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Creative Thinking Process of Prospective Mathematics Teacher Students in Solving Numerical Problems

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Abstract

Background/purpose. Creative thinking is an essential 21st-century skill in mathematics education, closely connected to logical-mathematical ability. Solving numerical problems requires students to think systematically, flexibly, and deeply beyond technical skills. In this context, the creative thinking process remains underexplored empirically. Therefore, this research aims to describe and visualize the stages of students' creative thinking in solving numerical problems.

Materials/methods. This research used a quantitative-descriptive and qualitative phenomenological method to investigate the creative thinking process. Category development was achieved through a combined concept-driven and data-driven process. The subjects were students in the Mathematics Education Research Program at Muhammadiyah University of Purwokerto, Indonesia. Students selected had taken courses relevant to numerical problems, namely the methods course.

Results. Students' creative thinking process in solving numerical problems reflected an integration of logical-mathematical intelligence skills across all stages from preparation in understanding the problem, incubation in planning, to illumination in generating strategic ideas. In the formulation and verification stages, students exhibited systematic thinking. However, limited alternative exploration and critical evaluation reduced the overall solution efficiency. These results emphasized the importance of instructional methods that promoted cognitive flexibility and metacognitive reflection throughout each stage of the creative thinking process.

Conclusion. The development of students' creative thinking in solving numerical problems required strong logical-mathematical intelligence, alternative solution exploration, and intensive metacognitive training. The results showed that curriculum design could balance theoretical and practical aspects to enhance cognitive flexibility, strengthen conceptual mastery, and support the formulation of creative numerical solutions.

1. Introduction

Creative thinking is the most important 21st-century skill in mathematics education. Beyond education, human creativity is expected to shape the ecology of the mind, expand the boundaries of thinking, and find new methods to understand and interact with the world (Malafouris, 2014). Creativity is the ability of an individual to generate new theories or knowledge through conscious and unconscious thinking processes that underlie scientific discovery, artistic originality, and inspiration (Sitorus and Masrayati, 2016; Gunawan, 2025). The process includes the recurring and dynamic stages of preparation, incubation, illumination, and verification (Wallas, 1962; Sawyer, 2021). In the context of learning mathematics, creative thinking has an important role in solving complex numerical problems. Mumford prioritizes three relevant assumptions, namely (1) Creative problem-solving requires the production of high-quality, original, and elegant solutions to complex, new, and ambiguous issues, (2) Problem-solving requires knowledge or skills, and (3) Similar processes depend on innovative thinking in most domains of effort, regardless of the different understanding requirements, pressures, weights, and procedures imposed by different performance sectors (Mumford et al., 1991; Mumford & McIntosh, 2017). Creative thinking process allows students to determine innovative and effective solutions through different linear methods.

Solving numerical problem often requires more than technical skills. A thinking process, including exploration, in-depth analysis, and synthesis of information, is needed to produce solutions. This shows that the creative thinking process has an important position in solving mathematical problems (Daiana, Surahmat, and Fathani, 2021). Therefore, creative thinking is considered a prerequisite for the growth of problem-solving skills (Talib, 2021). The process by which students engage in creative thinking when solving numerical problems remains a compelling subject for further research. A limited investigation specifically examines the dynamics in a numerical context as well as the practical challenges of connecting abstract concepts to real applications. This is important to understand when designing strategies to promote the development of creative thinking.

The creative thinking process of students in solving numerical problems should reflect systematic and patterned stages. Creativity in mathematics is conceptualized as a product-oriented, dynamic, and discipline-specific construct (Bicer, 2024). The ability closest to creativity is probably intelligence (Simonton, 2018). The creative thinking process requires a deep understanding of adapting to various problems (Akhsani et al., 2022). Many students have difficulty following the stages of the creative thinking process optimally. Students are often trapped in a linear mindset and are less able to explore alternative solutions in depth. Enjoyment in the learning process can be an important factor in supporting the development of creative ideas in mathematics (Sitar et al., 2016).

Previous research has examined the relationship between mathematical and logical intelligence, learning experiences, and teaching methods in the development of creative thinking skills (Hadi et al., 2025; Sospedra-Baeza et al., 2022; Sukmawati et al., 2023; Ureña-Villamizar et al., 2024). However, few investigations have thoroughly examined students' creative thinking processes in relation to mathematical logical ability, using a combination of tests, interviews, and documentation to trace the stages. This gap underscores the need for empirical research exploring the influence of mathematical and logical ability on the stages of creative thinking, thereby providing a more comprehensive understanding and serving as a basis for instructional strategies.

This research aims to describe and visualize the creative thinking process of students in solving numerical problems (Guilford, 2017). The urgency lies in the importance of empirically understanding the dynamics of creative thinking in the context of numerical problems to overcome the gap between theory and practice in mathematics learning within higher education. This understanding provides a theoretical contribution to the development of learning models that promote the creativity of prospective mathematics teachers, as well as practical implications for the design of 21st-century

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learning. The results contribute to the development of effective learning methods that improve the creative thinking process and enrich the literature on creativity. Specifically, several questions are answered, namely: what are the stages of the creative thinking process in solving a numerical problem? And what is the visualization of the creative thinking process in the form of a scheme used as a reference?

2. Literature Review

2.1. Creative Thinking Process

The stages of the creative thinking process have been proposed by several experts, such as Wallas' analysis, which identifies four phases: preparation, incubation, illumination, and verification (Maharani, Sukestiyarno, and Waluya, 2017; Ratnaningsih, 2021). This is not in line with Sitorus's development, which comprises five stages: orientation, preparation, incubation, illumination, and verification (Sitorus & Masrayati, 2016). Creative process focuses on problem definition, information acquisition, concept and case selection, conceptual combination, idea generation and evaluation, implementation planning, and adaptive execution (Mumford & McIntosh, 2017). These stages are analyzed using Sawyer's eight steps of creative thinking. According to Sawyer (2012) and Sawyer (2021), the eight steps include problem determination, knowledge acquisition, related information derivation, incubation, idea generation, combination, selection, and externalization. Gunawan reported that the process consisted of preparation, incubation, estimation, illumination, and verification (Gunawan, 2025). A table was constructed by comparing the creative thinking process with those proposed by other experts.

Table 1. The Creative Thinking Process in This Study as Viewed from Other Experts

Problem-Solving Process Using Numerical Methods (Munir, 2006; Capra, 2015)	Creative Thinking Process (Wallas, 1962)	Creative Thinking Process (Sitorus 2016)	Creative Thinking Process (Mumford 2017	Creative Thinking Process (Sawyer, 2021)	Creative Thinking Process (Gunawan 2025)	Creative Thinking Process in This Study
Modeling	Preparation	Orientation Preparation	Problem Definition Information Gathering	Find the problem Acquire knowledge Gather related information	Preparation	**Preparation**
Simplification	Incubation	Incubation	Concept/ Case Selection Conceptual Combination	Incubation	Incubation	**Incubasi**
	Illumination	Ilumination	Idea Generation	Generate ideas	Estimation Illumination	**Illumination**
Formulation			Idea Evaluation	Combine ideas		**Formulation**
Solution	Verification	Verification	Implementation Planning	Select the best ideas	Verification	**Verification**
Interpretation			Adaptive execution	Externalize ideas		

2.2. Numerical Problem-Solving

The steps of numerical problem-solving are modeling, simplification, numerical formulation, programming, operationalization, and evaluation (Munir, 2006). The stages of problem solving include formulation, solution, and interpretation (Capra, 2015). The difference between the stages and previous research lies in the formulation. Therefore, the creative thinking process has five stages, namely preparation, incubation, illumination, formulation, and evaluation.

2.3. Logical-Mathematical Ability

Logical-mathematical intelligence refers to students' ability to identify and classify objects, perform mathematical calculations, solve problems, think logically and critically, and draw conclusions (Arum, Kusmayadi, and Pramudya, 2018). This type of intelligence includes the ability to calculate, measure, formulate propositions and hypotheses, and carry out numerical operations. The core competencies comprise understanding logical and numerical patterns and processing complex thoughts, with related numeracy, reasoning, logical thinking, and problem-solving (Azinar, Munzir, and Bahrun, 2020). Logical-mathematical intelligence reflects the ability to identify and classify objects, perform mathematical operations, solve problems, engage in logical and critical thinking, and draw inferences. According to Saragih (2019), the characteristics of individuals showing logical-mathematical intelligence include a) an enjoyment of experimenting, asking questions, and assembling puzzles, b) a fondness for and skill in calculating and playing with numbers, c) an interest in organizing and developing scenarios, d) the ability to think inductively and deductively, e) an enjoyment of syllogisms, f) a preference for abstract and symbolic thinking, and g) a habit of collecting objects and keeping records of the collections. Based on the explanation, a conceptual framework is developed to show the relationship between the creative thinking process and logical-mathematical ability.

