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Students' Mathematical Creative Thinking and Learning Obstacles in Solving Ill-Structured Exponential Problems

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Abstract. *Mathematical creative thinking (MCT) is crucial for equipping students to solve complex, real-world problems. However, students frequently encounter difficulties with non-routine tasks that require divergent thinking. This study investigates students' MCT and identifies their learning obstacles when solving ill-structured exponential problems. A qualitative descriptive approach under the Didactical Design Research (DDR) framework was employed, involving seven high school students from high, medium, and low achievement levels. Data were gathered through tests and semi-structured interviews, analyzing four MCT indicators: fluency, flexibility, originality, and elaboration. Results showed that students predominantly struggled with fluency and flexibility, often depending on a single method and facing difficulty in generating diverse representations. Originality was restricted by reliance on routine classroom procedures, whereas elaboration, despite being relatively stronger, occasionally led to incorrect conclusions. Identified learning obstacles (didactical, ontogenetic, and epistemological) stemmed from an instructional emphasis on procedural tasks, foundational conceptual misunderstandings, and rigid mathematical perceptions. Ill-structured tasks proved effective in revealing hidden learning obstacles that are often overlooked in routine activities. The study highlights the significance of regularly integrating ill-structured problems into mathematics instruction to foster creativity and address underlying learning challenges.*

Keywords*: mathematical creative thinking abilities, learning obstacles, ill-structured problems, exponential, didactical design research*

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Introduction

Mathematics is more than a tool for computation; it is a structured language for interpreting patterns, analyzing data, and solving complex real-world problems through abstraction and reasoning (Brady et al., 2015; Brousseau, 2002). Through modeling, mathematics becomes applicable to daily life, such as interpreting financial growth, environmental changes, or social phenomena. However, students' ability to use mathematics meaningfully depends heavily on how it is taught, particularly through problems that demand analysis beyond rote procedures (Kohen, 2025; Siller et al., 2023). These needs call for the integration of authentic, open-ended problem contexts in mathematics instruction.

One key component for engaging with such contexts is mathematical creative thinking (MCT), which plays a central role in equipping students to face unfamiliar and non-routine tasks.

MCT refers to the capacity to formulate novel, flexible, and elaborated mathematical solutions (Johar et al., 2023; Suherman & Vidákovich, 2022). Khalil (2024) emphasizes that creative thinking not only enhances conceptual understanding but also develops adaptive strategies to solve real-world problems. Furthermore, Santos-Trigo (2024) suggests that nurturing creativity in mathematics supports the formation of problem-solving habits critical for innovation in STEM disciplines. As such, MCT must become an integral part of both learning goals and classroom assessment.

The theoretical foundation of MCT is based on Guilford's (1967) theory of divergent thinking, as extended by Torrance (2011), which outlines four key indicators: fluency, flexibility, originality, and elaboration. These indicators are not isolated traits but interact dynamically to support creative mathematical cognition (Liu et al., 2024; Suherman & Vidákovich, 2022). Fluency enables students to generate multiple ideas, flexibility allows them to shift perspectives or strategies, originality supports the construction of novel models, and elaboration enhances the depth of reasoning. When embedded in classroom learning, these skills provide a foundation for approaching complex and uncertain mathematical situations.

One mathematical concept that aligns naturally with these indicators is exponential growth and decay. Exponential functions allow students to model diverse phenomena, from compound interest to viral transmission and material shrinkage (Budinski, 2020; Mahato et al., 2024). Magaletto (2021) demonstrated that exponential modeling in realistic classroom contexts significantly improved students' engagement and analytical reasoning. Similarly, Kohen (2025) and Siller et al. (2023) found that using authentic exponential modeling tasks fostered students' mathematical sense-making and creativity. These findings suggest that exponential contexts are fertile ground for cultivating MCT, especially when delivered through open-ended or ill-structured tasks.

Ill-structured problems (ISPs), by definition, do not offer clear goals, data, or solution paths, making them ideal for stimulating creative thought and revealing deeper cognitive processes (Cho & Kim, 2020; Simon, 1973). Unlike well-structured problems, ISPs require students to make assumptions, interpret ambiguity, and construct their models, a process that demands flexible and original thinking. Research indicates that students frequently struggle with ISPs due to limited exposure and an over-reliance on procedural routines (Schukajlow et al., 2023). Nonetheless, when guided properly, ISPs help develop abstraction, metacognition, and conceptual understanding, particularly in topics like exponential functions (Hong & Kim, 2016).

Despite these benefits, the use of ISPs in Indonesian classrooms remains limited, and few studies have directly examined how students apply MCT in solving exponential problems framed as ISPs. Moreover, learning obstacles, classified as ontogenetic, didactic, and epistemological, may further hinder students' creative performance (Suryadi, 2019). For example, a lack of foundational knowledge (ontogenetic), poor instructional sequencing (didactic), or rigid concept images (epistemological) can prevent students from expressing ideas in novel ways (Kusumanegara, 2024). As Santos-Trigo (2024) and Suherman Vidákovich (2022) emphasize, overcoming these barriers is key to fostering meaningful mathematical learning and creativity.

Therefore, this study aims to investigate the mathematical creative thinking and learning obstacles faced by high school students when solving ill-structured problems in exponential contexts. Using the Didactical Design Research (DDR) framework, this research aims to contribute both theoretically and practically by expanding the literature on creativity-based instruction and providing strategies for overcoming cognitive and instructional obstacles that hinder students' full mathematical potential.

Method

This study employed a qualitative descriptive approach embedded within the Didactical Design Research (DDR) framework, aiming to investigate students' MCT and the learning obstacles they face when solving ill-structured problems (ISPs) in the context of exponential functions. The DDR model, developed by Suryadi (2019), is especially effective in designing and analyzing learning situations by anticipating students' difficulties and constructing didactical interventions. It integrates practical teaching experiments with theoretical reflection, thus supporting a cyclical and adaptive process suitable for addressing complex educational phenomena (Brousseau, 2002; Prediger et al., 2015).

The research subjects were tenth-grade high school students in the Bandung area who had previously studied exponents. Subjects were selected using purposive sampling. Purposive sampling techniques are commonly used in qualitative approaches to select participants who represent a variety of responses and provide in-depth, informative insights, as affirmed by Palinkas et al. (2015) in an implementation-based qualitative study. The specific criteria used were having studied exponents and being able to provide varied and analyzable responses. Of 40 students who took the test, 23 submitted partial or complete answers, while 17 gave blank responses. After data reduction, seven students were selected to represent high (1 student: HA), medium (2 students: MZ and MH), and low (4 students: LR, LA, LL, and LT) performance categories. The initial letters of the pseudonyms (high, medium, low) reflect these categories for ease of reference. The selection was based on the representativeness of responses, solution diversity, and MCT scores (see Table 2).

