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Students' Creative Thinking Indicators in Solving Open-Ended Problems Across Different Levels of Mathematical Ability

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ABSTRACT

Previous studies have examined mathematical creative thinking in open-ended problem solving; however, qualitative investigations that explicitly trace the emergence of each creative thinking indicator — fluency, flexibility, originality, and reasoning depth — across different mathematical ability levels remain limited. Departing from the traditional elaboration indicator, this study adopts reasoning depth to more accurately capture students' process-oriented mathematical reasoning, representing a conceptual novelty in the assessment framework applied. This study aims to describe how students' mathematical creative thinking indicators emerge in solving open-ended problems based on mathematical ability. A descriptive qualitative approach was employed with six students from SMA Negeri 14 Kota Jambi, Indonesia, representing high, medium, and low mathematical ability levels. Data were collected through written tests and semi-structured interviews and analyzed through data reduction, data display, and conclusion drawing. The findings indicate that mathematical ability shapes students' creative thinking profiles but does not guarantee the development of all indicators. Fluency and reasoning depth emerged more consistently among high-ability students, while originality remained the most constrained indicator across all groups, regardless of ability level. Medium-ability students showed inconsistent indicator emergence, whereas low-ability students exhibited limited development across all four indicators. These findings imply the need for instructional designs that integrate open-ended tasks with strategies explicitly promoting divergent thinking, strategic flexibility, and reflective reasoning across all ability levels.

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1. INTRODUCTION

Creative thinking is widely recognized as one of the essential higher-order thinking skills in 21st-century mathematics education [1,2]. In contemporary learning contexts, students are expected not only to master procedures and obtain correct answers, but also to generate ideas, explore multiple solution strategies, and provide logical and meaningful explanations for the solutions they produce [5]. The World Economic Forum [3] identifies creative thinking as a crucial skill for addressing global challenges, while the OECD [4] emphasizes creativity as an integral component of mathematical literacy and problem-solving competence. These perspectives collectively reinforce that creative thinking is not merely an additional competency, but a foundational capacity students need for meaningful mathematical engagement and long-term academic and professional development.

Mathematical creative thinking is commonly characterized by four key indicators: fluency, flexibility, originality, and elaboration [6,7]. However, this study consciously adopts reasoning depth in place of the traditional elaboration indicator. This conceptual shift is grounded in contemporary research emphasizing that mathematical creative thinking is not only reflected in the variety of ideas or strategies generated, but also in the depth of reasoning used to explain and validate solutions [12]. Reasoning depth captures how coherently, logically, and reflectively students articulate their thinking processes, a dimension that elaboration, as originally defined in psychometric frameworks, does not fully address within the context of mathematical problem solving [10,13]. This perspective aligns with constructivist views that regard reasoning and reflection as essential components of meaningful mathematical learning [13]. It corresponds directly to the verification stage in the Wallas model of creative thinking, in which students critically evaluate and refine their solutions [8,9]. A systematic review by Suherman and Vidákovich [10] confirms that fluency, flexibility, originality, and elaboration remain the most frequently referenced framework for assessing mathematical creative thinking; however, the growing emphasis on process-oriented assessment in mathematics education justifies the conceptual evolution toward reasoning depth as a more contextually relevant indicator [12,23].

One instructional approach widely recognized as effective in facilitating mathematical creative thinking is the use of open-ended problems [14]. Open-ended problems allow more than one correct answer or solution strategy, thereby providing students with opportunities to think divergently and flexibly [7,15]. Through open-ended tasks, students are encouraged to select strategies independently, connect mathematical concepts, and reflect critically on the steps they take during problem solving [16]. The conceptual linkage between open-ended problems, creativity, and reasoning processes is direct and theoretically robust: open-ended tasks create conditions that demand idea generation, strategy exploration, and solution evaluation processes that are inherently aligned with fluency, flexibility, originality, and reasoning depth [5,19]. Furthermore, these tasks naturally activate students' reasoning processes, as students must not only arrive at a solution but also justify and verify their thinking, reinforcing the centrality of reasoning depth as a creative thinking indicator [12,23]. Prior studies confirm that open-ended problems can elicit a wide range of strategies and ideas in mathematics classrooms, making them a productive vehicle for observing the emergence of creative thinking indicators [15,24,25].

However, empirical findings indicate that the emergence of creative thinking indicators through open-ended problems is not always optimal in practice. Students tend to demonstrate fluency more readily, while flexibility, originality, and reasoning depth remain limited, particularly when prior learning experiences emphasize procedural instruction and single-solution examples [13,17]. A significant factor that shapes this variability is mathematical ability. Mathematical ability reflects students' conceptual understanding, procedural fluency, and capacity to relate multiple mathematical representations [7,18]. Students with different levels of mathematical ability exhibit distinct patterns in strategy selection, solution construction, and the degree of novelty in their ideas when solving open-ended problems [18,22]. Students with higher mathematical ability tend to demonstrate greater strategic flexibility, whereas those with lower ability often rely on familiar procedural approaches, which further constrains the emergence of originality and reasoning depth [22].