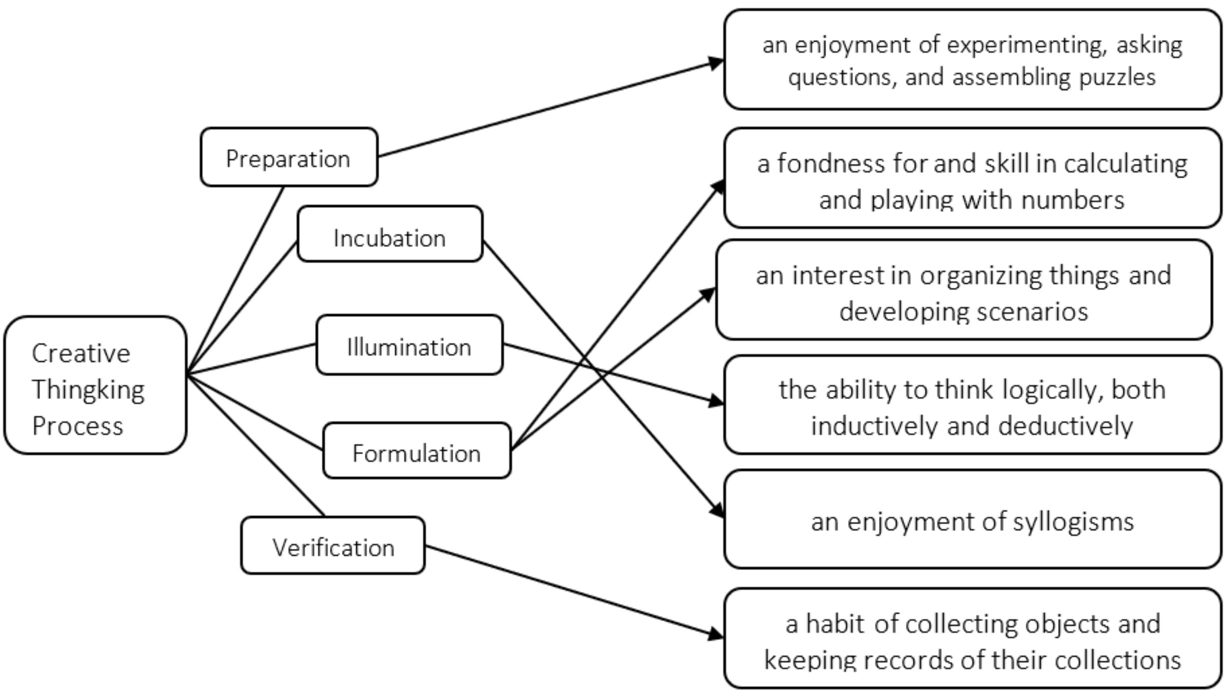

Figure 1. Conceptual Framework Diagram

2.4. Creative Thinking and Neural Problem Solving

The literature on the relationship between brain activity and creative thinking and complex problem solving shows that these variables involve the dynamic cooperation of multiple neural networks. Research on complex problem solving using the Tower of London (TOL) task shows that planning demands more complex brain activity than the execution phase, characterized by a greater number of hubs and stronger interregional connectivity (Alchihabi et al., 2018). Meanwhile, research on mathematical word problems shows that solving arithmetic problems engages the fronto-insular-parietal network, including the intraparietal sulcus (IPS), dorsolateral prefrontal cortex (PFC), and anterior insula (AI). This activation plays a crucial role in constructing mathematical models rather than understanding narrative contexts, showing the inclusion of higher-order cognitive processes (Chang et al., 2019).

Research in the neuroscience of creativity shows that two major brain networks, the Default Mode Network (DMN) and the Executive Control Network (ECN), play central roles in supporting idea generation and evaluation, respectively. Research using Representational Similarity Analysis (RSA) found that information reinstatement occurred within and between the networks during the generative and evaluative phases, reporting the dynamic interaction within the dual-process model of creativity (Matheson et al., 2023). Moreover, experimental evidence from functional near-infrared spectroscopy (fNIRS) indicates that it improves creative performance in generating original ideas. These results suggest that in mathematical problem solving and creative thinking, coordination among neural systems plays a central role in supporting higher-order cognitive activity (Luchini et al., 2025).

Additional literature indicates that heuristic and creative problem solving include complex coordination among mental representation, solution search, and neural activity. Research based on the ACT-R model shows that the posterior parietal cortex (PPC) is essential for forming and reinforcing mental imagery through enhanced connectivity with the prefrontal cortex and fusiform gyrus during heuristic problem solving (Shen et al., 2013). Meanwhile, the Neuro-Explicit-Implicit Interaction (Neuro-EII) theory posits that creativity arises from the dynamic interplay between explicit and implicit neural processes, enabling individuals to construct and explore problem spaces. This research emphasizes that heuristic and creative abilities are supported by integrative neural mechanisms (Helie, 2013).

3. Methodology

This research used a quantitative-descriptive and qualitative method with a phenomenological design. The quantitative-descriptive method was used to provide an overview of the creative thinking process of prospective mathematics teachers when solving numerical problems, using measurable indicators. The quantitative data served to identify general patterns and tendencies in the creative thinking process before conducting an in-depth qualitative analysis. Meanwhile, a qualitative method with a phenomenological design was applied to gain a deeper understanding of the creative thinking process during problem-solving. The meaning, stages, and characteristics of the creative thinking process were explored through the method. Therefore, this research aimed to provide a comprehensive understanding of the creative thinking process of prospective mathematics teachers. Category development was achieved through a combined concept-driven and data-driven process (Kuckartz, 2019). This method enabled the analysis to commence with an initial category framework derived from theoretical or existing literature, developed openly based on empirical data.

3.1. Subjects

The subjects were students in the Mathematics Education Research Program at Muhammadiyah University of Purwokerto. Students selected had taken courses relevant to numerical problems, namely the methods course. The selection of subjects was conducted using purposive sampling, with the criterion of logical-mathematical ability based on results from a psychology institution.

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Table 2. Characteristics of Research Subjects

Criteria	Frequency	Percentage (%)
Gender		
Male	7	23.33
Female	23	76.67
Age		
19 years old	1	3.33
20 years old	15	50.00
21 years old	11	36.67
22 years old	3	10.00
Logical-Mathematical Ability		
Fair	13	43.33
Slightly Low	17	56.67

Based on the intelligence test, 13 and 17 students had sufficient and low logical-mathematical ability, respectively. Interviews were conducted with three students from each category. In this context, two were selected from the interview to ensure clear answers. Furthermore, subjects with sufficient and low logical-mathematical ability were designated C1 and AR1, respectively.

3.2. Data Collection Procedure

Data collection was conducted through a test, in-depth interviews, and document analysis. The test was used to measure the ability to solve open-ended numerical problems, focusing on answers that reflect the stages of the creative thinking process. In-depth interviews were also used to explore the process and influencing factors. The document analysis included students' work and reflective notes. Table 3 presents the creative thinking process as reflected in the opinions of experts. Each indicator was analyzed using a Likert scale ranging from 1 to 4.

Table 3. Indicators of Creative Thinking Process

Creative thinking process	Criteria for Creative Thinking Process
Preparation	Understanding the problem to be solved.
	Gathering information on the problem.
	Using the knowledge owned as material to determine the desired alternative solution.
Incubation	Resting the mind and letting ideas come to mind to find a method that fits the problem.
	Reflecting on the intent of the problem and thinking of a plan to solve the problem.

Creative thinking process	Criteria for Creative Thinking Process
	Finding ways to connect the information gathered during the preparation stage.
Illumination	The emergence of new and unexpected insights or understanding related to a problem or a goal.
	A feeling of discovery or "aha moment" that accompanies a new understanding or developing idea.
	The ability to make connections or see patterns not previously apparent.
Formulation	Developing ideas during the illumination stage into more concrete concepts or plans.
	Further thinking to formulate ideas into practical solutions or implementations that can be performed.
	Considering various aspects, such as feasibility, practicality, and impact of the ideas generated.
	Determining strategies or concrete steps to implement these ideas.
Verification	Analyzing the strengths and weaknesses of the ideas or solutions produced.
	Conducting a test by comparing with the error rate or other methods.
	Connecting the concepts and applications carried out.

3.3. Instrument

Data were collected using the following three instruments:

1. Mathematical Logic Ability Test

This test was designed to measure students' levels of mathematical logical ability. The Psychological Consultation Bureau of Universitas Muhammadiyah Purwokerto administered the test.

2. Creative Thinking Ability Test

This test was developed based on the stages of the creative thinking process, including preparation, incubation, illumination, formulation, and verification. The instrument was validated by experts, obtaining an average validation score of 4.27, which falls into the very valid category.

3. Unstructured Interviews and Documentation

The interview guidelines were developed to obtain data regarding students' creative thinking processes, aligned with the documentation of their test answer sheets.

3.4. Data Analysis Method

The data analysis method was carried out using the following combinative process.

1. Initial step (concept-driven): The research developed an initial framework of categories based on constructivist theory in mathematics learning, teaching strategies, or previous literature. These initial categories were used to create a coding frame.

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2. Next step (data-driven): The collected data was analyzed using open coding to determine new categories from empirical data. This process was carried out until no new categories were found (saturation).

3. Category refinement: Initial categories were revised, developed, or combined with new categories based on field findings. This process included the formation of principal codes and subcodes at various levels.

4. Analysis was carried out iteratively between data, categories, and theories to build a complete understanding.

Data analysis was conducted using NVivo Pro 12, and the results were presented.