Two primary instruments were used: (1) an ill-structured problem set and (2) a semi-structured interview guide.

a. Ill-Structured Problem (ISP)

The main problem consisted of a descriptive scenario involving two camphor balls (green and red) placed in the same environment. The scenario is as follows:

"*Two camphor balls - green and red - both cylindrical, are placed in the same room at the same time. The green ball has a radius of 8 mm and a height of 4 mm, while the red one has a radius of 32 mm and a height of 8 mm. Every 15 days, the green camphor's radius and height shrink to half, while the red camphor's radius and height shrink to a quarter. However, environmental factors such as humidity and temperature may affect the rate of shrinkage, which may be faster or slower depending on the room conditions.*"

Based on this core scenario, four questions were developed to assess MCT indicators:

1) Fluency: Students were asked to write three exponential expressions based on the shrinkage of radius and height after 75 days.
2) Flexibility: Students were asked when the height ratio between the green and red camphor would be 4:1 or 8:1. Each student received slightly different ratios to vary the question.
3) Originality: Students were asked to develop a mathematical model that represents the shrinkage of radius and height, incorporating environmental variables such as humidity.
4) Elaboration: Students evaluated a given statement about the volume of the green camphor on day 60 and were asked to explain their reasoning in detail.

b. Semi-Structured Interview Guide

The interview was used to gain deeper insight into students' reasoning and difficulties. This qualitative interview technique has been shown to reveal deeper layers of cognitive obstacles, such as concept image gaps or instructional misalignments (Sfard, 2008). The interview protocol aimed to identify possible ontogenetic, didactic, and epistemological obstacles that students face in expressing their MCT. Sample questions included:

1) "*How did you feel when you first saw the problem? Were there any parts you found confusing?*"
2) "*What did you think or do when you didn't know how to start solving the problem*?"
3) "*What do you think is the best way to solve a problem like this?*"

Students' responses were scored using a rubric adapted from Fitriani and Yarmayani (2018). Such scoring models are widely used in mathematical creativity research for their clarity and alignment with theoretical constructs (Leikin & Levav-Waynberg, 2008). The detailed scoring criteria are presented in Table 1. The data were collected using 1) written tests with ISP and WSP formats to analyze students' creativity and concept understanding, 2) semi-structured interviews, and 3) observations using learning materials, students' notes, and their prior knowledge.

Table 1 . Rubric for assessment of MCT

No	Indicator	Score	Criteria
1	Fluency	3	Provides 3 correct and distinct exponential expressions.
		2	Provides 2 correct exponential expressions.
		1	Provides 1 correct exponential expression.
		0	No answer or all answers incorrect.
2	Flexibility	3	Solves using two different and correct methods.
		2	Uses two methods, but one is incorrect or nearly identical.
		1	Uses only one method.
		0	No clear method fails to solve the problem.
3	Originality	3	Presents a unique model with logical assumptions and relevant environmental factors.
		2	Uses a standard model with minor originality; includes assumptions but lacks novelty.
		1	Replicates known model formats with minimal explanation or creativity.
		0	No model is presented or simply copied from the problem.
4	Elaboration	3	Gives a detailed explanation of steps (shrinkage, substitution, interpretation of volume).
		2	Nearly correct but lacks completeness or includes minor errors.
		1	Incorrect answer but shows partial conceptual understanding.
		0	No explanation or just a final answer without reasoning.

The analysis included descriptive analysis, identification of learning obstacles, and validation through triangulation. Obstacles were categorized as (a) ontogenetic, cognitive limitations caused by task difficulty not matching students' developmental readiness; (b) didactic: instructional issues like sequencing or presentation that hinder conceptual continuity; and (c) epistemological: students' limited understanding bound to a specific context due to prior learning experience. Validation involved cross-checking written responses, interview data, and classroom observations to ensure conceptual consistency. Triangulation aimed to ensure that findings were valid and useful for informing effective learning strategies aligned with the study objectives.

Results and Discussion

This section presents findings aligned with the research objectives, focusing on students' MCT and the learning obstacles they encountered. The discussion is organized into two parts: MCT, based on four creativity indicators, and learning obstacles, categorized into three types.

Students' Mathematical Creative Thinking (MCT)

Students' MCT was assessed using four indicators and evaluated across seven students with varying achievement levels (see Table 2). HA, categorized as high, showed strong flexibility and originality; MH and MZ, classified as medium, demonstrated elaboration but lacked fluency and method variation. The remaining students fell into the low category, marked by incomplete answers and conceptual weaknesses.

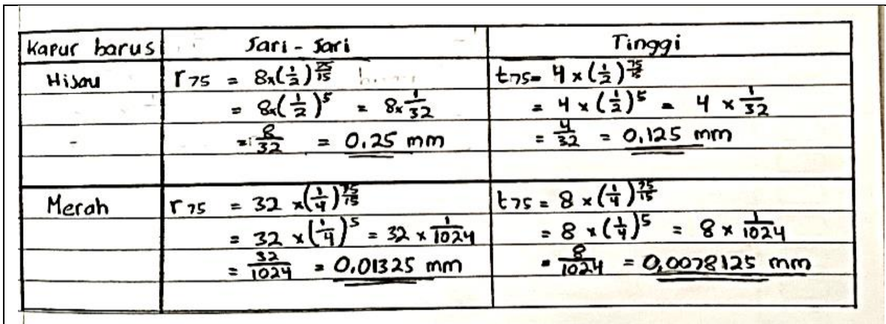
Table 2. Students' MCT scores by indicator

No	Name	Fluency	Flexibility	Originality	Elaboration	Average
1	HA	1	2	3	2	2,0
2	MH	1	1	1	3	1,5
3	MZ	0	1	2	3	1,5
4	LR	0	0	0	-	0
5	LA	0	0	0	0	0
6	LL	0	-	-	0	0
7	LT	0	-	-	-	0

Notably, elaboration was the strongest indicator overall, likely due to its alignment with previously learned procedural content. The next section discusses each indicator in detail, starting with fluency.

Mathematical Creative Thinking Abilities – Fluency Indicator

The fluency indicator assesses students' ability to generate multiple correct mathematical expressions accurately and efficiently. In this task, students were asked to give three exponential expressions representing camphor shrinkage after 75 days. However, none achieved full marks. Even high-achieving students like HA and MH gave correct calculations but did not follow the required exponential form, suggesting a misinterpretation of the instructions, as illustrated in Figure 1.



Kapur barus	Jari - Jari	Tinggi
Hijau	$r_{75} = 8 \times \left(\frac{1}{2}\right)^{\frac{75}{15}}$	$t_{75} = 4 \times \left(\frac{1}{2}\right)^{\frac{75}{15}}$
	$= 8 \times \left(\frac{1}{2}\right)^{5} = 8 \times \frac{1}{32}$	$= 4 \times \left(\frac{1}{2}\right)^{5} = 4 \times \frac{1}{32}$
	$= \frac{8}{32} = 0{,}25$ mm	$= \frac{4}{32} = 0{,}125$ mm
Merah	$r_{75} = 32 \times \left(\frac{1}{4}\right)^{\frac{75}{15}}$	$t_{75} = 8 \times \left(\frac{1}{4}\right)^{\frac{75}{15}}$
	$= 32 \times \left(\frac{1}{4}\right)^{5} = 32 \times \frac{1}{1024}$	$= 8 \times \left(\frac{1}{4}\right)^{5} = 8 \times \frac{1}{1024}$
	$= \frac{32}{1024} = 0{,}01325$ mm	$= \frac{8}{1024} = 0{,}0078125$ mm