Despite the growing body of research on creative thinking and open-ended problem solving, studies that explicitly examine the emergence of creative thinking indicators across different levels of mathematical ability using qualitative approaches remain limited. Most prior research has focused predominantly on quantitative measurement of creative thinking outcomes, offering limited insight into how individual indicators manifest during the problem-solving process [10,11]. Siswono [18] proposed a leveling framework for students' creative thinking in problem solving and posing, yet did not specifically analyze the process-based emergence of each indicator across ability levels in qualitative depth. Leikin [19] explored mathematical creativity through multiple solution tasks but concentrated on solution variety rather than the developmental process of individual indicators. Hanurrani and Susanah [22] examined creative thinking in open-ended problem solving by mathematical ability but did not distinguish reasoning depth as a separate indicator from elaboration, nor did they conduct a detailed process-based qualitative analysis of indicator emergence. Saraswati [13] investigated creative thinking levels through multiple solution tasks, yet focused more on outcome categorization than on how indicators progressively appear during problem solving. Additionally, Rohati et al. [23] explored students' mathematical reasoning behavior qualitatively but did not directly link reasoning processes to creative thinking indicators across ability levels. This gap, the absence of qualitative investigations that explicitly trace the emergence of each creative thinking indicator, including reasoning depth, across different mathematical ability levels, constitutes the core research problem that this study seeks to address.

Therefore, this study aims to describe the emergence of students' mathematical creative thinking indicators, specifically fluency, flexibility, originality, and reasoning depth in solving open-ended problems based on differences in mathematical ability. Using a descriptive qualitative approach, the study captures not only the outcomes but also the processes of students' creative thinking through written tests and semi-structured interviews. The findings are expected to contribute to a deeper theoretical understanding of the relationship between mathematical ability and the development of creative thinking indicators, while also providing practical implications for teachers in designing open-ended tasks supported by instructional strategies that explicitly promote idea exploration, strategic adaptation, and reflective reasoning [1,5,25]. Ultimately, this study aspires to support more equitable and intentional development of mathematical creative thinking across students with varying ability levels.

2. METHOD

This study employed a descriptive qualitative approach to examine the emergence of students' mathematical creative thinking indicators in solving open-ended problems based on differences in mathematical ability. A qualitative approach was deemed appropriate given that the primary aim of this study was to describe and interpret the thinking processes of individual students in depth, rather than to measure or generalize outcomes across a large population. Descriptive qualitative research allows the researcher to capture the nuances of students' reasoning, strategy use, and idea generation as they naturally unfold during the problem-solving process, which is directly aligned with the process-oriented nature of the research questions in this study.

Research Setting and Participants

The research was conducted at SMA Negeri 14 Kota Jambi, Indonesia, during the even semester of the 2024/2025 academic year. Participants were selected through purposive sampling, a technique considered appropriate when the selection of research subjects is guided by specific, theoretically relevant criteria rather than by random procedures. In this study, the primary criterion was the representation of different levels of mathematical ability, ensuring that the data would capture diverse patterns of creative thinking indicator emergence across the ability spectrum. This approach is consistent with qualitative research traditions that prioritize information-rich cases over statistical representativeness, as the goal is depth of understanding rather than breadth of generalization [18,22].

The research subjects consisted of six students, with two representing high mathematical ability (S1 and S2), two representing medium ability (S3 and S4), and two representing low ability (S5 and S6). The decision to involve six participants was grounded in the principle of informational adequacy appropriate for descriptive qualitative research. In qualitative inquiry, the sufficiency of participants is not determined by fixed numerical criteria but by the depth and richness of data generated and the degree to which emerging patterns can be identified within and across cases [23]. With two participants at each ability level, the study enabled cross-case comparison between ability groups as well as within-group confirmation of emerging patterns. Data saturation was assessed iteratively throughout the data collection and analysis process. Saturation was considered achieved when the written responses and interview data from participants within each ability level displayed consistent thematic patterns regarding the emergence of creative thinking indicators, and no substantially new or divergent information continued to emerge from additional analysis within the same group. The categorization of mathematical ability was determined based on students' cumulative mathematics scores from prior assessments and was confirmed through direct consultation with the mathematics subject teacher. This categorization served as an analytical context for the study rather than as a formal psychometric classification.