Table 4. Description of the table of Criteria for Creative Thinking Process

Code	Criteria for Creative Thinking Process
T1I1	Students write down what is known about the problem.
T1I2	Students detail what is known.
T1I3	Students detect information known in the problem with their knowledge.
T2I1	Students organize the steps needed before determining the solution to the nonlinear equation.
T2I2	Students clearly describe the steps to be taken.
T2I3	Students detail the steps to be taken.
T3I1	Students organize the interval [a,b] to determine the number of iterations.
T3I2	Students describe the number of iterations using the interval only without calculating the value of f(x).
T3I3	Students narrow the interval and identify several new intervals in the prepared table.
T4I1	Students use the new interval to do iterations.
T4I2	Students diagnose new intervals with the criterion f(a). .f(c)<0 and prepare a table according to the needs of the method used.
T4I3	Students use the criterion f(a). .f(c)<0 to continue the next iteration based on the stopping criterion.
T4I4	Students make the right decision to stop the iteration.
T5I1	Students connect the solutions of the methods used.
T5I2	Students support their answers by comparing the methods selected before and after the interval is modified.
T5I3	Students draw conclusions based on the problem.

3.5. Data Validity

Triangulation of sources and methods was conducted to ensure the validity of the data. Source triangulation compared data from interviews, documentation, and observations. Meanwhile, the triangulation method combined interviews, observations, and document analysis to determine the consistency of the results. Data validity was ensured through triangulation of sources and methods, discussions with experts, and member checking to ensure that the interpretation was consistent with the subjects' experiences. The results were expected to provide a detailed image of the creative thinking process for solving numerical problems and producing theoretical schemes, serving as the basis for developing innovative learning strategies.

4. Results

Based on the Creative Thinking Test, students at the Preparation stage reported a high level of ability, with an average score of 3.86. The student performed exceptionally well in understanding the problem (4.23) and gathering information (3.90). However, there was a slight decline in the ability to utilize the information (3.43). This shows that students are cognitively prepared to face problems. However, improvement is needed in the practical processing of the collected information to develop initial solutions.

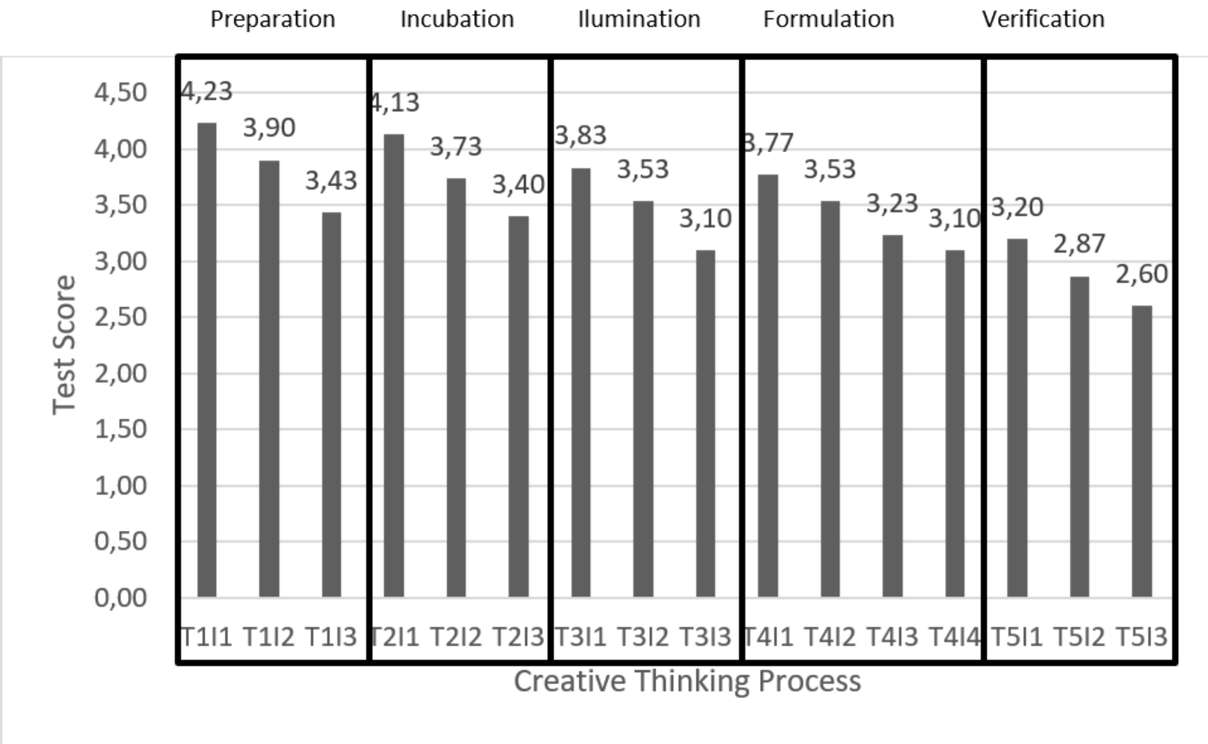


Figure 2. Achievement in Each Aspect of the Creative Thinking Process

The Incubation stage performed pretty well, with an average score of 3.76. Students appeared capable of taking a brief pause while continuing to process the problem subconsciously (4.13), as well as reporting the ability to reflect (3.73) and generate initial ideas (3.40). The ability to "generate" ideas appeared slightly lower than the others, showing a challenge during the latent phase.

At the Illumination stage, the average score was 3.49, with students experiencing “aha” moments (3.53) and developing ideas (3.83), but not fully connecting new ideas to a broader context (3.10). In the Formulation stage, difficulties are experienced in evaluating (3.23) and implementing (3.10) ideas into concrete forms. Finally, the Verification stage received the lowest score (2.89), particularly in terms of testing (2.87) and linking the solution to outcomes (2.60). This shows a weakness among students in evaluating and validating the formulated solutions.

Table 5. Creative Stem-and-Leaf Plot

Frequency	Stem & Leaf		
2,00	3	.	69
3,00	4	.	012
5,00	4	.	66799
7,00	5	.	0012344
2,00	5	.	67
3,00	6	.	123
4,00	6	.	7778
1,00	7	.	0
3,00	7	.	588

Table 5 presents the distribution of creative thinking process data, showing the spread of participants' scores across tens and units. In this diagram, the stem represents tens of values, such as 30s, 40s, 50s, while the leaf is the units of each score. A stem width of ten reports that each row is a range of ten numbers (e.g., 60–69, 70–79, etc.), and the leaf represents one participant.

The participants' scores range from the 30s to the 70s, with the highest concentration between 50–59. There are two main groups in stem 5, namely 1) seven participants with scores of 50, 50, 51, 52, 53, 54, and 54, and 2) two participants with scores of 56 and 57. This shows that most participants have creativity scores in the middle to upper category. Other groups with high frequencies were the 40–49 and 60–69 age ranges, with eight participants each. In the 40s group, scores ranged from 40 to 49, with the highest numbers at 46, 47 49, and 49. In the 60s, scores were spread from 61 to 68, with additional concentrations at 67, 67, 67, and 68. The 30–39 range had the lowest frequency, with only two participants scoring 36 and 39. This shows that only a few participants have very low creativity scores. The 70–79 group comprises only four participants since high creativity scores are not dominant.

The data distribution tends to form a pattern close to symmetrical, with a peak at 50–54 and a decline at both extremes. Therefore, most participants report moderate levels of creative thinking ability, with a few at very low or high levels. This distribution is used to select two participants with high creativity scores to be interviewed, with sufficient (C1) and low (AR4) mathematical logic abilities. Figure 3 shows the achievement of each indicator for C1 and AR1.

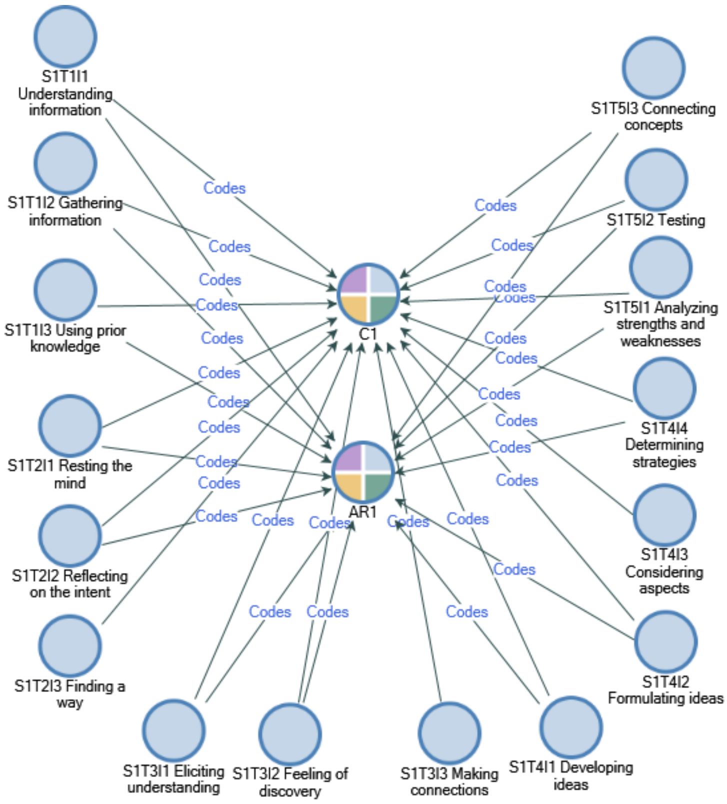
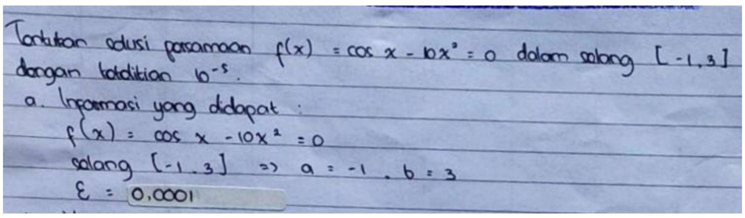


