this research was carried out through several systematic and structured stages (Miles & Huberman, 2014). The first stage is data reduction, where the researcher selects, focuses attention, and simplifies the rough data from written field notes. At this stage, researchers sort relevant information and discard unnecessary details, resulting in a clearer data set. The second stage is data presentation, which involves organizing structured information to facilitate the drawing of conclusions and decision-making. In this stage, data is presented in a more organized and comprehensible form, such as narrative descriptions, charts, category relationships, or flow diagrams.

The third stage involves concluding, wherein the researcher seeks to identify meaning from the collected data by noting regularities, patterns, explanations, potential configurations, causal flows, and propositions. Initial conclusions are tentative and subject to change if further strong evidence is found in subsequent stages of data collection. The fourth stage focuses on identifying students' thinking patterns in solving mathematical problems. During this stage, researchers conduct an in-depth analysis of students' thought processes, problem-solving strategies, and the steps they take when faced with mathematical challenges. This analysis aids in understanding students' difficulties and capabilities in problem-solving.

Results

The results of the mathematics literacy test administered to students were then analyzed in depth, focusing on the student's mathematical thinking patterns in solving mathematical literacy problems. The data analyzed were derived from the mathematics literacy test results, in-depth interviews, and observations conducted during the students' problem-solving processes. The answers from the three students are explained as follows.

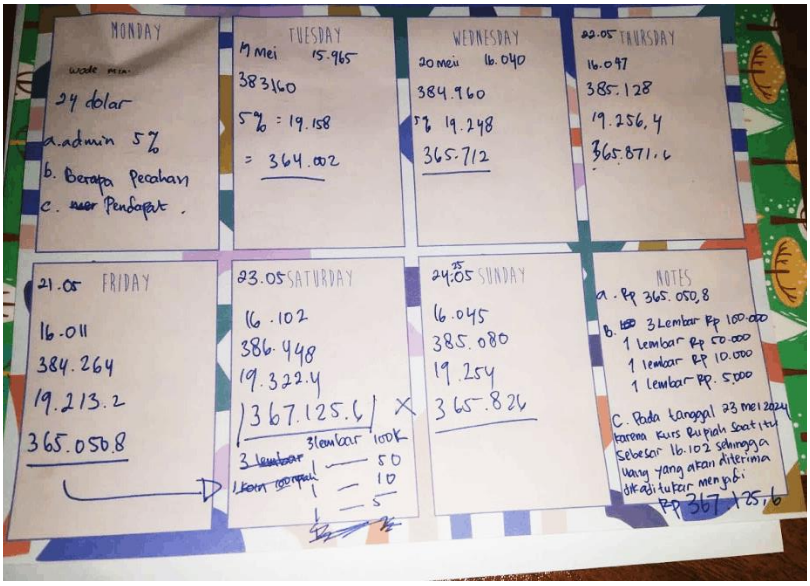

Figure 2. Student A's Answer in Completing Mathematical Literacy

By examining Figure 2, regarding the indicator of the ability to formulate situations mathematically, it appears that the student is able to identify some relevant mathematical information. However, the formulation of problems into mathematical models remains incomplete and lacks accuracy. Regarding the indicator of the ability to use mathematical concepts, procedures, facts, and tools, the student demonstrates the use of certain concepts, procedures, facts, and tools, although with some errors. The student applies a moderately adequate problem-solving strategy, albeit with limited efficiency.

For the indicator of the ability to interpret, apply, and evaluate mathematical results, the student shows proficiency in interpreting and applying mathematical results, despite a few minor errors. Additionally, the student can evaluate the appropriateness and logic of mathematical results, although some minor deficiencies are present. To further understand Student A's mindset, the following interview was conducted below.

Lecturer : Is the question given difficult? Then, explain the steps you used to solve this problem.
Student A : The questions given are quite easy. My step in solving this problem was to multiply all the daily exchange rates in rupiah, and then I reduced the result by 5%.
Lecturer : What decision did you make that enabled you to answer point A?
Student A : I reviewed all my calculations, and then I focused on the calculations from May 21, 2024.
Lecturer : To complete point b, what denominations of money did Santi receive and why did he choose those denominations?
Student A : The denominations of money obtained by Santi are 3 sheets of 100,000, 1 sheet of 50,000, 10,000, and 5,000. The reason is that the money Santi obtained is thinner.
Lecturer : For point C, why choose the date May 23, 2024?
Student A : By looking at the table, it can be seen that the exchange rate of the rupiah on that date was higher than on other days.
Lecturer : When solving this problem, did you use any mathematical aids?
Student A : Yes, I use the calculator on my phone to make the calculation process easier for me.