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Ethical Considerations

Prior to data collection, all required ethical procedures were fulfilled. Formal written permission to conduct the research was obtained from the principal of SMA Negeri 14 Kota Jambi. The mathematics teacher whose class was involved was also formally informed regarding the research procedures, instruments, timeline, and intended use of data. All six student participants, along with their parents or legal guardians, received clear and complete informed consent information explaining the purpose of the study, the voluntary nature of participation, and the right to withdraw at any time without academic consequence. Participants were assured of the confidentiality of their identities throughout all stages of the research. To protect anonymity, all participants were assigned coded identifiers (S1 through S6) in all data recording, analysis, and reporting. No personally identifying information was disclosed in any part of the study documentation or dissemination.

Research Instruments

The research instruments consisted of open-ended mathematics problems and a semi-structured interview guide. The open-ended problems were drawn from the topic of Systems of Linear Equations in Three Variables (SPLTV), selected because of its contextual applicability and its structural potential to elicit diverse mathematical representations and solution strategies. The problem presented a real-life contextual scenario involving three unknown quantities, specifically a price-based context requiring students to construct a system of equations independently, select appropriate solution methods, and determine a valid contextual answer that satisfied multiple simultaneous conditions. The problem was designed at a moderate-to-high level of cognitive complexity, demanding that students engage in mathematical modeling, strategic decision-making, and reflective evaluation of their results [7,14].

The open-ended nature of the problem was intentionally designed to accommodate multiple valid formulations and solution pathways, thereby creating conditions for the emergence of all four creative thinking indicators. Expected solution diversity included variations in how students constructed and labeled the equation system, differences in the pairs of equations selected for elimination, variations in the sequence of substitution steps applied, and a range of numerically valid contextual answers satisfying the given conditions. This diversity of possible responses provided a productive basis for observing fluency, flexibility, originality, and reasoning depth across students with varying mathematical ability levels [5,19].

The semi-structured interview guide was developed to complement the written test by assessing dimensions of students' thinking not fully visible in their written responses. Interview questions were designed to elicit students' reasoning behind strategy choices, their awareness of alternative approaches, and their reflective evaluation of the solutions they produced. Prior to data collection, both instruments were validated through expert judgment by two mathematics education experts, who evaluated content relevance, conceptual alignment with the creative thinking indicators, and clarity of language.

Revisions were made based on the experts' feedback before the instruments were administered.

Data Collection Procedures

Data were collected through two sequential phases. In the first phase, all six participants completed the open-ended written test individually under standard classroom conditions. In the second phase, semi-structured interviews were conducted with each participant individually, immediately following the written test session. The interviews were audio-recorded with participants' prior consent and subsequently transcribed verbatim for analysis. Each interview session focused on probing the reasoning processes, strategy selection rationale, and problem understanding of each participant, particularly in areas where the written responses were incomplete, ambiguous, or lacked explicit articulation of the thinking process.

Data Analysis

Data analysis was conducted qualitatively through three iterative stages: data reduction, data display, and conclusion drawing. The analysis focused on the emergence of four creative thinking indicators fluency (FC), flexibility (FX), originality (OG), and reasoning depth (RD) using a scoring rubric as a qualitative categorical framework, as presented in Table 1. The rubric scores were not used for quantitative computation but served to categorize the level of each indicator's emergence as evident, moderately evident, less evident, or not evident, providing a structured and consistent basis for cross-case comparison.

The coding process was carried out systematically by the first researcher, who carefully reviewed each student's written work and assigned analytical codes to specific response segments that reflected the characteristics of each creative thinking indicator. To strengthen the credibility and consistency of this process, a cross-checking procedure was conducted in which the second and third researchers independently reviewed a representative selection of coded data segments and evaluated the appropriateness of the assigned codes. Any discrepancies or differences in interpretation were resolved through structured discussion and consensus among all three researchers, thereby strengthening the inter-rater reliability of the analytical process and reducing the risk of single-researcher bias.

The interview data served a distinct and analytically complementary role in the analysis. While the written responses provided direct observable evidence of indicator emergence at the level of the final product, the interview data were used to assess students' internal reasoning processes, strategic awareness, and reflective thinking that were not explicitly articulated in written form. In practice, interview transcripts were systematically cross-referenced with written response codes to confirm, elaborate, or appropriately qualify the categorization assigned to each indicator. For instance, when a student's written work was coded as moderately evident for reasoning depth based on visible justification steps, interview data revealing the student's explicit verbal articulation of solution verification, even when absent from the written response, contributed to a more accurate and nuanced final categorization. This analytical integration of written and interview data ensured that the findings captured both the product and the process dimensions of students' creative thinking, strengthening the overall depth and trustworthiness of the analysis. Data trustworthiness was further established through technique triangulation, whereby evidence from written tests and interview transcripts was consistently compared for each participant across all four creative thinking indicators.