Figure 3. Achievement of creative thinking process indicators

4.1. Subject 1: Sufficient Logical-Mathematical Ability (C1)

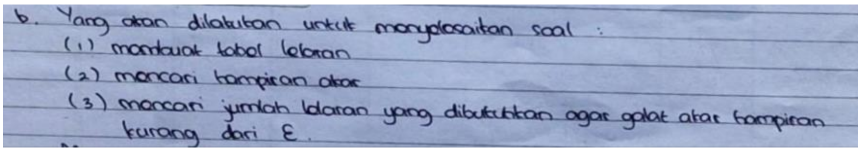
Good ability in understanding and formulating numerical problem is shown in C1. In the problem exporation stage, the subject can correctly identify important information from problem. However, in the incubation stage, the subject tends to take a direct method without exploring alternative solutions. In the illumination stage, the subject finds a solution idea with quite clear logic, even though only one method is used. The formulation stage is carried out quite well, with structured calculation steps. However, in the verification stage, the subject only checks the final result without evaluating process thoroughly. The subject writes the interval [-1,3] with the symbols a and b. In this context, C1 understands problem as well as uses knowledge to prepare and determine alternative solutions. The function also includes trigonometric elements (cos x) and square (10x2) since analytical solutions are difficult to obtain. This understanding motivates the use of numerical methods such as bisection to solve problem.


Tentukan solusi persamaan $f(x) = \cos x - 10x^2 = 0$ dalam selang $[-1,3]$ dengan ketelitian 10^{-5}.
a. Informasi yang didapat :
$f(x) = \cos x - 10x^2 = 0$
selang $[-1,3] \Rightarrow a = -1, b = 3$
$\varepsilon = 0{,}0001$

Translated version:
Determine the solution of the equation f(x)=cos x – 10x2, in the interval [-1,3] with an accuracy of 10-5.
Information obtained:
f(x)=cos x-10x2=0
interval [-1,3] , a=-1, b=3
ε=0,0001

Figure 4. Problem Determination of C1

The activities carried out by students in Figure 4 show the stage of gathering related information in creative thinking process. At this stage, analytical solutions are difficult to obtain since the idea use numerical methods, such as bisection. The subject writes a plan to solve problem and organizes the steps needed before determining the solution to the nonlinear equation as seen in the answers of C1. The activities reflect the stages of acquiring knowledge and deriving related information in creative thinking process. Students gather information and understand concepts relevant to problem, such as the characteristics of nonlinear equations and methods used. Furthermore, the steps needed are organized before determining the solution by connecting the information obtained from problem. This process shows that students understand problem and can design a systematic solution strategy, as seen in the compiled answers.



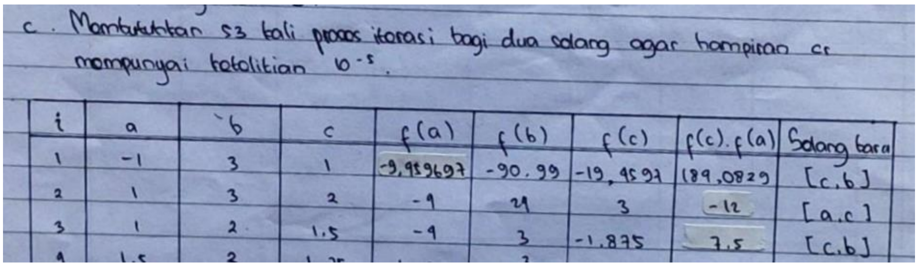
b. Yang akan dilakukan untuk menyelesaikan soal :
(1) membuat tabel lelaran
(2) mencari hampiran akar
(3) mencari jumlah lelaran yang dibutuhkan agar galat akar hampiran kurang dari ε.

Translated version:

Steps to be taken to solve problem:
(1) Create an iteration table
(2) Find the approximation root
(3) ind the number of iterations needed hence the approximation root error is less than ε

Figure 5. Information Acquisition in Problem Exporation for C1

C1 organizes the interval [a,b] as a material for determining the number of iterations. The subject uses the calculation to determine the possible number of iterations and compare the results with process having narrowed interval.



c. Membutuhkan 53 kali proses iterasi bagi dua selang agar hampiran cr mempunyai ketelitian 10^{-5}.

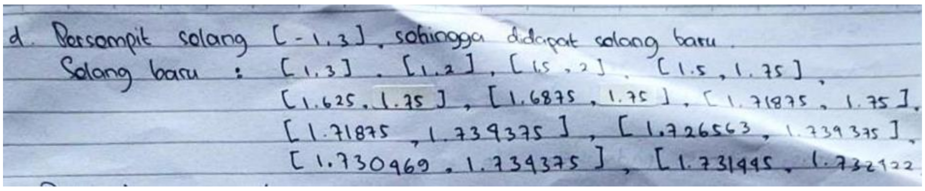
i	a	b	c	f(a)	f(b)	f(c)	f(c).f(a)	Selang baru
1	-1	3	1	-9,959697	-90.99	-19,4597	189,0829	[c,b]
2	1	3	2	-9	21	3	-12	[a,c]
3	1	2	1.5	-9	3	-1,875	7.5	[c,b]

Translated version:
Determine 53 iteration processes for two intervals hence the c_r approximation has an accuracy of 10^{-5}.
……………….table…………………………………

Figure 6. Gathering Information on the Number of Iterations for C1

The interval [a,b] is organized as a material for determining the number of iterations and uses the calculation to determine the possibility. Additionally, the subject compares the results with process whose interval has been narrowed to show the stage of gathering related information. This supports the incubation process, where C1 connects the information obtained with other relevant concepts, such as the use of tables to calculate iterations and verify the accuracy of the solution. Even though C1 is actively organizing and calculating, the brain is unconsciously processing the collected information to produce a deeper understanding, giving time to find a more efficient iteration method.

C1 describes several new intervals used for the calculation process. The subject narrows the interval and uses the concept to iterate. The ends of the interval also need to be narrowed since no solution is reported. The two new intervals are selected to compare the results and this shows flexibility in thinking even though the calculations have not been performed.



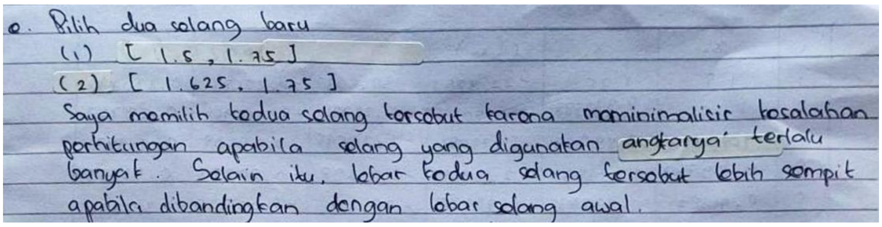
d. Persempit selang [-1,3], sehingga didapat selang baru.
Selang baru : [1,3], [1,2], [1.5,2], [1.5,1.75],
[1.625, 1.75], [1.6875, 1.75], [1.71875, 1.75],
[1.71875, 1.734375], [1.726563, 1.734375],
[1.730469, 1.734375], [1.731445, 1.732422

Translated version:
d. Narrow the interval [-3,3], hence a new interval is obtained.
New interval: [1,3], [1,2],[1.5;2],[1.5;1.75]

Figure 7. C1 Narrows the Interval as a Result of the Incubation Process

In the answer provided, the incubation stage is visible where C1 elaborates and narrows the interval. Process gives the brain time to work in the background and the subject allows ideas to develop without direct pressure. This led to a deeper understanding of narrowing the interval needs to determine the right solution by thinking about various possible intervals used for iteration.

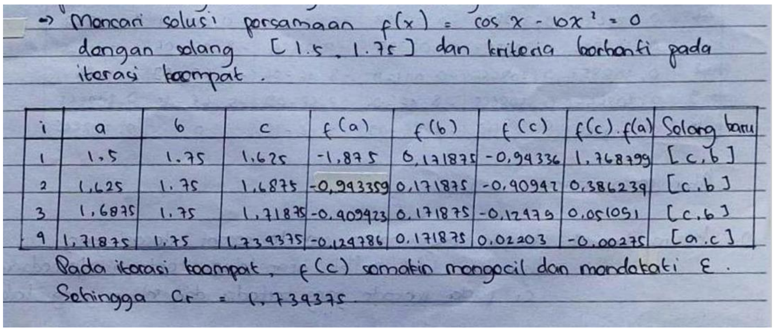
C1 selects two intervals to minimize errors in the calculation. The calculation carried out is correct when thinking about various possible intervals used for iteration. This is a feeling of discovery accompanying new knowledge from the developing ideas and patterns not seen directly in problem can be connected. Students may also realize the importance of examining the change in function values at the midpoint of the interval as an initial step in the bisection method. Moreover, the illumination stage is characterized by generating ideas from narrowing the interval. This is marked by C1 identifying and selecting several new intervals as alternatives for further calculations. The subject tests possibilities by selecting two new intervals to compare, showing the exploration of creative ideas in finding more effective solutions. This flexibility of thinking reflects the ability to generate different methods to solve problem even though concrete calculations have not been carried out.



e. Pilih dua selang baru
(1) [1.5, 1.75]
(2) [1.625, 1.75]
Saya memilih kedua selang tersebut karena meminimalisir kesalahan perhitungan apabila selang yang digunakan angkanya terlalu banyak. Selain itu, lebar kedua selang tersebut lebih sempit apabila dibandingkan dengan lebar selang awal.