Based on the answer sheet and interview results, this student has demonstrated the ability to understand and solve mathematical literacy problems correctly and has successfully integrated them into contextual situations. However, there are discrepancies in the mathematical procedures.

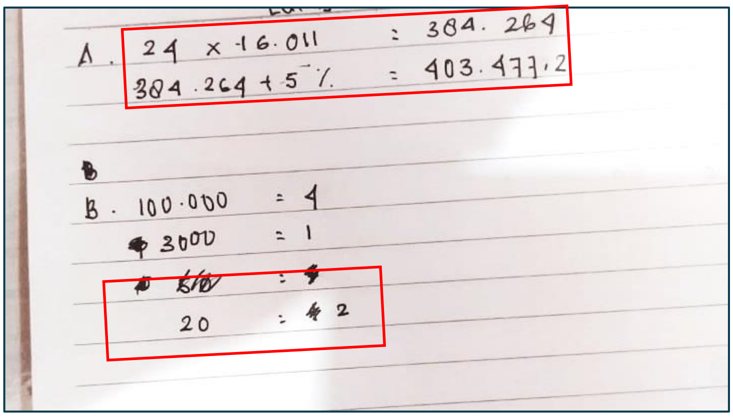

Figure 3. Student B's Answers in Solving Mathematical Literacy

By examining Student B's answers (see Figure 3), it appears that they are less capable of identifying relevant mathematical information and less able to accurately formulate problems into mathematical models. In terms of using concepts, procedures, facts, and mathematical tools, the student demonstrates limited capability in correctly applying these elements and employing effective problem-solving strategies. Regarding the ability to interpret, apply, and evaluate mathematical results, the student appears less proficient in interpreting mathematical outcomes and less able to apply these results for decision-making or drawing conclusions. They also show limited capability in evaluating the appropriateness and logic of mathematical results. To further understand Student B's mindset, an interview was conducted as follows.

Lecturer : *Is the question given difficult? Then, explain the steps you used to solve this problem.*
Student B : *The questions given are quite difficult, where I have to read them too much, and I am confused in solving them. For that reason, I then read it 6 times before I understood the meaning of the given question.*
Lecturer : *Which decision did you make so that you were able to answer question point A?*
Student B : *I immediately looked at the line on May 21, 2024, and then I multiplied the exchange rate by 24 and added 5% as the administrative fee.*
Lecturer : *Why did you write it as 384,286 + 5% = 403,477.2?*
Student B : *I was in the process of working on it using my HP calculator, first I pressed* 24×16011 *and then the result came out, I just pressed* $\times$ 5% *and the number 403,477.2 appeared.*
Lecturer : *Can you explain the meaning of 1=400.00, 1=3000, and 2=20?*
Student B : *This is based on the calculation results I obtained, which amount to 403,477.2, so the money he received was 400,000 each, 3,000 each, and 20 two pieces.*
Lecturer : *Is that denomination of money currently available in reality?*
Student B : *Oh right, nothing*
Lecturer : *Try again, how much do you think he got?*
Student B : *I don't know, I'm confused about the number 403,477.2. What does it mean if it's converted into rupiah denominations?*

From the explanation, it was obtained that student B lacks mathematical literacy in terms of problem-solving, understanding the required concepts, and integrating them into contextual situations.

Examining Student C's answers (see Figure 4), regarding the indicator of the ability to formulate situations mathematically, it appears that they can identify some relevant mathematical information, though it remains incomplete. They can formulate problems into mathematical models fairly well, although there are some errors. The indicator of the ability to use mathematical concepts, procedures, facts, and tools shows that they can apply some of these elements and utilize fairly effective problem-solving strategies. Concerning the indicator of the ability to interpret, apply, and evaluate mathematical results, the student demonstrates an ability to interpret and apply mathematical results for decision-making, despite some errors. They also show proficiency in evaluating the appropriateness and logic of mathematical results, although there are some shortcomings.