Table 1. Scoring Rubric for Mathematical Creative Thinking Indicators

Score	Fluency	Flexibility	Originality	Reasoning Depth
4 Evident	Generates more than one relevant idea or solution step fluently.	Uses more than one strategy or approach consciously and appropriately.	Produces a unique solution that differs from most other students' responses.	Provides coherent, logical, and reflective reasoning, including justification of strategy choice and solution verification.
3 Moderately evident	Generates one relevant idea or solution step fluently.	Uses an alternative strategy, but not consistently or reflectively.	Produces a solution that is slightly different from common solutions.	Provides reasonably coherent reasoning without explicit reflection or verification.
2 Less evident	Generates limited and less varied ideas.	Switches strategies without a clear justification or relies on a single strategy.	Produces common and procedural solutions.	Reasoning is limited and stops at the final result.
1 Not evident	Fails to generate relevant ideas.	Shows no variation in strategy use.	Shows no originality in the solution.	Shows no reasoning or explanation.

3. RESULTS AND DISCUSSION

3.1. Results

Coding System and Analytical Framework

A systematic coding scheme was applied to identify the emergence of mathematical creative thinking indicators across all written responses. Four analytical codes were used: FC (fluency) for the smoothness and continuity of solution execution; FX (flexibility) for conscious and purposeful adjustments to solution steps or strategies; OG (originality) for modifications departing from standard instructional patterns; and RD (reasoning depth) for the logical coherence, justification, and reflective verification embedded in students' reasoning. Each indicator was categorized along a four-level scale Evident (E), Moderately Evident (ME), Less Evident (LE), or Not Evident (NE) based on the scoring rubric in Table 1. These codes functioned as qualitative analytical tools, not quantitative scores, and were applied jointly to written responses and interview transcripts to ensure comprehensive coverage of both product and process dimensions.

Students with High Mathematical Ability (S1 and S2)

S1 demonstrated the most stable and structured profile among all participants. Fluency was the clearest strength: the elimination-substitution procedure was executed continuously and coherently from initial formulation to the final result, without unnecessary repetition or strategic disruption. Flexibility was present but constrained. S1 consciously selected specific equation pairs to simplify computation, reflecting deliberate tactical adjustment within a single dominant method, without venturing into alternative approaches. Originality was the weakest point; the construction of equations, the solution method, and the overall structure followed conventional classroom procedures closely, with no meaningful reframing of the problem context or solution logic. Reasoning depth was moderate: S1 connected intermediate results to the contextual demands of the problem and verbally confirmed during the interview a sense of needing to verify the solution, yet this reflective step did not appear explicitly in the written work. Summary profile S1: FC = E, FX = ME, OG = LE, RD = ME.

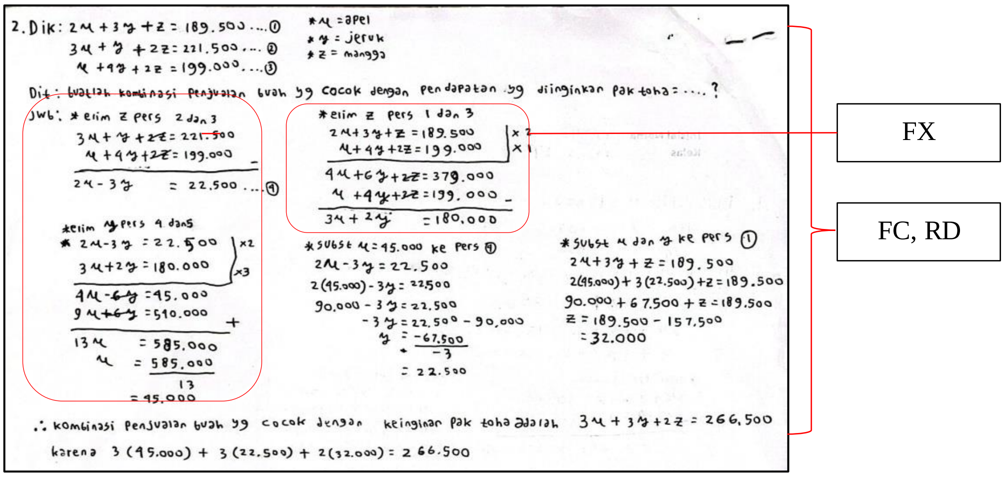

Figure 1. Written response of S1 (high mathematical ability) to Problem 1

S2 presented a balanced but uniformly moderate profile. The solution proceeded in an organized, goal-directed manner, though some steps were repeated due to computational errors, introducing minor discontinuities. Flexibility was visible in S2's reordering of elimination steps and systematic exploration of numerical combinations when identifying the contextual answer. A distinguishing feature compared to S1 was S2's originality: the student independently constructed a self-generated problem scenario during equation formulation, indicating that the modeling process involved independent conceptual decisions rather than mechanical replication of classroom examples. Reasoning depth mirrored S1's level. S2 demonstrated the ability to extend the system's solution to satisfy contextual conditions, though verification and reflective reasoning were not articulated in the written response despite being acknowledged verbally during the interview. Summary profile S2: FC = ME, FX = ME, OG = ME, RD = ME.