Translated version:
e. Select two new intervals
(1) [1.5,1.75]
(2) [1.625, 1.75]
I selected these two intervals because they minimize calculation errors if the interval has too many roots. Additionally, the width of the two intervals is narrower when compared to the width of the initial interval.

Figure 8. C1 Selects a New Interval That Has Been Narrowed Down



→ Mencari solusi persamaan f(x) = cos x - 10x² = 0 dengan selang [1.5, 1.75] dan kriteria berhenti pada iterasi keempat.

i	a	b	c	f(a)	f(b)	f(c)	f(c).f(a)	Selang baru
1	1,5	1.75	1,625	-1,875	0,171875	-0,94336	1,768799	[c, b]
2	1,625	1.75	1,6875	-0,943359	0,171875	-0,90942	0,386239	[c, b]
3	1,6875	1.75	1,71875	-0,409923	0,171875	-0,12979	0,051051	[c, b]
4	1,71875	1,75	1,734375	-0,124786	0,171875	0,02203	-0,00275	[a, c]

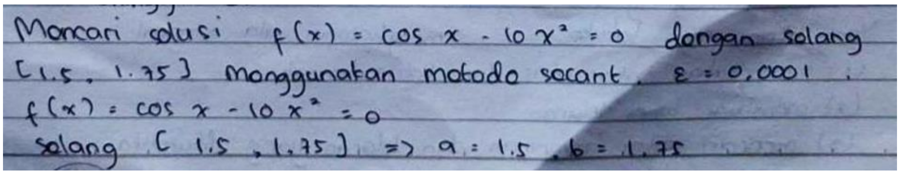
Pada iterasi keempat, f(c) semakin mengecil dan mendekati ε.
Sehingga Cr = 1,734375.

Translated version:
Find the solution of the equation f(x)=cos x – 10x2=0 with the interval [1.5, 1.75] and the criteria in the fourth iteration
……………… (table)……………………
In the fourth iteration, f(c) gets smaller and approaches ε hence cr=1.734375.

Figure 9. C1 Performs Formulation with an Iteration Table

Based on the idea, C1 compiles a formulation in the form of an iteration table (Figure 9). The subject uses the new interval to iterate with the bisection method. The criterion f(a).f(c)<0 is used to continue the subsequent iteration based on the stoppage. The selected subinterval also fulfills the requirements for the existence of roots for efficient performance of iteration.

C1 diagnoses a new interval with the criterion f(a).f(c)<0 and prepares a table according to the needs of the method. The subject calculates using the new interval and shows that the iteration runs differently through oscillation from the previous interval. The iteration does not lead to the desired solution and the subject uses the secant method as a comparison. This shows quite good flexibility and fluency in thinking process. Students show the effect of the secant method on the iteration results in various conditions, such as differences within the intervals and other methods used. This stage is not seen explicitly but is reported by the statement showing the differences in Cr (convergence criteria or certain tolerance results) at different intervals. Furthermore, C1 mentally processes the relationship between the method parameters and the final results.



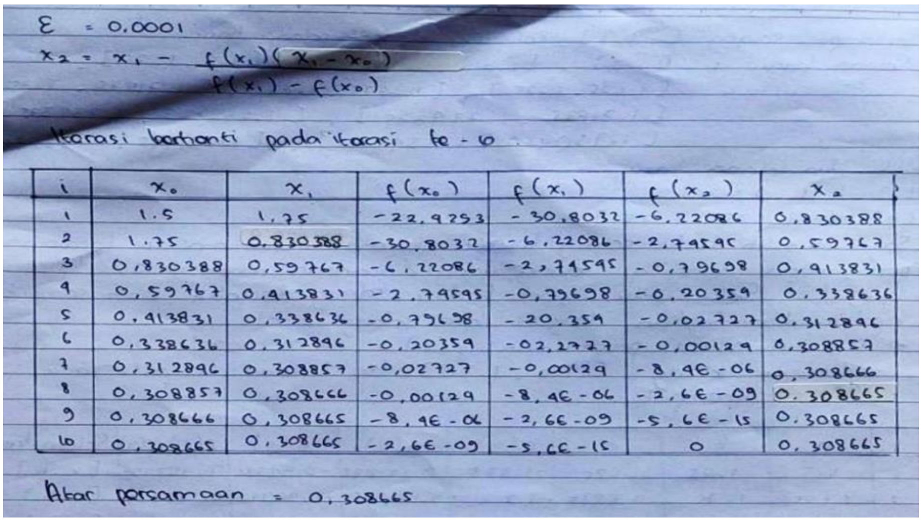
Mencari solusi f(x) = cos x - 10x² = 0 dengan selang [1.5, 1.75] menggunakan metode secant, ε = 0,0001
f(x) = cos x - 10x² = 0
selang [1.5, 1.75] => a = 1.5, b = 1.75

Translated version:
Find the solution of the equation f(x)=cos x – 10x^2=0 with the interval [1.5, 1.75] using the secant method, ε = 0,0001
f(x)=cos x – 10x^2=0
Interval [1.5, 1.75], a=1.5, b=1.75.

Figure 10. C1 Uses Other Methods

The secant method is systematically applied in a structured manner. The subject calculates iteration until reaching the 10th, where the root of the equation is found to be close to 0.308665. The steps are recorded in the iteration table, including the values of x_0, x_1, $f(x_0)$, $f(x_1)$, and x_2. This structured method shows the ability to formulate solutions based on the rules of the secant method.

C1 integrates the observation and analysis results into a clear conclusion (Figure 11). The secant method is more efficient in the number of iterations. However, the final result (Cr) varies depending on the initial interval and other methods used. This stage reflects the ability to connect various elements of the iteration results into a comprehensive and meaningful statement. C1 verifies the results by ensuring the value of f(x) in the solution is close to zero with a given error tolerance (ε=0.0001). After the 10th iteration, the root of the equation is $x \approx 0.308665$. This verification stage shows the reflective ability to ensure that the solution truly fulfills the criteria of problem.



ε = 0.0001

$x_2 = x_1 - \frac{f(x_1)(x_1 - x_0)}{f(x_1) - f(x_0)}$

Iterasi berhenti pada iterasi ke - 10

i	x_0	x_1	$f(x_0)$	$f(x_1)$	$f(x_2)$	x_2
1	1.5	1,75	-22,9253	-30,8032	-6,22086	0,830388
2	1.75	0.830388	-30,8032	-6,22086	-2,79595	0,59767
3	0,830388	0,59767	-6,22086	-2,79595	-0,79698	0,413831
4	0,59767	0,413831	-2,79595	-0,79698	-0,20359	0,338636
5	0,413831	0,338636	-0,79698	-20,359	-0,02727	0,312896
6	0,338636	0,312896	-0,20359	-02,2727	-0,00129	0,308857
7	0,312896	0,308857	-0,02727	-0,00129	-8,4E-06	0,308666
8	0,308857	0,308666	-0,00129	-8,4E-06	-2,6E-09	0,308665
9	0,308666	0,308665	-8,4E-06	-2,6E-09	-5,6E-15	0,308665
10	0,308665	0,308665	-2,6E-09	-5,6E-15	0	0,308665

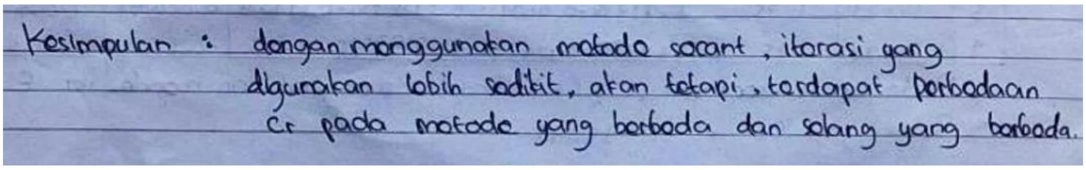
Akar persamaan = 0,308665

Translated version:
ε = 0,0001

$$x_2 = x_1 - \frac{f(x_1)(x_1 - x_0)}{f(x_1) - f(x_0)}$$

Iteration stops at the 10th iteration
………………..table ……………………
Root of equation = 0.308665

Figure 11. C1 Determines the Solution Using the Secant Method



Kesimpulan : dengan menggunakan metode secant, iterasi yang digunakan lebih sedikit, akan tetapi, terdapat perbedaan Cr pada metode yang berbeda dan selang yang berbeda.

Translated version:
Conclusion: with the secant method, fewer iterations are used but there are differences in Cr in different methods and intervals.

Figure 12. C1 Compares Two Ideas (Methods)

C1 validates the conclusion by comparing the efficiency of the secant method with others in terms of the number of iterations and the Cr results. This process shows the critical reflection on the data generated and the analysis carried out. The analysis of answers related to the achievement of all creative thinking indicators can be understood more systematically to solve numerical problems.