Camphor	Radius	Height
Green	$r_{75} = 8 \times \left(\frac{1}{2}\right)^{\frac{75}{15}}$ $= 8 \times \left(\frac{1}{2}\right)^{5} = 8 \times \frac{1}{32}$ $= \frac{8}{32} = 0{,}25\, mm$	$t_{75} = 4 \times \left(\frac{1}{2}\right)^{\frac{75}{15}}$ $= 4 \times \left(\frac{1}{2}\right)^{5} = 4 \times \frac{1}{32}$ $= \frac{4}{32} = 0{,}125\, mm$
Red	$r_{75} = 32 \times \left(\frac{1}{4}\right)^{\frac{75}{15}}$ $= 32 \times \left(\frac{1}{4}\right)^{5} = 32 \times \frac{1}{1024}$ $= \frac{32}{1024} = 0{,}01325\, mm$	$t_{75} = 8 \times \left(\frac{1}{4}\right)^{\frac{75}{15}}$ $= 8 \times \left(\frac{1}{4}\right)^{5} = 8 \times \frac{1}{1024}$ $= \frac{8}{1024} = 0{,}0078125\, mm$

Figure 1. Responses of HA and MH to the fluency indicator task and their translations

Low-performing students struggled more fundamentally. Some, like LR and LT, misunderstood key concepts such as radius or exponent notation, while others admitted to copying answers or leaving the item blank. Their responses revealed minimal engagement and limited understanding of exponential reasoning.

These results echo Guilford's (1967) view that fluency requires both idea generation and appropriate representation and align with Suherman and Vidákovich (2022), who emphasized that mathematical fluency involves producing varied, structured responses. Overall, students' limited experience with expressive, open-ended tasks hindered their ability to articulate multiple valid solutions, highlighting a need for instruction that emphasizes modeling and multiple representations.

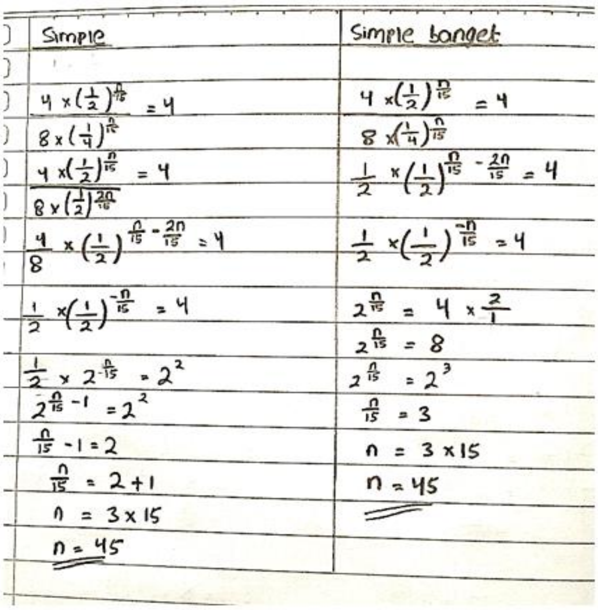
The findings suggest that students' low fluency may stem not only from content gaps but also from instructional practices that prioritize fixed methods over exploratory thinking. As noted by Leikin and Levav-Waynberg (2008), exposure to multiple-solution tasks is crucial for developing the ability to express ideas diversely. Without opportunities to experiment with representations, students tend to rely on familiar procedures rather than explore alternative forms. This rigidity in expression highlights the importance of designing tasks that explicitly encourage divergent thinking, a key aspect closely connected to the next indicator: flexibility.

Mathematical Creative Thinking Abilities – Flexibility Indicator

According to Torrance, as cited in Yulianti et al. (2025), flexibility refers to the ability to remain open to various ideas and approaches. In this study, the flexibility indicator was assessed by asking students to determine when the height ratio between the green and red camphor would become 4:1, using two different solution methods.

None of the students successfully provided two distinct methods. HA attempted two approaches (see Figure 2), but further analysis revealed that both used the same underlying structure, with the second merely being a simplified version of the first. When asked whether the two methods differed, HA responded: "*The answer is similar, but the first method is longer. The second one is just more concise. As for other methods, I was confused, ma'am… I only know this way*." HA was then guided to attempt an alternative approach using a table of values but expressed unfamiliarity with this strategy, stating that such methods were uncommon in their school experience, which often emphasized direct modeling. This response reflects a tendency to rely on procedural knowledge rather than explore alternative pathways.

Meanwhile, MH and MZ each provided only one method but used different strategies (see Figures 3 and Figure 4). MH employed logarithmic reasoning, while MZ compared exponential bases to evaluate the same ratio. Although each student offered a single solution, their approaches demonstrated potential flexibility.



Simple

$$\frac{4\times\left(\frac{1}{2}\right)^{\frac{n}{15}}}{8\times\left(\frac{1}{4}\right)^{\frac{n}{15}}}=4$$

$$\frac{4\times\left(\frac{1}{2}\right)^{\frac{n}{15}}}{8\times\left(\frac{1}{2}\right)^{\frac{2n}{15}}}=4$$

$$\frac{4}{8}\times\left(\frac{1}{2}\right)^{\frac{n}{15}-\frac{2n}{15}}=4$$

$$\frac{1}{2}\times\left(\frac{1}{2}\right)^{-\frac{n}{15}}=4$$

$$\frac{1}{2}\times 2^{\frac{n}{15}}=2^2$$

$$2^{\frac{n}{15}-1}=2^2$$

$$\frac{n}{15}-1=2$$

$$\frac{n}{15}=2+1$$

$$n=3\times 15$$

$$n=45$$

Simpler

$$\frac{4\times\left(\frac{1}{2}\right)^{\frac{n}{15}}}{8\times\left(\frac{1}{4}\right)^{\frac{n}{15}}}=4$$

$$\frac{1}{2}\times\left(\frac{1}{2}\right)^{\frac{n}{15}-\frac{2n}{15}}=4$$

$$\frac{1}{2}\times\left(\frac{1}{2}\right)^{-\frac{n}{15}}=4$$

$$2^{\frac{n}{15}}=4\times\frac{2}{1}$$

$$2^{\frac{n}{15}}=8$$

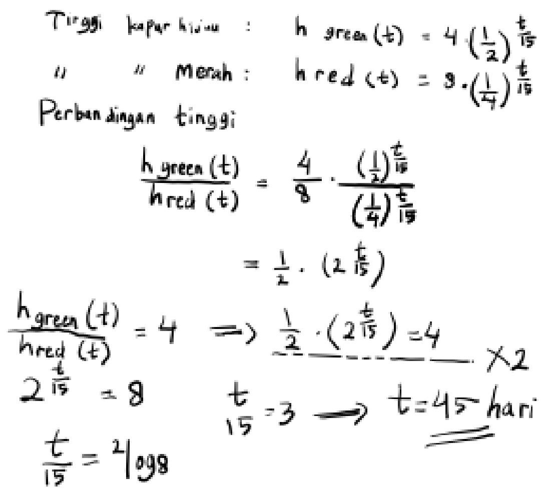
$$2^{\frac{n}{15}}=2^3$$

$$\frac{n}{15}=3$$

$$n=3\times 15$$

$$n=45$$

Figure 2. HA’s response to the flexibility indicator problem and its translation



Green lime height: $h_{green}(t)=4\cdot\left(\frac{1}{2}\right)^{\frac{t}{15}}$

Red lime height: $h_{red}(t)=8\cdot\left(\frac{1}{4}\right)^{\frac{t}{15}}$

High Ratio

$$\frac{h_{green}(t)}{h_{red}(t)}=\frac{4}{8}\cdot\frac{\left(\frac{1}{2}\right)^{\frac{t}{15}}}{\left(\frac{1}{4}\right)^{\frac{t}{15}}}=\frac{1}{2}\cdot(2)^{\frac{t}{15}}$$