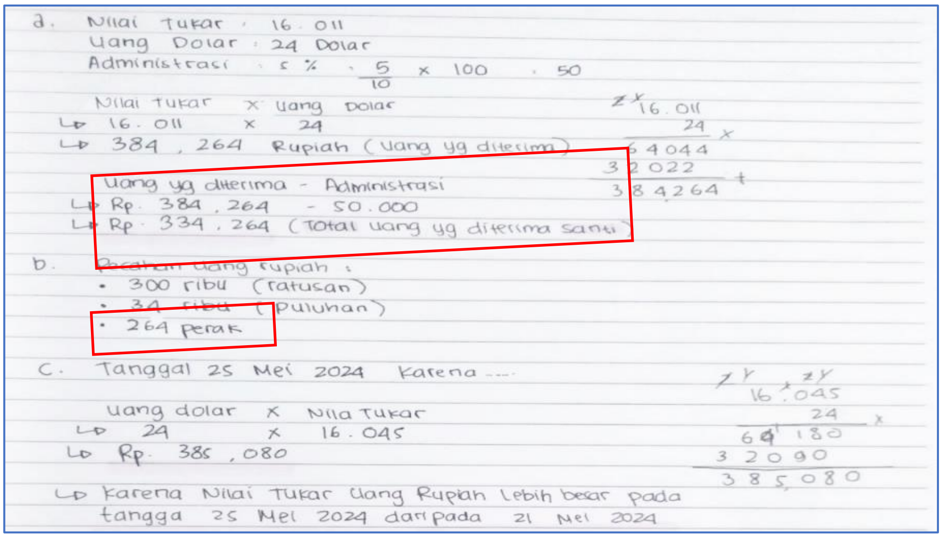

Figure 4. Student C's Answer in Solving Mathematical Literacy

To further understand Student C's mindset, the following interview was conducted below

Lecturer : *Is the question given difficult? Then, in the answer to point a, why did you make a deduction of 50,000?*

Student C : *The question given is quite easy because I have previously learned the concept of percentages. Then, the reason I subtracted 50,000 is based on the written question of 5%, where 5% is 50,000.*

Lecturer : *To solve point b, how much did Santi get?*

Student C : *The money Santi obtained is 300 thousand (hundreds), which means there are 3 hundred-thousand bills, 34 thousand (tens), which means there are 3 ten-thousand bills and 4 one-thousand bills, and 264 (cents), these are coins, ma'am.*

Lecturer : *Is there real money for the 264 cents?*

Student C : *Oh, yes, ma'am, there is no money with such a number.*

Lecturer : *For that, how many denominations of money did Santi receive? Why?*

Student C : *The money obtained by Santi amounts to 334,300, consisting of 3 hundred-thousand bills, 3 ten-thousand bills, 4 one-thousand bills, and 3 one-hundred coins, ma'am. I rounded up from the number 64, ma'am.*

Lecturer : *For point c, why did you choose May 25, 2024?*

Student C : *When I looked at the table, the exchange rate of the rupiah on May 25, 2024, was higher.*

Lecturer : *Try to examine the presented table in more detail.*

Student C : *Oh, yes, ma'am, I misread it. I thought the date of May 25, 2024, was larger because I was looking at it from top to bottom. I assumed that the exchange rate for the rupiah would increase as you go down, but it turns out it doesn't. I didn't read the table in detail, ma'am. So, ma'am, the actual answer is on May 21, 2024.*

From the explanation above, it is concluded that student C is capable of solving mathematical literacy problems, but there are errors in several concepts leading to incorrect decisions, as well as a lack of thoroughness in reading the presented questions.

Discussion

Understanding students' mathematical thinking patterns in solving mathematical literacy problems is crucial for improving educational strategies and outcomes. Mathematical literacy involves the ability to apply mathematical knowledge to real-world problems, requiring various cognitive processes and problem-solving strategies. Reflective thinkers exhibit different patterns, such as complete, incomplete, consistent, and inconsistent problem-solving approaches (Kholid, 2022). Key aspects of mathematical thinking include reasoning, abstraction, symbolization, and representation. Students often use prior knowledge and concepts to solve problems, with abstraction evident when they identify patterns (Susanti, 2023). The process of correcting mathematical understanding errors involves reminding students of relevant concepts, documenting known information, and using examples to clarify variables (Hapsari et al., 2022; Sari et al., 2023). Students demonstrate relational thinking when solving mathematical literacy problems, showing a structured approach to understanding relationships between concepts (Pratama, 2020). Rewriting standard word problems to introduce uncertainty about the outcome can benefit student performance and understanding by requiring explicit reasoning about the mathematical context (Kirkland & McNeil, 2021).