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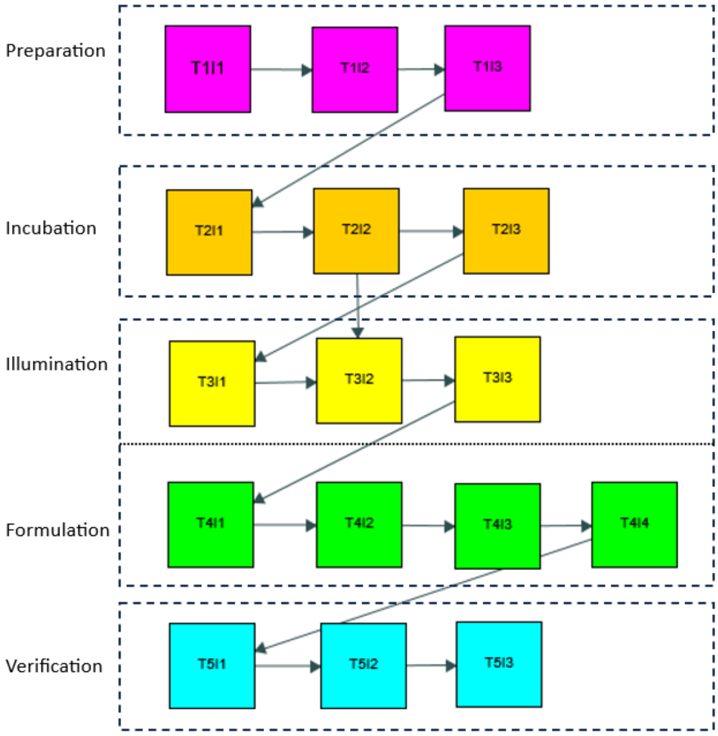


Figure 13. Analysis of C1's Creative Thinking Process

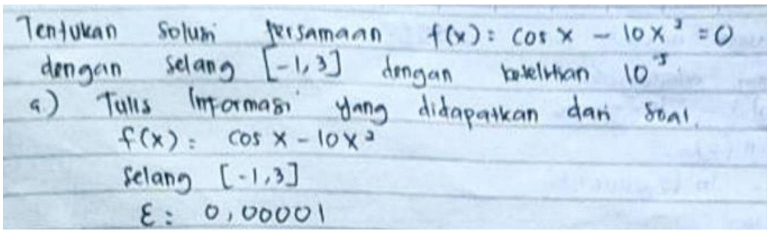
Here is the table describing the analysis results of C1's answers according to the stages of creative thinking.

Table 6. Description Table for Figure 13

Code	Criteria for Creative Thinking Process
T1I1	writes the interval [-1,3], recognizes the function includes cos(x) and $10x^2$
T1I2	specifies that the function cannot be solved analytically
T1I3	relates the form of the function to numerical methods as an alternative solution
T2I1	writes a plan for solving the problem and the steps for the numerical solution
T2I2	prepares steps such as creating a table and using intervals
T2I3	develops a calculation strategy, such as determining the number of iterations
T3I1	determines iterations using a table and an initial interval
T3I2	organizes iteration calculations by considering only the length of the initial interval
T3I3	selects and tests two new intervals for comparison
T4I1	applies a new interval for iteration using the bisection and secant methods
T4I2	prepares and calculates an iteration table based on root existence criteria
T4I3	continues iterations based on the table results until the tolerance limit is reached
T4I4	stops iteration when a root is found with $\varepsilon = 0.0001$ after 10 iterations
T5I1	compares the bisection and secant methods in terms of results and iteration efficiency
T5I2	tests two different intervals and methods, then draws a conclusion
T5I3	concludes that the root is approximately 0.308665 and that the secant method is more efficient in terms of the number of iterations

4.2. Subject: Rather Low Logical-Mathematical Ability (AR1)

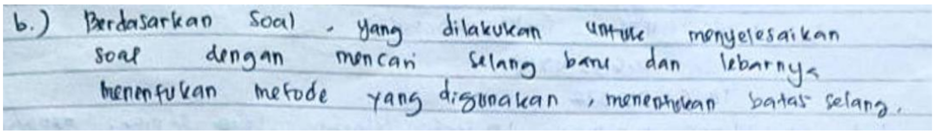
AR1 starts by understanding the information given in a structured manner. The subject rewrites the function f(x)=cos x $-10x^2$, as an important step in understanding the nature of the function, including the changes of sign to find roots in a certain interval [−1,3]. This knowledge is the basis for further dividing the interval during iteration. According to the required precision (ε=10−5), the final result should fulfill the criterion for the solution to be considered valid. This process shows that students are focused on gathering the key information needed to solve problem.


Tentukan solusi persamaan $f(x): \cos x - 10x^2 = 0$
dengan selang $[-1,3]$ dengan ketelitian 10^{-5}.
a.) Tulis informasi yang didapatkan dari soal.
$f(x): \cos x - 10x^2$
Selang $[-1,3]$
ε: 0,00001

Translated version:
Determine the solution of the equation $f(x)=\cos x - 10x^2$, with the interval [-1,3] and an accuracy of 10^{-5}.
Write the information obtained from problem:
$f(x)=\cos x-10x^2=0$
interval [-1,3]
ε=0,00001

Figure 14. AR1's Problem Determination

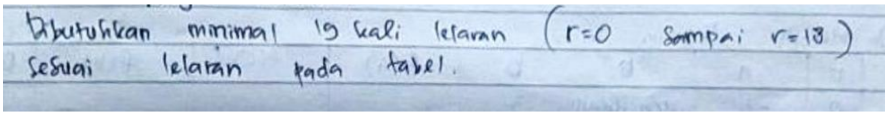
AR1 understands that solving problem requires dividing the given interval used in the iteration (Figure 14). In this context, students understand the importance of selecting subintervals to find roots based on the nature of the function in the interval. Subsequently, AR1 selects a specific numerical method, such as bisection or Regula Falsi, according to the characteristics of the problem. The choice of method shows the mastery of strategic and relevant initial steps for numerical method. AR1 determines the boundaries of a new interval as part of the preparation for the iteration. This step includes analytical skills to ensure the selected subintervals fulfill the requirements for the existence of roots.

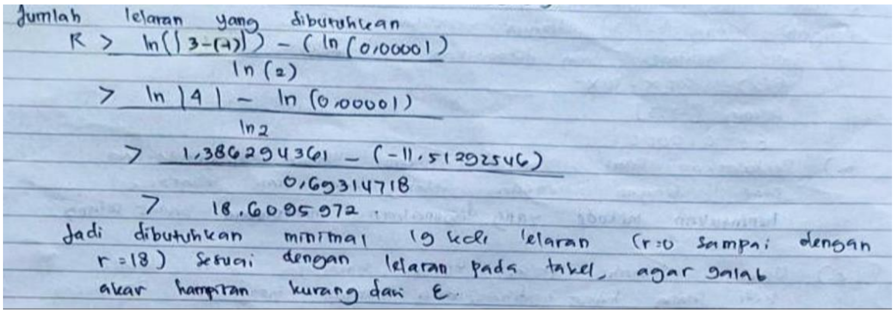

b.) Berdasarkan soal, yang dilakukan untuk menyelesaikan soal dengan mencari selang baru dan lebarnya, menentukan metode yang digunakan, menentukan batas selang.

Translated version:
Based on problem, the steps to solve it involve determining the new interval and its width, selecting the appropriate method, and defining the interval limits.

Figure 15. Information Acquisition in Problem Exporation for AR1

Figure 16, There is an "aha!" moment where AR1 concludes that 19 iterations (from r=0 to r=18) are needed for the approximation root error to be below the specified tolerance (ε). This is achieved by comparing the last iteration with the tolerance value ε. The subject clearly states the analysis result, where the number of iterations is the minimum solution to fulfill the error requirement.


Dibutuhkan minimal 19 kali lelaran (r=0 sampai r=18) sesuai lelaran pada tabel.


Jumlah lelaran yang dibutuhkan

$$R > \frac{\ln(|3-(-1)|) - (\ln(0{,}00001))}{\ln(2)}$$

$$> \frac{\ln|4| - \ln(0{,}00001)}{\ln 2}$$

$$> \frac{1{,}386294361 - (-11{,}51292546)}{0{,}69314718}$$

$$> 18.6095972$$

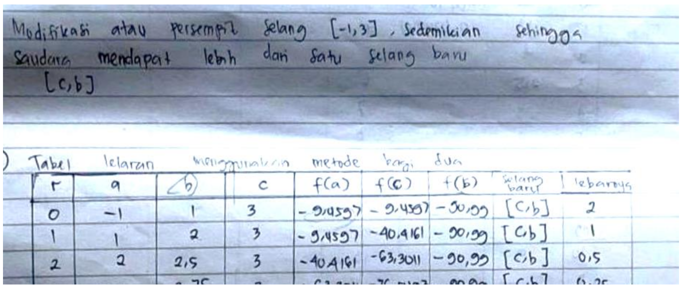
Jadi dibutuhkan minimal 19 kali lelaran (r=0 sampai dengan r=18) sesuai dengan lelaran pada tabel, agar galat akar hampiran kurang dari ε.

Translated version:
It takes a minimum of 19 iterations (r=0 to r=18) according to the iterations in the table.
Number of iterations needed
R > 18.6095972
Hence, it takes a minimum of 19 iterations (r=0 to r=18) according to the iterations in the table hence the approximation root error is less than ε.