$$\frac{h_{green}(t)}{h_{red}(t)}=4\rightarrow\frac{1}{2}\cdot\left(2^{\frac{t}{15}}\right)=4\mid\times 2$$

$$2^{\frac{t}{15}}=8$$

$$\frac{t}{15}=\log_2 8$$

$$\frac{t}{15}=3$$

$$t=45\ day$$

Figure 3. MH's response to the flexibility indicator problem and its translation

MH, in particular, acknowledged that finding a second method only occurred after fully understanding the first: “*To be honest, thinking of another method only came after I understood the first one. If I don't get the first method yet, I won't know where to begin with another. And there wasn't much time during the test*.” This supports the findings of Ningrum et al. (2023), who reported that deeper conceptual understanding often precedes the generation of alternative problem-solving strategies.

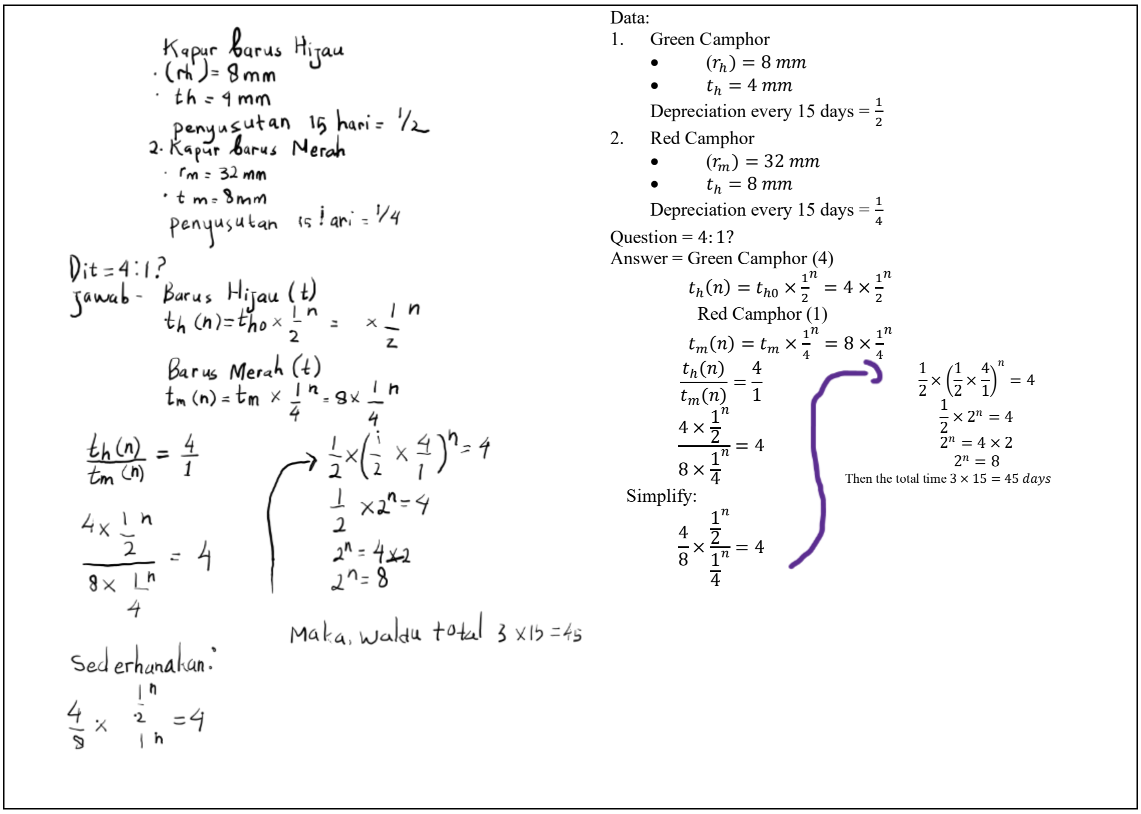


Figure 4. MZ's response to the flexibility indicator problem and its translation

In contrast, students in the low-performance category exhibited significant difficulty. Several misunderstood the ratio, confusing 4:1 with 8:1, while others gave irrelevant or blank responses (see Figure 5). These responses suggest not only a conceptual misunderstanding but also a lack of experience in using varied approaches when solving mathematical problems.

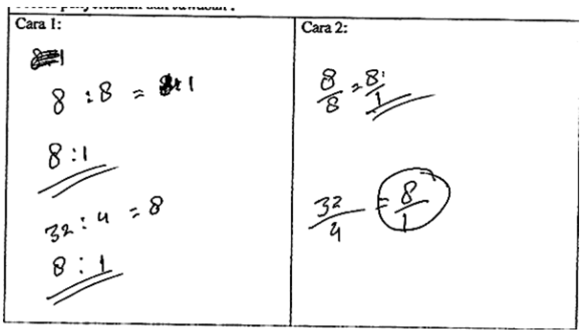
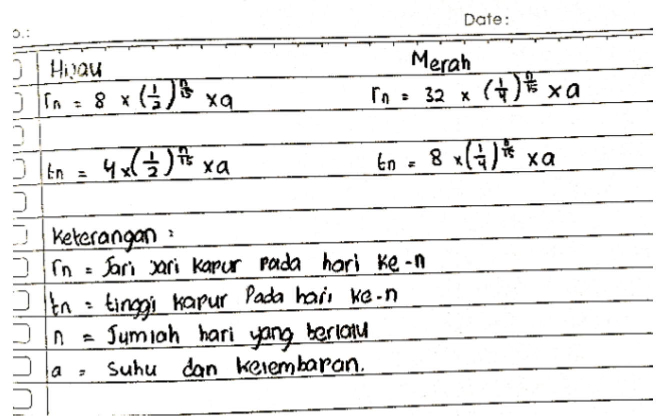


Figure 5. LA's response to the flexibility indicator problem

Overall, students' flexibility in problem-solving was limited by their overdependence on routine procedures and their unfamiliarity with open-ended tasks. This aligns with Schukajlow et al. (2023), who argue that instructional environments must model and encourage alternative strategies to foster cognitive flexibility. Without such experiences, students often lack the initiative and confidence to explore diverse methods, underscoring the importance of promoting flexibility through intentional task design.

Mathematical Creative Thinking Abilities – Originality Indicator

The originality indicator assessed students' ability to construct unique mathematical models that reflect real-world variability, such as environmental factors influencing camphor shrinkage. Among the participants, only HA effectively integrated external elements, such as humidity, demonstrating conceptual independence and contextual awareness (see Figure 6). Her response reflected the kind of innovative mathematical thinking that goes beyond routine application.