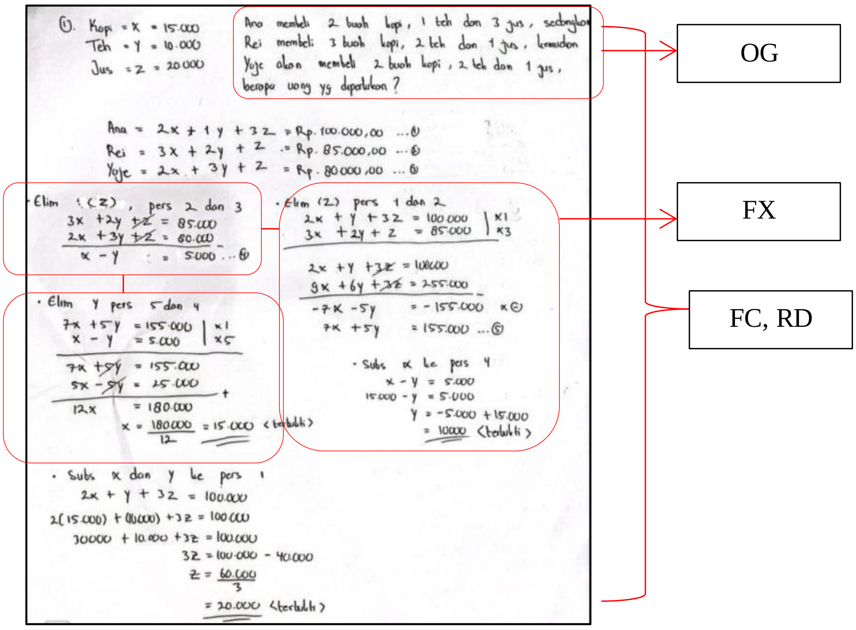

Figure 2. Written response of S2 (high mathematical ability) to Problem 1

Students with Medium Mathematical Ability (S3 and S4)

S3 exhibited a creative thinking profile that developed gradually throughout the problem-solving process. Initial hesitation in constructing suitable equations required early corrections before the solution flow became structured and directional. Once appropriate equations were established, S3 proceeded through elimination and substitution to obtain the correct result. Flexibility appeared in the purposeful replacement of initially ineffective equations and in the exploration of numerical combinations at the final stage, though no alternative methods beyond elimination and substitution were employed. Originality was limited; the combination exploration at the closing stage reflected procedural adjustment rather than conceptual novelty. Reasoning depth was moderate; S3 connected the obtained values to the contextual requirements of the problem, and interview data confirmed awareness of the need to recheck the answer, though this reflective process was absent from the written response. Summary profile S3: FC = ME, FX = ME, OG = LE, RD = ME.