Figure 16. Collecting Information on the Number of Iterations for AR1

AR1 shows concrete steps by narrowing the interval [−1,3] into several new sub-intervals (Figure 16). This is conducted to fulfill the requirement for the existence of roots in each sub-interval, namely f(a)·f(b)<0. In the incubation result, AR1 generates ideas through clear steps. This reflects the ability to apply mathematical principles strategically in solving problem. By selecting the bisection method, AR1 explicitly determines the iterative method used to improve the approximation to the root. The subject also creates an iteration table as a tool to track the progress of process and ensure the final result fulfills the error tolerance criteria. However, the subject uses [-1,3] despite having a plan to make a narrower interval. The answer tends to be less than perfect because the subject does not detail problem-solving stage due to suboptimal incubation.

AR1 checks the last result of the iteration table to ensure the approximate root value (x = 2.99994) fulfills the given error criteria ($\varepsilon = 10^{-5}$). The formulation carried out by the subject is good enough to obtain a convergent solution. This shows that the subject can carry out detailed checks on the calculation in terms of root values and conformity with error tolerance.

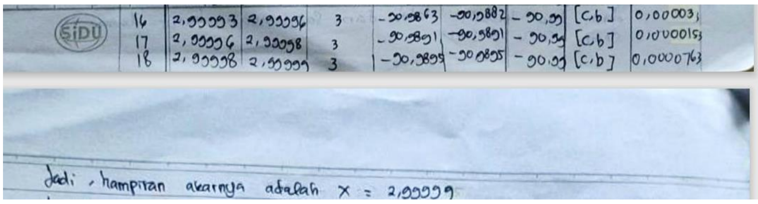

Modifikasi atau persempit selang [-1,3], sedemikian sehingga saudara mendapat lebih dari satu selang baru [c,b]

Tabel lelaran menggunakan metode bagi dua

r	a	b	c	f(a)	f(c)	f(b)	selang baru	lebarnya
0	-1	1	3	-9,4597	-9,4597	-90,99	[c,b]	2
1	1	2	3	-9,4597	-40,4161	-90,99	[c,b]	1
2	2	2,5	3	-40,4161	-63,3011	-90,99	[c,b]	0,5

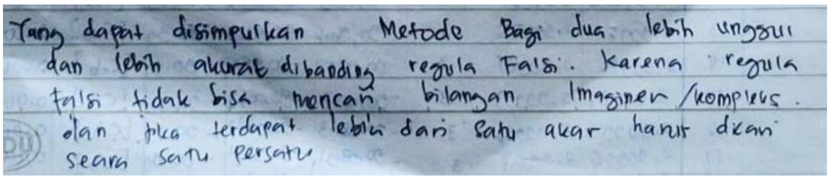
Translated version:
Modify or narrow the interval [-1,3], thereby getting more than one new interval.
Iteration table using the bisection method.
……………………… table …………………………………………

Figure 17. AR1 Narrows the Interval as a Result of the Incubation Process



Translated version:
……………… Table …………………..
Hence, the approximate root is x=2.99994

Figure 18. AR1 Performs Formulation with Iteration Table



Translated version:
The bisection method is superior and more accurate than the Regula Falsi. This is because the Regula Falsi cannot search for imaginary/complex numbers and process should be carried out simultaneously when there is more than one root.

Figure 19. AR1 Compares Two Ideas (Methods)

AR1 stating the superiority of the bisection method over the Regula Falsi shows a deep understanding of the characteristics of numerical method (Figure 19). The conclusion reflects a thorough verification of the solution and process. The subject shows a broader understanding by assessing the advantages and limitations of the method.

The analysis of the answer related to the indicators can be understood systematically through the scheme used to visualize creative thinking process of students in solving numerical problem (Figure 20).

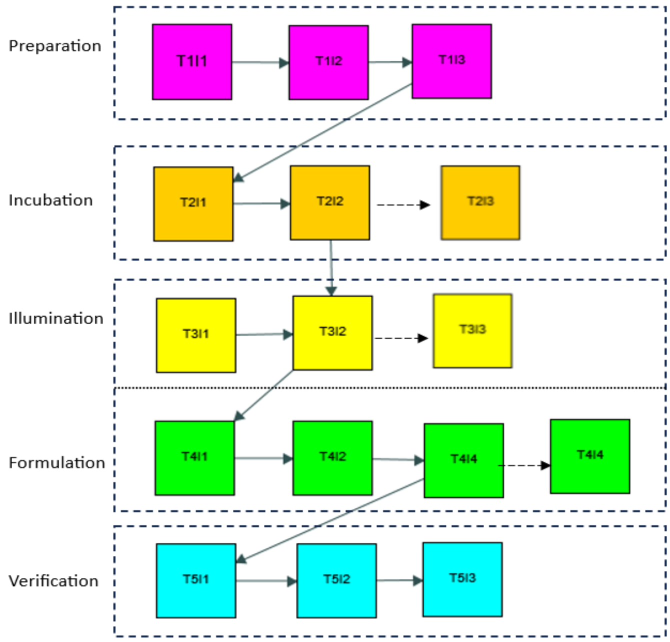


Figure 20. Analysis of AR1's Creative Thinking Process

Here is the table describing the analysis results of AR1's answers according to the stages of creative thinking.

Table 7. Description Table for Figure 20

Code	Criteria for Creative Thinking Process
T1I1	Writes the function $f(x) = \cos(x) – 10x^2$
T1I2	States the root-finding interval [−1, 3] and the tolerance $\varepsilon = 10^{-5}$
T1I3	Understands the function's properties and the importance of sign changes in determining the root
T2I1	Divides the interval [−1, 3] into new subintervals for iteration
T2I2	Selects a numerical method (bisection or regula falsi) based on the problem’s characteristics
T2I3	Does not elaborate on the steps to be taken
T3I1	Determines a minimum of 19 iterations to meet the tolerance ε
T3I2	Compares iteration results with the error criteria without always calculating all function values
T3I3	Plans to narrow down the interval and identify several new intervals in the constructed table, though they are not used in calculations
T4I1	Performs iterations using the new interval
T4I2	Applies the criterion $f(a)\cdot f(c) < 0$ to validate subintervals and prepares an iteration table
T4I3	Uses error criteria to stop the iteration at the right time
T4I4	Ensures the approximate root meets the specified error tolerance (ε)
T5I1	Compares the advantages of the bisection and regula falsi methods
T5I2	Explains the reasons for selecting a method and the differences in the results
T5I3	Concludes that the bisection method is more suitable for the given problem

5. Discussion

In the problem exporation stage, C1 shows good ability in understanding and formulating numerical problem. The subject identifies important information from problem, such as the interval, and rewrites the function. Creative problem-solving activities provide new challenges for students, specifically in understanding and organizing information innovatively (İncebacak and Ersoy 2018). Furthermore, the function includes trigonometric and quadratic elements, which are difficult to solve analytically. The interaction of fluency with originality is the most important in predicting creativity and achievement activities (Runco 2024). This aspect reports good numerical and logical-mathematical intelligence because students can connect information with relevant concepts. Creative activities such as drawing sketches interpret real-world mathematical problem (Wijirahayu and Ayundhari 2018). AR1 systematically records important information, such as intervals and tolerance criteria. However, the subject uses the interval, despite having a plan to narrow the concept. This causes the answer to be less precise and shows an opportunity for further development in understanding the importance of specific intervals. This understanding suggest the capacity for logical thinking in support of mathematical analysis process (Cırıt 2023).

In the incubation stage, C1 tends to take a direct method without exploring many alternative solutions. This reflects efficient but less flexible thinking because the concept focuses on problem-solving path without considering other possibilities. The subconscious process contributes significantly to creativity, specifically in the ability to obtain the most creative idea (Ritter, Baaren, and Dijksterhuis, 2012; Greenwood and Gibson, 2020). AR1 also selects the appropriate numerical method by considering the characteristics of problem. This choice shows the mastery of the initial strategic steps to narrow the interval. Lack of exploration has a direct impact on the effectiveness of the illumination stage because there is no clear basis for narrowing the interval optimally. Even though AR1 has the logical-mathematical intelligence to select a method, the lack of detail in planning affects the process. Creative thinking in mathematics involves activating different neurocognitive networks to understand patterns, solve complex problems, and generate innovative solutions, with the possible role of deactivating certain areas to facilitate thinking flexibility (Park, Kirk, and Waldie 2015). Students who think and learn with the right brain are more creative than those using the left part (Piaw 2014). The tendency to try more divergent ideas in the early stages may trigger a creativity advantage in subsequent stages relevant to developing creative solutions in mathematical thinking process (Kachelmeier, Wang, and Williamson, 2019).

In the illumination stage, C1 obtains the idea to narrow the iteration interval based on the criteria. Additionally, the subject selects two new sub-intervals to compare the results, reflecting the flexibility of thinking. This understanding becomes a turning point in the problem-solving process to realize the importance of validation. The "aha!" moment occurs when AR1 concludes that at least 19 iterations are needed to reach the error. This results from a systematic analysis of the iteration table. Since no strategy details are made in the incubation stage, AR1 fails to narrow the initial interval into smaller subintervals. Therefore, the solution is less efficient and shows opportunities for improvement in implementing a more strategic plan. According to the associative theory, creative thinking involves connecting concepts related to memory, a process influenced by the semantic memory structure (Beaty & Kenett, 2020).