Thus, students' mathematical thinking patterns in solving mathematical literacy problems are influenced by cognitive development, cognitive styles, and problem-solving strategies. Key aspects such as reasoning, abstraction, and representation play a crucial role, while empirical and visual thinking necessitate significant representation. Reflective and impulsive cognitive styles lead to different phases of problem-solving, and error correction patterns enhance understanding. Relational thinking and problem-solving styles also significantly impact the level of mathematical literacy. Understanding these patterns can help educators adapt their teaching methods to improve students' mathematical literacy skills.

The findings of this research have several important implications for mathematics education in higher education:

1. Emphasis on Conceptual Understanding
   Given the importance of conceptual thinking in mathematical literacy (Iruntyasari et al., 2024), mathematics education in higher education should place greater emphasis on developing students' conceptual understanding. This can be achieved through: the use of student-centered learning approaches, such as inquiry-based learning or problem-based learning (Larmer et al., 2015); the integration of activities that encourage exploration, discovery, and discussion of mathematical concepts; and the provision of questions and tasks that challenge students to explain, justify, and generalize their understanding (Schoenfeld, 2016a).
2. The balance between Procedure and Concept
   Although procedural thinking is important in solving mathematical problems, mathematics education at the university level must balance the emphasis on both procedures and concepts. Strategies that can be employed include: teaching procedures within the context of meaningful problem-solving (Handal & Herrington, 2003); encouraging students to question, analyze, and justify the procedures they use

(Morrison et al., 2010); integrating tasks that require flexibility in selecting and applying appropriate procedures.

3. Utilization of Visual Representation
   The use of various visual representations in teaching, such as graphs, diagrams, or physical models (OECD, 2022b). Encouraging students to produce, interpret, and connect visual representations (Rau, 2017). Integrating technology that supports the visualization and exploration of mathematical concepts (Lestari, 2019).

The findings of this research also have significant implications for the development of teaching materials and mathematical literacy questions in higher education:

1. Teaching Material Design that Supports Various Mindsets: Mathematical teaching materials should be designed to accommodate and support diverse student mindsets. This can be achieved through: presenting mathematical concepts through various representations, such as verbal, visual, or symbolic (Morrison et al., 2010); integrating tasks and questions that encourage the use of conceptual, procedural, intuitive, and visual thinking (Lithner, 2003); and providing examples and exercises that connect mathematical concepts with real-world situations or meaningful contexts.
2. Development of Authentic Mathematical Literacy Questions: The mathematical literacy questions developed should be authentic and reflect real-world challenges (Musaad et al., 2023). Effective characteristics of these questions include: realistic contexts relevant to students' lives (Dahliani, 2015), complexity that requires the integration of various concepts and mathematical skills (Schoenfeld, 2016a), opportunities to use various strategies and representations in problem-solving (Lesh et al., 2010), and openness that encourages multiple solutions or interpretations (Gravemeijer et al., 2017).

Conclusion

Based on the research results on students' mathematical thinking patterns in solving mathematical literacy problems, it can be concluded that students' mathematical thinking patterns are influenced by various factors, such as cognitive development, cognitive styles, and problem-solving strategies. Key aspects like reasoning, abstraction, and representation play an important role in mathematical literacy.

The findings of this research have implications for mathematics learning in higher education, specifically: Emphasizing conceptual understanding through student-centered learning approaches, exploratory activities, and challenging questions; Balancing procedures and concepts by teaching procedures within the context of meaningful problem-solving and encouraging flexibility in choosing appropriate procedures; and Effectively using visual representations through various teaching methods and encouraging students to produce, interpret, and connect visual representations.

Implications also exist for the development of teaching materials and mathematical literacy questions in higher education, including: Designing teaching materials that support and accommodate various student mindsets through the presentation of mathematical concepts in multiple representations and the integration of tasks that encourage diverse thinking styles; and Developing authentic mathematical literacy questions with realistic contexts, complexities requiring the integration of various concepts and skills, and opportunities to use multiple strategies and representations in problem-solving. According to these implications, lecturers and curriculum developers can design more effective mathematics learning and teaching materials to support the development of students' mathematical literacy in higher education.

Declarations

Author Contribution	:	NH: Resources, Data Curation, Writing – Review & Editing, Funding Acquisition. DA: Supervision, Validation. IZ: Supervision, Validation. ED: Supervision, Conceptualization ES: Supervision, Conceptualization
Conflict of Interest	:	The authors declare no conflict of interest.
Additional Information	:	Additional information is available for this paper.

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