Green Red

$r_n = 8 \times \left(\frac{1}{2}\right)^{\frac{n}{15}} \times a$ $r_n = 32 \times \left(\frac{1}{4}\right)^{\frac{n}{15}} \times a$

$t_n = 4 \times \left(\frac{1}{2}\right)^{\frac{n}{15}} \times a$ $t_n = 8 \times \left(\frac{1}{4}\right)^{\frac{n}{15}} \times a$

Information:

$r_n = radius\ of\ camphor\ on\ day\ n$

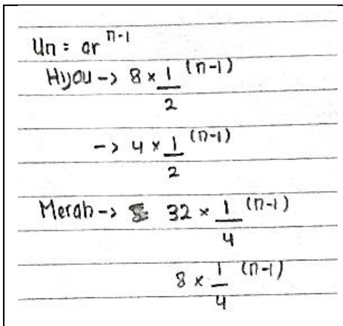
$t_n = height\ of\ camphor\ on\ day\ n$

$n = number\ of\ days\ elapsed$

$a = temperature\ and\ humidity\ factor$

Figure 6. HA's response to the originality indicator problem and its translation

In contrast, most students submitted conventional models replicating classroom examples. For instance, MH used a geometrically valid exponential model but did not justify the selection of constants or include any contextual parameters (see Figure 7). When prompted, MH revised the response but remained focused on the standard procedural structure, indicating limited creative divergence.



$U_n = ar^{n-1}$

Green $\rightarrow\ 8 \times \left(\frac{1}{2}\right)^{n-1}$

$\rightarrow\ 4 \times \left(\frac{1}{2}\right)^{n-1}$

Red $\rightarrow\ 32 \times \left(\frac{1}{4}\right)^{n-1}$

$\rightarrow\ 8 \times \left(\frac{1}{4}\right)^{n-1}$

Figure 7. MH's response to the originality indicator problem and its translation

Low-performing students, including LR, struggled with both the modeling concept and the language of the task (see Figure 8). Some misunderstood the term “model,” while others provided either incomplete or irrelevant responses. These patterns reflect Runco’s notion, cited in Sta. Maria et al. (2022) stated that originality requires not only deviation from the norm but also ownership of one’s ideas. Unfortunately, many students demonstrated dependence on external models or rote memory rather than constructing novel representations.

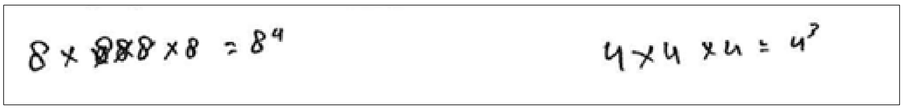


Figure 8. LR's response to the originality indicator problem

The overall findings suggest that students may lack opportunities to engage in creative modeling during regular instruction. Leikin and Levav-Waynberg (2008) argue that originality is best developed through exposure to tasks that invite diverse, personalized responses. Without such practice, students often default to procedural habits, leaving little room for originality to emerge.

Mathematical Creative Thinking Abilities – Elaboration Indicator

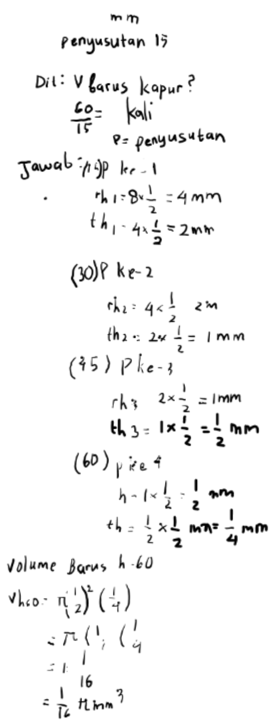
Elaboration refers to the ability to provide detailed and coherent reasoning when explaining mathematical ideas. In this task, students were asked to evaluate whether the given value for the green camphor's volume on the 60th day (after four shrinkage intervals) was accurate. Among the four indicators of MCT, elaboration yielded the highest scores overall.

HA demonstrated an organized approach using the correct exponential model but ultimately reached an incorrect conclusion, answering "False" when the correct answer was "True". Despite this error, her process showed structured reasoning. MH, on the other hand, used the same model and correctly confirmed the result, indicating a strong conceptual understanding. MZ applied a different strategy by calculating the camphor's radius and height at each interval manually, followed by computing the volume using the cylinder formula (see Figure 9). This approach, while more procedural, still demonstrated clear logic and sequential reasoning.

The relative success in elaboration is likely due to the alignment of the task with concepts already encountered in previous learning, such as volume, multiplication, and exponential properties. As a result, students were more confident in articulating their steps, even if some conclusions were flawed. This reflects what Suherman and Vidákovich (2022) describe as the importance of scaffolding in supporting students' ability to explain ideas clearly within familiar mathematical structures.

Conversely, low-performing students struggled to provide coherent explanations. Several expressed confusion about terms like "*day n*" or "*exponential model*," suggesting gaps in both comprehension and exposure to these concepts. For instance, some provided short or disconnected statements, while others left the item blank. These patterns indicate that while elaboration was relatively stronger, it still depended heavily on prior instruction and concept clarity.

In summary, the elaboration indicator revealed that students are more effective at explaining their reasoning when tasks are closely tied to established procedures. However, success in elaboration alone is not sufficient to reflect full mathematical creativity, as it does not necessarily require divergent thinking. This insight connects directly to the broader challenge of integrating both procedural fluency and open-ended reasoning in creative problem solving (Siller et al., 2023; Suherman & Vidákovich, 2022).



Data: $r_h = 8\ mm$

$t_h = 4\ mm$

Depreciation every 15 days $= \frac{1}{2}$

Question: $V_{Camphor}$?

$$\frac{60}{15} = 4\ kali$$

$$p = depreciation$$

Answer: (15) First P

$$r_{h1} = 8 \times \frac{1}{2} = 4\ mm$$

$$t_{h1} = 4 \times \frac{1}{2} = 2\ mm$$

(30) Second P

$$r_{h2} = 4 \times \frac{1}{2} = 2\ mm$$

$$t_{h2} = 2 \times \frac{1}{2} = 1\ mm$$

(45) Third P

$$r_{h3} = 2 \times \frac{1}{2} = 1\ mm$$

$$t_{h3} = 1 \times \frac{1}{2} = \frac{1}{2}\ mm$$

(60) Fourth P

$$r_{h4} = 1 \times \frac{1}{2} = \frac{1}{2}\ mm$$

$$t_{h4} = \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}\ mm$$

The volume of Camphor on the 60th day:

$$V_{h60} = \pi \left(\frac{1}{2}\right)^2 \left(\frac{1}{4}\right)$$

$$= \pi \left(\frac{1}{4}\right)\left(\frac{1}{4}\right)$$

$$= \pi \frac{1}{16}$$

$$= \frac{1}{16} \pi mm^3 \surd$$

TRUE

Figure 9. MZ's response to the elaboration indicator problem and its translation

Cross-Indicator Reflection and Suggestions

The results across all four MCT indicators (fluency, flexibility, originality, and elaboration) reveal distinct patterns in how students engage with ill-structured exponential problems. While each indicator highlights different aspects of creative thinking, a comparative reflection offers a more holistic view of student learning behavior and areas requiring pedagogical attention.