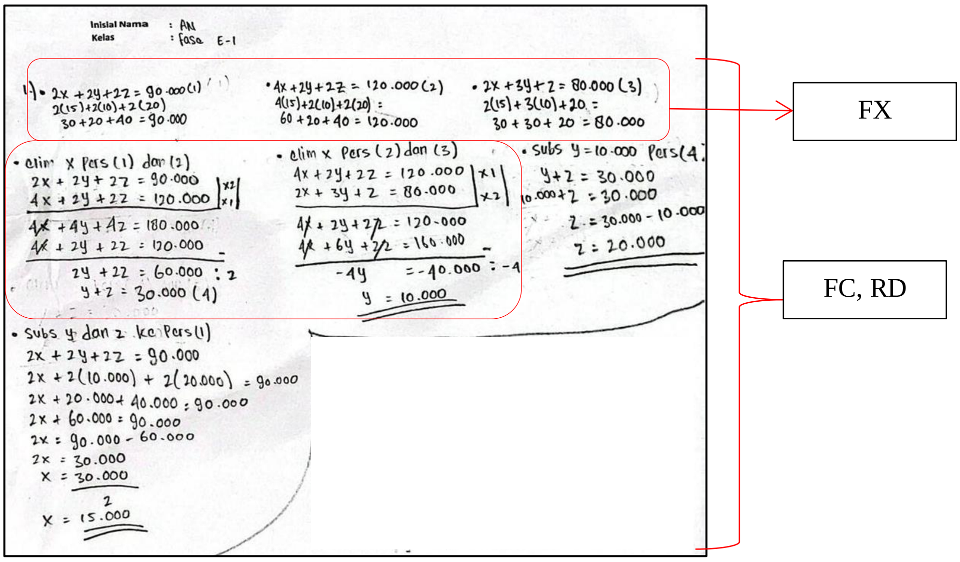

Figure 3. Written response of S3 (medium mathematical ability) to Problem 1

S4 demonstrated a noticeably weaker profile, with all four indicators at the less evident level. Interview data revealed a critical finding absent from the written work: S4 had initially misunderstood the problem requirements, producing and subsequently erasing an incorrect formulation before arriving at the correct equations. As a result, the final written response appeared more complete and fluent than the actual problem-solving process warranted. The adjustments observed were reactive corrections of a misconception rather than strategic adaptations, and therefore did not qualify as flexibility. After resolving the misconception, S4 returned to a standard procedural pathway without any conceptual modification, yielding no evidence of originality. Reasoning depth was similarly constrained: while the final result was mathematically correct, the written response lacked coherent justification, stepwise logical connection, or concluding statements linking the solution to the problem context. Summary profile S4: FC = LE, FX = LE, OG = LE, RD = LE.

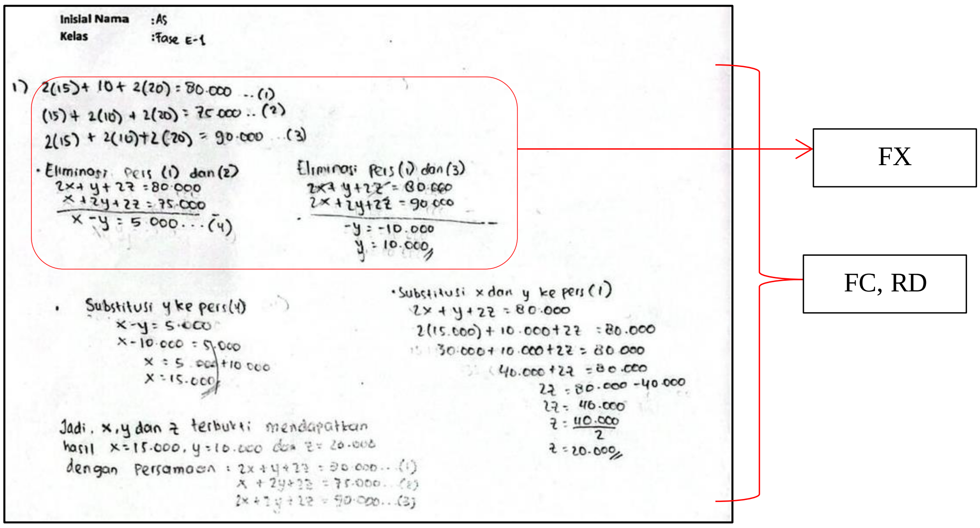

Figure 4. Written response of S4 (medium mathematical ability) to Problem 1

Students with Low Mathematical Ability (S5 and S6)

S5's final written response appeared relatively complete, yet interview data disclosed a substantially more fragmented process. S5 had initially relied on guessing when constructing the equations, without appropriately linking variable assignments to the contextual information provided. These early errors were corrected and erased prior to submission. The remaining visible solution relied exclusively on a single procedural approach, and only one numerical combination was offered for the contextual answer, with no alternative comparisons explored. Originality was absent; the method was fully conventional, and reasoning depth was similarly underdeveloped: S5 verbally acknowledged the need to verify the result during the interview, yet no explicit justification or verification appeared in the written work. Summary profile S5: FC = LE, FX = LE, OG = LE, RD = LE.