In the formulation stage, C1 organizes the iteration steps by creating a table to record the values and results. This reflects the ability to formulate solutions in a structured manner. AR1 also creates an iteration table to track the process in detail and demonstrate comprehensive mastery of methods. There are two main stages of the creative thinking process, namely preparation and action (Konecni, 2012). This stage reports the integration of numerical and logical-mathematical intelligence supporting optimal problem-solving. Horizontal individualism and collectivism support idea generation, while vertical collectivism facilitates idea implementation (Yao et al., 2012).

Verification is performed by ensuring the function value is consistent with zero in the solution. However, C1 does not thoroughly evaluate the entire process; it focuses only on the final result. In this context, logical-mathematical intelligence needs to be further honed in terms of critical evaluation. Scientific and mathematical creativity is influenced by a combination of divergent thinking skills and domain knowledge, with varying degrees of influence (Huang et al., 2017). AR1 checks the final iteration result to ensure the approximate root value meets the error tolerance. Additionally, the efficiency of bisection and Regula Falsi methods is compared, reflecting a mature reflective ability. The lack of initial interval narrowing leads to a less efficient solution. This verification emphasizes the importance of critical evaluation in solving numerical problem and shows deep logical intelligence. Metacognition plays a key role in evaluating creative potential holistically (Puryear, 2016). In addition, C1 and AR1 build understanding based on knowledge. Constructivism-based learning and interactive media also enhance creativity by engaging in an active learning process centered on problem-solving and collaboration (Sumalee, Charuni, and Issara, 2012). This process is consistent with Piaget's view of schema adaptation through assimilation and accommodation. Problem-solving significantly improves the creative thinking process (Çetinkaya, 2014). Students broaden horizons about numerical solutions by exploring new concepts. Creativity is an innate result enhanced through well-designed learning methods and supportive educational environments (Kim, 2023). The creative thinking process in higher education is influenced by the diversity of implicit theories held by teachers, rooted in a growth mindset, and makes important contributions to the understanding and development of creativity as a fuel for innovation in society (Pavlović and Maksić, 2019).

Factors such as lack of self-confidence and experience in dealing with non-routine problems, as well as time constraints in completing assignments, also affect creative thinking abilities. Ratnaningsih stated that students with guardian, artisan, and idealist personality types expressed a process as explained by Wallas, which showed only the preparation and incubation stages (Ratnaningsih, 2021). This is contrary to Setiawani, in which students are unable to reach the illumination stage due to moderate and low problem-solving ability (Setiawani et al., 2019). The achievement of creative mathematical reasoning skills has not been carried out correctly in terms of novelty indicators (Hendriana et al., 2018). This shows a gap between ideal and reality, which is a major challenge in numerical learning. The method allows an in-depth exploration of phenomena based on empirical data. The creative thinking process is discussed in the context of divergent production and transformation capabilities related to the intellectual aspects of creative disposition (Guilford, 2017).

The subjects show awareness of strategies used, specifically in selecting relevant numerical methods and designing iteration steps. This awareness organizes thinking process efficiently and different methods produce equally meaningful results (Abraham et al., 2014). Process of problem-solving includes the use of metacognitive sub-processes, such as information representation, review, and error correction (García, 2016). The creation of iteration tables by C1 and AR1 shows the systematic management of information in working memory. This structuring of information becomes the foundation for more complex analysis. The development of creative personality requires the stimulation of activities supported by personal characteristics, a conducive environment, and efforts to overcome psychological barriers (Dubinka, 2014). Developing mathematical creativity requires a supportive environment, differentiation of challenges, and the provision of real problem open to innovative exploration (Pham and Cho, 2018). Creative thinking process in science is influenced by knowledge and gender, hence learning strategies are needed to improve scientific creativity by considering the factors (Okere and Ndeke, 2012). The integration of advanced technologies plays an important role in designing innovative learning environments and enhancing creative capacities in the digital era (Liu, Vobolevich, and Oparin, 2023). Currently, the use of Artificial Intelligence (AI) technology has been incorporated into learning. Increasing AI literacy in higher education requires a collaborative, creative thinking process, including lecturers and students as partners to form an ethical, inclusive, and innovative educational ecosystem (Bian, Ling, and Yan, 2024). The revolutionary potential of digital technology can be realized when the implementation challenges are overcome through strategic recommendations to promote equitable, effective, and sustainable modern learning (Koshiry and Tony, 2025).

AR1 shows high mastery of numerical and logical-mathematical intelligence, specifically in analyzing patterns. Meanwhile, C1 has great potential through alternative exploration and critical reflection training. The cognitive stage has a significant role in determining the mathematical creative thinking process, but is not directly correlated with thinking habits (Romdon and Puspsowati, 2019). Numerical intelligence and learning independence are the keys to developing mathematical critical thinking skills (Suseno et al., 2023). Strengthening creative thinking process in learning also increases innovation and contributes to optimal academic achievement (Fatmawati, Zubaidah, Mahanal and Sutopo, 2019). Creative thinking process should be instilled early in the education system because creativity is needed by artists, scientists, economists, and engineers. Therefore, changes in policies and teaching methods are required to support the development of creativity in learning (Šorgo, 2012). Creative thinking process in science can be improved through the application of teaching. In this context, a diverse method is used to develop creative skills of prospective teachers in terms of character, process, and products (Akcanca and Ozsevgec, 2018). In the face of policies, creative thinking skills enable teachers to develop adaptive and critical pedagogical strategies (Chen, 2024). Teacher adaptability and creative teaching efficacy partially mediate the relationship between perceived school support and behaviour, serving as a critical foundation for designing strategies to enhance teaching quality (Meng and Wang, 2024). The reformation of the academic system demands a bold and directed creative thinking process to build an adaptive, contextual, and meaningful learning model amidst the challenges of social and internal campus change (Yuan and Wu, 2024). The development of teacher training programs that are culturally sensitive and focused on spontaneous communication skills reports the importance of facilitating the process (Tiang-Uan, 2025).

Other research have shown that numerical ability has a positive and significant influence on academic achievement (Kirana et al, 2023. Students with high and low logical-mathematical intelligence show an improved and reduced level of creative thinking. These results confirm the existence of a relationship between logical-mathematical intelligence and the level of creative thinking ability in solving mathematical problems (Prastika et al, 2021). Academic achievement has a positive and significant relationship with linguistic, logical-mathematical, spatial, and interpersonal intelligences, as well as creativity. In this context, the level of intelligence and creativity is directly proportional to the academic achievement (Sospedra-Baeza et al., 2022).

This research provides a unique contribution by examining the interaction between mathematical logical ability and the creative thinking process among prospective teachers. The results indicate that mathematical logical ability plays a crucial role in supporting the stages of creative thinking, from preparation, incubation, and illumination to formulation and verification. Theoretically, this research extends the understanding of logical and creative thinking in solving mathematical problems. Methodologically, a combination of logical ability tests, creative thinking tests, interviews, and documentation is used, enabling an in-depth and systematic tracing of creative thinking patterns. Practically, the results have implications for designing mathematics instruction that balances logical skill development with creativity, allowing students of varying logical abilities to engage in the creative thinking process.

6. Conclusion

In conclusion, students with sufficient logical-mathematical ability had good analytical skills. For optimization, the exploration of alternative solutions and the evaluation of the overall process were increased. This could be conducted through more intensive metacognitive training and the introduction of other varied numerical methods. Students with low logical-mathematical ability also had better critical reflection between theory and practice. However, this became less good when the incubation process was not balanced with good conceptual knowledge. This research showed the importance of developing a creative thinking process through a problem-based learning method to support the exploration of numerical solutions. Practical implications also included the preparation of a curriculum that emphasized the combination of theory and practice to build numerical and logical-mathematical competencies comprehensively. Students could be trained to obtain solutions as well as evaluate and reflect on the learning process in depth. A strong concept assisted students in increasing flexibility in solving problems. Actualization of ideas in the form of precise numerical formulations could also be easily achieved. The practical implications of the results showed the need for curriculum design between theoretical and practical aspects, developing comprehensive numerical and mathematical logic competencies. Students should be trained to obtain solutions as well as evaluate and reflect on learning processes. A strong mastery of concepts enhanced cognitive

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flexibility, increased the formulation of accurate numerical approaches, and enabled the generation of more creative and accountable solutions.

7. Limitation

The results may not be generalizable to all learning contexts since factors such as the learning environment, instructor support, and access to technology can vary. This research was conducted within a specific timeframe, which might not be sufficient to observe significant changes in the creative thinking process.

8. Recommendations

Teachers should implement diverse forms of scaffolding to support students at each stage of the creative thinking process, in order to optimize potential for exploration and innovative problem-solving. The development of training programs is suggested to help prepare all components of learning. Further research is recommended to be conducted over a longer period to evaluate the impact of learning activities on creative thinking processes. Future research may explore other factors influencing creativity. The adjustment of teaching methods is important to suit the individual needs and abilities of students, optimizing the enhancement of creativity.

Declarations

Author Contributions. L.A.: analysis, statistical analysis, drafting manuscript. K: Conceptualization, reviewing, supervision, securing funding, final approval. I.J.: Conceptualization, design. T.S.N.A: Conceptualization, final approval.

Conflicts of Interest. The authors declare no conflict of interest.

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Data Availability Statement. The datasets supporting the findings of this study are available from the first author upon reasonable request.

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