A notable finding is that elaboration emerged as the most accessible indicator for students across all ability levels, likely due to its alignment with previously taught procedural content. In contrast, originality and flexibility posed the greatest challenges, particularly for students accustomed to single-solution tasks. Fluency also remained low, with most students struggling to generate multiple valid representations, a critical component of mathematical creativity, as emphasized by Torrance (2011) and Leikin and Levav-Waynberg (2008).

Across cases, students who performed well in elaboration did not necessarily score high in originality or flexibility. This suggests that procedural strength alone does not ensure creative competence. For instance, while HA displayed strong elaboration and originality, others, such as

MH and MZ, exhibited unbalanced profiles, capable of explanation but limited in generating alternatives or unique models. Such variation reflects a fragmented development of creative thinking skills, influenced by both cognitive readiness and instructional exposure.

This cross-indicator inconsistency highlights the need for instructional strategies that explicitly target creativity across multiple dimensions. Classroom practices should shift beyond focusing on correct answer patterns to encourage divergent thinking, open reasoning, and flexible strategies. According to Schukajlow et al. (2023), creative thinking in mathematics thrives when students regularly engage in non-routine tasks that require interpretation, representation, and reflection. Providing space for such engagement is especially important for students in the low category, who showed both conceptual confusion and expressive hesitation.

In light of these findings, it is recommended that future instructional designs integrate varied solution formats, encourage contextual modeling, and provide guided practice in interpreting open problems. By addressing these cross-indicator gaps, teachers can better support students in developing more balanced and adaptable mathematical thinking.

Students' Learning Obstacles

The results of the study revealed that students' low MCT was influenced not only by cognitive limitations but also by various learning obstacles that occurred during the problem-solving process. These learning obstacles were classified into three types: didactical, ontogenetic, and epistemological, following the theoretical framework proposed by Brousseau (2002) and elaborated by Suryadi (2019). Table 3 summarizes the student errors identified in the tests along with the associated obstacle types.

Table 3. Categorization of student learning obstacles based on their mistakes

Q	Students' Mistakes	D	O	E
1	Students did not present answers as requested (three exponential forms). They only provided final answers in decimal or other forms.	√	√	√
	Lack of understanding of fraction multiplication.	√	√	√
2	Only one method to solve the problem.	√	√	√
	Misunderstood the context of the problem; focused only on numbers given.		√	√
3	Students provided correct answers and could explain them, but an AI system generated the answers.	√	√	√
	Nearly correct answers but did not consider environmental factors.	√	√	√
	Irrelevant answers to the question.	√	√	√
	Misunderstood terms like "day n" and "mathematical model."	√	√	√
4	Correct method but has an incorrect conclusion.		√	√

The following is a detailed description of each type, supported by data and interview responses.

Didactic Obstacles

Didactical obstacles stem from how mathematical material is delivered, the clarity of instruction, and the use or lack of effective learning strategies. In this study, such obstacles were particularly evident in students' unfamiliarity with ill-structured problems (ISP), which require interpretation, exploration, and the construction of multiple solutions. Most students reported that they had never encountered ISP-type tasks in their regular classroom experience.

Student MH illustrated this point clearly, stating:

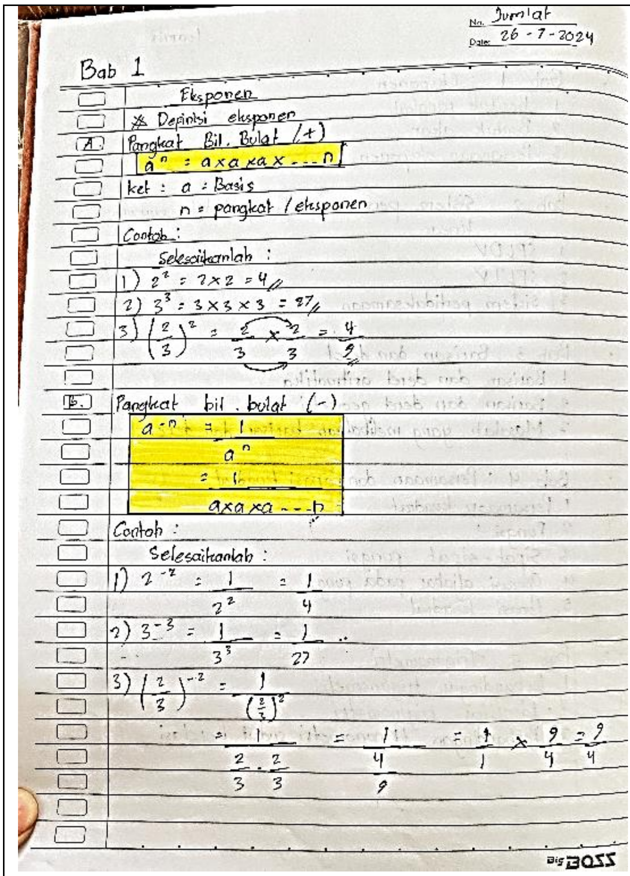
"Luckily, I was helped because I had participated in the Olympiad extracurricular. So, I am accustomed to encountering problems that require thinking before calculation. In class, to be honest, we rarely get questions like this. Usually, it's just plug in the formula and done."

This testimony underscores that familiarity with the problem was not cultivated through regular instruction, but rather through enrichment activities outside the standard curriculum. Further evidence was gathered through analysis of students' notebooks (see Figure 10), which revealed a predominant focus on procedural problem types. Exercises primarily emphasized the direct application of formulas with minimal emphasis on inquiry, interpretation, or modeling. This pattern suggests that the prevailing instructional model was largely example-driven and did not provide structured opportunities to foster mathematical creative thinking.

Although the researcher did not directly observe classroom teaching, triangulated findings from student interviews and written work consistently indicate that instructional practices may not have supported habits of mind necessary for creativity. In particular, students were often unfamiliar with tasks requiring divergent strategies or non-algorithmic reasoning. When asked to solve a problem using two different methods, several students either repeated the same approach in varied forms or skipped the instruction entirely. This behavior may reflect entrenched classroom norms that prioritize efficiency and accuracy over exploration.

These findings are consistent with those of Susanto et al. (2021), who highlighted that many Indonesian mathematics textbooks and teaching practices remain focused on algorithmic routines rather than conceptual understanding or innovation. Moreover, Santos-Trigo (2024) emphasized that without regular engagement in exploratory mathematics, students are unlikely to develop the cognitive flexibility needed for creative problem-solving. The low performance observed in items 1, 2, and 3 of the test instruments, where students were asked to produce alternative models or solution paths, appears heavily influenced by this instructional context.