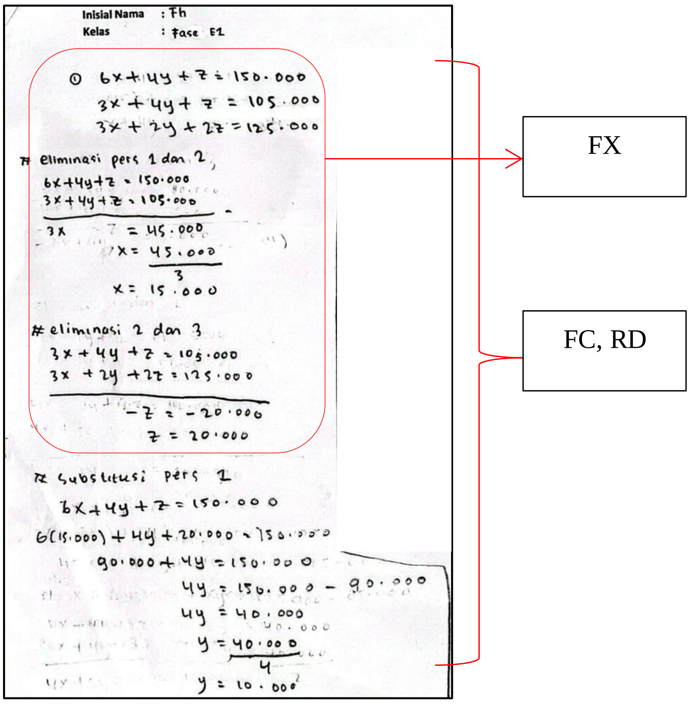

Figure 5. Written response of S5 (low mathematical ability) to Problem 1

S6 presented the least developed profile across all six participants, and uniquely, the instability was directly visible in the written response itself rather than only discoverable through interviews. The work showed frequent changes in steps, repeated elimination attempts across different equation pairs, and numerous written corrections, all reflecting sustained uncertainty rather than deliberate strategic exploration. Unlike the changes observed in other participants, S6's alterations were reactive responses to calculation errors rather than conscious strategic decisions, and thus did not constitute flexibility. Originality was absent, with any observed variation traceable to confusion rather than creative initiative. Reasoning depth was minimal; despite eventually reaching a numerically plausible answer, S6 produced no explicit justification, logical linkage between steps, or concluding verification, and interview data confirmed that all reflective

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checking remained entirely internal. Summary profile S6: FC = LE, FX = LE, OG = LE, RD = LE.

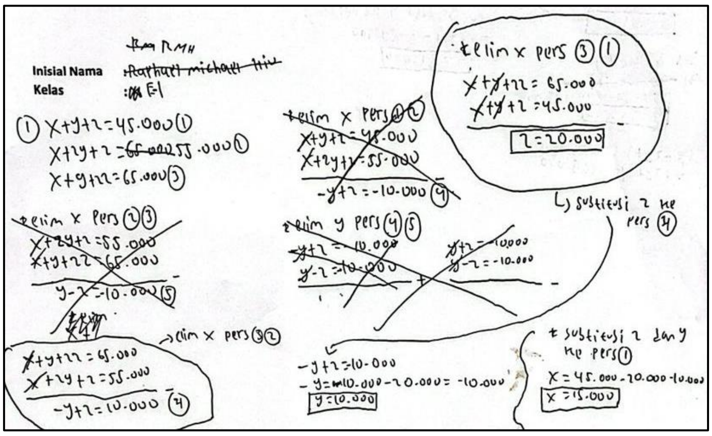

Figure 6. Written response of S6 (low mathematical ability) to Problem 1

Comparative Summary of Indicator Emergence

Table 2 presents a cross-participant comparison of creative thinking indicator emergence, organized by mathematical ability level. The abbreviated labels E, ME, and LE denote Evident, Moderately Evident, and Less Evident, respectively.

Table 2. Comparative Summary of Creative Thinking Indicator Emergence Across Participants

Participant	Ability Level	Fluency (FC)	Flexibility (FX)	Originality (OG)	Reasoning Depth (RD)
S1	High	E	ME	LE	ME
S2	High	ME	ME	ME	ME
S3	Medium	ME	ME	LE	ME
S4	Medium	LE	LE	LE	LE
S5	Low	LE	LE	LE	LE
S6	Low	LE	LE	LE	LE

Note: E = Evident; ME = Moderately Evident; LE = Less Evident

Synthesis of Cross-Case Patterns

First, originality was the most consistently constrained indicator across all six participants, regardless of ability level. No student reached the Evident level for originality, and only S2 reached the Moderately Evident level. This pattern suggests that open-ended problem conditions alone, in the absence of deliberate instructional scaffolding for novel thinking, are insufficient to stimulate genuinely original mathematical responses under current classroom conditions.

Second, a clear and progressive decline in indicator emergence is observed as mathematical ability decreases. High-ability students achieved the broadest indicator profiles, with at least partial evidence across all four categories. Medium-ability students showed pronounced internal variation. S3 maintained a moderate profile broadly comparable to the high-ability group, while S4's profile collapsed uniformly to the less evident level, indicating that the medium-ability category encompasses considerable developmental heterogeneity rather than a uniform intermediate profile. Low-ability students showed consistently limited emergence across all four indicators, with the primary difference between S5 and S6 being the visibility of their instability: S5's fragmented process was concealed in the final written work through erasure, while S6's uncertainty was explicitly present throughout the written response.

Third, a persistent and cross-cutting gap between internal reasoning and written articulation was observed across all ability levels. In every case, interview data revealed reflective awareness, including intentions to verify solutions, recognition of errors, and implicit sensitivity to contextual constraints that were consistently absent from written responses. This gap implies that written test data alone would systematically underestimate the depth of students' actual reasoning processes, reinforcing the analytical necessity of combining written and interview data as complementary sources of evidence.