In essence, the didactical obstacles in this study were not simply about a lack of content, but about how mathematics was framed and experienced. The absence of diverse, exploratory tasks in daily instruction limits students' ability to develop the habits of modeling, interpreting, and expressing mathematics creatively. Addressing these barriers will require deliberate shifts in pedagogy, curriculum materials, and teacher training to support multi-solution thinking and open-ended exploration.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Date: 26 - 7 - 2024

Bab 1

Eksponen

* Definisi eksponen

A. Pangkat Bil. Bulat (+)

$a^n = a \times a \times a \times \ldots n$

ket : a : Basis

n = pangkat / eksponen

Contoh :

Selesaikanlah :

1) $2^2 = 2 \times 2 = 4$

2) $3^3 = 3 \times 3 \times 3 = 27$

3) $\left(\frac{2}{3}\right)^2 = \frac{2}{3} \times \frac{2}{3} = \frac{4}{9}$

B. Pangkat bil. bulat (-)

$a^{-n} = \frac{1}{a^n} = \frac{1}{a \times a \times a \ldots n}$

Contoh :

Selesaikanlah :

1) $2^{-2} = \frac{1}{2^2} = \frac{1}{4}$

2) $3^{-3} = \frac{1}{3^3} = \frac{1}{27}$

3) $\left(\frac{2}{3}\right)^{-2} = \frac{1}{\left(\frac{2}{3}\right)^2} = \frac{1}{\frac{2}{3} \cdot \frac{2}{3}} = \frac{1}{\frac{4}{9}} = \frac{1}{1} \times \frac{9}{4} = \frac{9}{4}$

Exponent

#Definition of exponent

A. Power of an integer (+)

$$\boxed{a^n = a \times a \times a \times \ldots n}$$

Note: a = base

n = powers of numbers/ exponent

Example:

Complete it:

1) $2^2 = 2 \times 2 = 4$

2) $3^3 = 3 \times 3 \times 3 = 27$

3) $\left(\frac{2}{3}\right)^2 = \frac{2}{3} \times \frac{2}{3} = \frac{4}{9}$

B. Power of an integer (-)

$$\boxed{a^{-n} = \frac{1}{a^n} = \frac{1}{a \times a \times a \ldots n}}$$

Example:

Complete it:

1) $2^{-2} = \frac{1}{2^2} = \frac{1}{4}$

2) $3^{-3} = \frac{1}{3^3} = \frac{1}{27}$

3) $\left(\frac{2}{3}\right)^{-2} = \frac{1}{\left(\frac{2}{3}\right)^2} = \frac{1}{\frac{2}{3}\frac{2}{3}} = \frac{1}{\frac{4}{9}} = \frac{1}{1} \times \frac{9}{4} = \frac{9}{4}$

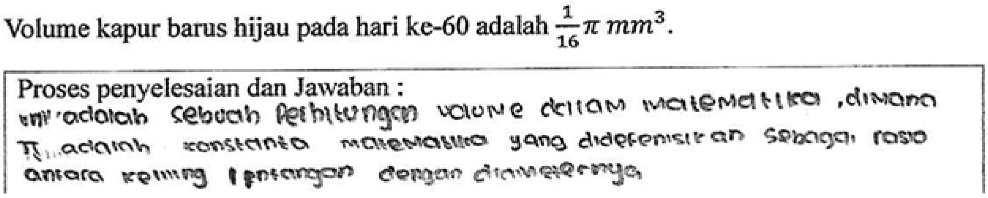
Figure 10. Student notes and translation

Ontogenic Obstacles

These obstacles are linked to students' cognitive development and prerequisite conceptual understanding. In this study, issues included difficulty with multiplication, especially with fractions. For instance, when asked, "*What shape is involved in this question*?", LT hesitated and replied, "Volume." When LR was asked to show the radius, he pointed to the circumference, unsure of the concept. These consistently showed a misunderstanding of basic geometric terms.

LL's confusion is also telling. One of her responses included the symbol π, which she read as "n," indicating a fundamental misunderstanding (see Figure 11). Moreover, LA's attempt to explore another method was hampered by poor arithmetic, as shown in Figure 12. During interviews, these students also revealed limited conceptual understanding and frequent confusion about problem requirements. For example, LT expressed uncertainty regarding how exponential functions work, indicating a gap in the understanding of core mathematical properties. LA mentioned difficulty in interpreting the question structure itself, which impeded the accurate application of relevant mathematical concepts. Such misunderstandings of foundational concepts align closely with observations by Rožman and Vreˇ (2025), who found that unresolved gaps in basic knowledge, established in earlier stages of learning, tend to persist and become more apparent as students encounter increasingly complex mathematical tasks.

These ontogenetic obstacles were particularly problematic when students attempted tasks involving ill-structured problems (ISP), as these types of tasks inherently require students to integrate multiple basic concepts and skills. The gaps in foundational knowledge meant students were unable to effectively transfer previously learned mathematical principles into novel contexts, exacerbating their confusion and uncertainty during problem-solving processes.

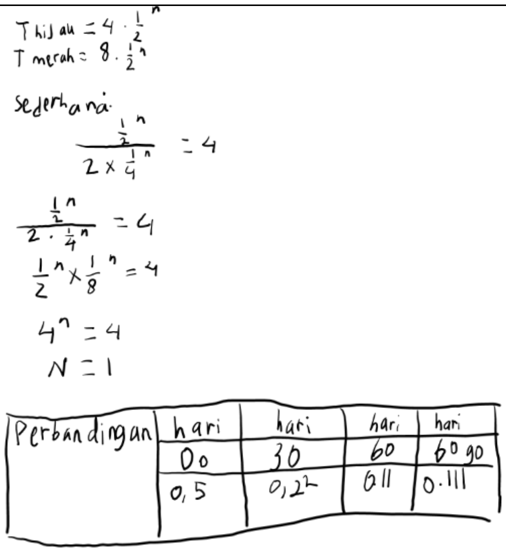

Volume kapur barus hijau pada hari ke-60 adalah $\frac{1}{16}\pi\ mm^3$.

Proses penyelesaian dan Jawaban :
ini adalah sebuah perhitungan volume dalam matematika, dimana π adalah konstanta matematika yang didefenisikan sebagai rasio antara keliling/pasangan dengan diameternya.

The volume of green camphor on the 60th day is $\frac{1}{16}\pi\ mm^3$. (Question)

Process and Final Answer:
This is a calculation of volume in mathematics, in which π is a mathematical constant defined as the ratio of the circumference/pair to its diameter.

Figure 11. LL's response to the problem related to the elaboration indicator and its translation



$$T_{hijau} = 4 \cdot \frac{1^n}{2}$$

$$T_{merah} = 8 \cdot \frac{1^n}{2}$$

Simple

$$\frac{\frac{1^n}{2}}{2 \times \frac{1^n}{4}} = 4$$

$$\frac{\frac{1^n}{2}}{2 \cdot \frac{1^n}{4}} = 4$$

$$\frac{1^n}{2} \times \frac{1^n}{8} = 4$$

$$4^n = 4$$

$$N = 1$$

Comparison	Day	Day	Day	Day
	0,	30	60	60, 90
	0.5	0.22	0.11	0.111

Figure 12. LA's response to the problem related to the flexibility indicator and its translation

Overall, the presence of ontogenetic obstacles highlighted the importance of ensuring conceptual clarity and depth in early mathematical learning stages. Without a robust foundational understanding, students find themselves consistently challenged by more advanced and open-ended tasks. Addressing these underlying issues requires targeted interventions that focus on clarifying core mathematical concepts, which in turn can significantly improve students' ability to engage creatively and confidently with complex mathematical problems.

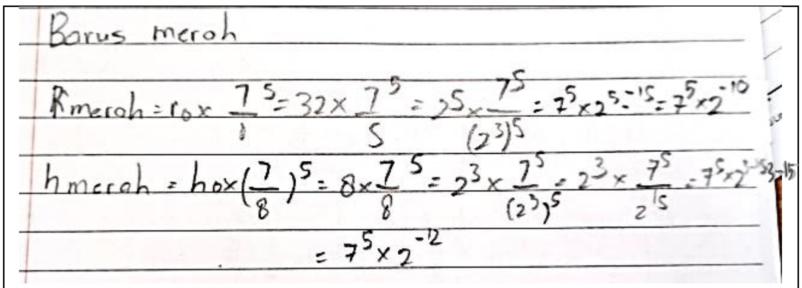
Epistemological Obstacles

Epistemological obstacles pertain to students' fundamental beliefs and conceptions about mathematics, particularly their understanding of the nature and purpose of mathematical reasoning. Many had only learned to use exponent-based models without understanding broader contexts. LL admitted copying answers and was unable to explain exponential shrinkage. LR showed similar confusion. When asked to name a cylindrical object, LR answered, "*LPG Cylinder*", which, does not have a mathematically perfect cylindrical shape. He simply associated the word "*cylinder*".

Middle-performing students, like MH and MZ, also exhibited epistemological gaps. In solving the problem on the 75th day, MH used a ¾ ratio, and MZ used 7/8 (See Figure 13). MH clarified during the interview:

> "*Haha, yeah, I realized I misunderstood. At first, I thought the shrinkage was ¾ because, in the previous question, that part was a bit unclear or missing. But after reading the complete version, I saw that the green one shrinks by ½, and the red one is even more extreme, it shrinks by ¼*".

While MH ultimately submitted a correct answer, his explanation reflected a temporary misunderstanding. MZ, on the other hand, could not explain his reasoning, suggesting a deeper gap. Many students also failed to consider environmental variables, such as temperature and humidity. This indicates limited experience with multi-variable modeling tasks. According to Fuadi et al. (2016), a contextual learning approach can enhance students' mathematical understanding and reasoning.



Red Camphor

$$r_{red} = r_0 \times \frac{7^5}{8} = 32 \times \frac{7^5}{8} = 2^5 \times \frac{7^5}{(2^3)^5} = 7^5 \times 2^{5-15} = 7^5 \times 2^{-10}$$

$$h_{red} = h_0 \times \left(\frac{7}{8}\right)^5 = 8 \times \frac{7^5}{8} = 2^3 \times \frac{7^5}{(2^3)^5} = 2^3 \times \frac{7^5}{2^{15}} = 7^5 \times 2^{3-15} = 7^5 \times 2^{-12}$$

Figure 13. MZ's response to the fluency indicator problem and its translation

The analysis of students' written work reinforced these epistemological constraints. Many responses indicated superficial engagement with mathematical tasks, typically characterized by formulaic repetition and a notable absence of deeper conceptual understanding. Several students provided step-by-step computations that directly mirrored examples from textbooks, without demonstrating an understanding of why specific formulas were appropriate or how to adapt them to new situations. This approach reflected an underlying belief that mathematics is merely about reproducing known methods rather than innovatively engaging with and interpreting complex situations.

Such rigid conceptions align closely with Sfard (2008) perspective, which emphasizes how epistemological beliefs fundamentally shape students' engagement with mathematics. Students who perceive mathematics predominantly as a mechanical activity tend to avoid intellectual risks and are less inclined to generate original or multiple solutions. Similarly, Leikin and Levav-Waynberg (2008) argued that entrenched epistemological views often restrict students' creative potential, as they lack confidence in exploring solutions beyond standard classroom practices.

In sum, addressing epistemological obstacles is not solely about altering teaching methods but involves reshaping students' conceptual frameworks about mathematics itself. Encouraging learners to view mathematics as a dynamic, contextually responsive discipline can greatly enhance their creative and analytical capacities. Instructional strategies that regularly integrate real-world applications, promote multiple-solution tasks and explicitly address students' underlying epistemological beliefs are essential for overcoming these profound conceptual barriers.

The Interrelation between Students' MCT and Learning Obstacles

Findings from this study demonstrate the interconnectedness between students' MCT and the various learning obstacles they encounter. Students' limited performance in critical indicators such as fluency and flexibility was not solely due to individual cognitive limitations but was strongly influenced by deeper instructional and epistemological obstacles.

Didactical obstacles, as articulated by Brousseau (2002), emerge prominently when instructional strategies fail to promote meaningful engagement with mathematics. In this study, the reliance of students on procedural and routine approaches was evident. For instance, MH explicitly mentioned the rarity of encountering non-routine tasks in regular lessons, stating that such problems were typically presented only in extracurricular mathematics competitions, such as Olympiads. This highlights an instructional gap, as classroom teaching often neglects opportunities for students to engage deeply with open-ended tasks that foster creative mathematical reasoning (Suherman & Vidákovich, 2022). However, Beghetto (2019) posits that constraints in learning environments, rather than hindering creativity, can structure and stimulate creative thought. Thus, didactical limitations identified in this study suggest opportunities for restructuring instructional methods to better support creativity.

Furthermore, originality and elaboration were particularly impacted by epistemological obstacles, characterized by fundamental misunderstandings of mathematical concepts. Students exhibited confusion when interpreting variables and applying exponential models to practical contexts. Such misconceptions align closely with Suryadi's (2019) framework, indicating that epistemological barriers often arise from prior learning experiences that constrain students' ability to represent mathematical ideas flexibly.

The interrelation between MCT and learning obstacles is further supported by Guilford's (1967) framework on divergent thinking, which emphasizes the critical roles of fluency, flexibility, originality, and elaboration in creative thinking. Moreover, recent cognitive research by Liu et al. (2024) highlights that divergent thinking involves extensive neural integration across cognitive functions, suggesting that creative thinking makes a significant contribution to broader cognitive development. In other words, developing creative thinking not only addresses immediate learning obstacles but also enhances overall cognitive flexibility and adaptability.

Therefore, effectively addressing these interrelated learning obstacles requires intentional didactical interventions designed to anticipate student difficulties. Approaches such as Didactical Design Research (DDR), as advocated by Suryadi (2019), offer structured yet flexible frameworks that can systematically nurture mathematical creativity. Ultimately, recognizing and addressing the close relationship between creative thinking abilities and learning obstacles is essential for fostering comprehensive and meaningful mathematical understanding among students.

Conclusion

This study revealed varied student abilities in MCT across four indicators: fluency, flexibility, originality, and elaboration when solving ill-structured exponential problems. Although some students demonstrated promising performance, none excelled in all indicators. Fluency and flexibility posed particular challenges, as students often relied on single approaches and struggled with multiple representations. Originality was constrained by habitual dependence on familiar classroom models, while elaboration, though stronger, was sometimes marred by incorrect conclusions.

The study also identified key learning obstacles (didactical, ontogenetic, and epistemological) that impacted students' creativity. Didactical obstacles emerged from instructional practices emphasizing procedural routines over exploratory tasks. Ontogenetic obstacles reflected foundational misunderstandings of exponential and geometric concepts. Epistemological obstacles arose from rigid views of mathematics, limiting contextual interpretations and real-world connections.

Ill-structured problems proved effective for diagnosing creative thinking and revealing learning barriers often hidden by routine exercises. These findings emphasize the need for instructional strategies encouraging exploration, multiple solutions, and contextualized mathematical tasks. Future research should investigate the impact of sustained exposure to ISP-based learning environments on enhancing MCT and reducing learning obstacles across diverse student populations.

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