Fourth, fluency and reasoning depth followed a different developmental trajectory compared to flexibility and originality. Among high and medium-ability students, fluency and reasoning depth emerged at moderate levels even when flexibility and originality were constrained, suggesting that these two indicators may be more readily activated by open-ended problem engagement. Flexibility and originality, by contrast, showed limited emergence across most participants, implying that these indicators depend more critically on prior exposure to exploratory and divergent learning experiences, conditions that standard procedural instruction does not consistently provide.

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3.2. Discussion

The findings of this study indicate that the emergence of mathematical creative thinking indicators in open-ended problem solving varies systematically across levels of mathematical ability. In general, students with high mathematical ability demonstrated broader creative thinking profiles than those with medium and low ability. However, not all indicators emerged at equivalent levels across any group, confirming that high academic achievement does not automatically ensure fully developed mathematical creativity [7,18].

Among high-ability students, fluency and reasoning depth were the most consistently evident indicators, while originality remained the most constrained across all six participants, regardless of ability level.

This suppression of originality, even among the highest-performing students, is theoretically significant. Siswono [18] distinguishes between skilled solvers, who execute procedures fluently and accurately, and creative thinkers, who generate solutions that deviate meaningfully from expected patterns. The high-ability students in this study consistently occupied the skilled-solver position without transitioning into genuine creative production. Leikin [19] similarly found that high-achieving students default to familiar solution schemas unless the instructional environment explicitly demands and rewards novelty. At the cognitive level, Schoenfeld [21] attributes this tendency to functional fixedness, the dominance of learned procedural associations that override divergent thinking even when the problem format permits it. Meier et al. [11] further demonstrated that originality in mathematical problem solving depends not only on competence but on domain-specific creative dispositions cultivated through deliberate instructional exposure, reinforcing that originality suppression reflects a systemic instructional gap rather than an inherent cognitive limitation.

The dominance of procedural solution patterns across all ability levels points to a deeper issue: the lasting influence of procedurally oriented instruction on students' mathematical thinking dispositions. Schoenfeld [21] argued that students develop belief systems mirroring their instructional environment. Students trained primarily through algorithmic, single-solution tasks come to regard mathematics as a domain of procedures to be executed rather than ideas to be generated. Kurniawan et al. [17] reported that students in similar instructional contexts struggle with open-ended problems precisely because they lack strategies for generating and evaluating multiple solution pathways. This study corroborates those findings directly: even when the problem format invited diverse approaches, most participants converged on the single elimination-substitution procedure taught in class. This pattern aligns with what Rohati et al. [23] describe as imitative reasoning, in which students reproduce learned procedures without engaging in the constructive, justification-driven thinking that constitutes genuine mathematical creativity. The persistent gap between students' private reflective awareness consistently revealed through interviews and their written articulation further confirms that students have not been taught to regard written justification as an integral component of mathematical problem solving [12].

The inconsistency within the medium-ability group warrants specific attention. S3 maintained a moderate creative thinking profile broadly comparable to the high-ability students, while S4 showed uniformly limited emergence across all indicators. Hanurrani and Susanah [22] similarly observed within-group variability among medium-ability students, attributing it to differences in self-regulatory strategies and prior exposure to exploratory tasks rather than raw competence differences. This finding implies that mathematical ability, as measured by achievement scores, is a necessary but insufficient predictor of creative thinking development, and that metacognitive and dispositional factors mediate the relationship [10]. Low-ability students showed patterns consistent with Krulik and Rudnick's [20] characterization of algorithmic thinking, with problem-solving processes dominated by procedural recall, hesitation, and withdrawal from strategic exploration, findings corroborated by Suherman and Vidákovich's [10] systematic review across multiple national contexts.

Although open-ended problems structurally create conditions for creative thinking, the findings of this study make clear that their potential is not automatically realized. Becker and Shimada [14] and Silver [7] both emphasized that the effectiveness of open-ended tasks depends critically on the surrounding instructional environment, specifically, whether teachers actively promote divergent thinking, acknowledge multiple solution pathways, and treat novelty as a legitimate mathematical achievement. Without these conditions, open-ended tasks risk being absorbed into the procedural culture of the classroom, with students selecting the most familiar and acceptable approach rather than genuinely exploring the solution space [15,25].

These findings carry important implications for mathematics teachers. At the task design level, isolated open-ended problems are insufficient to shift students' deeply conditioned thinking dispositions; sustained sequences of progressively divergence-demanding tasks are necessary [7,19]. At the pedagogical level, teachers should explicitly scaffold students' ability to generate multiple representations, evaluate alternative pathways, and articulate reasoning in writing, particularly for medium and low-ability students who are most vulnerable to procedural fixation [17,18]. At the assessment level, process-oriented tools such as solution journals or think-aloud protocols are needed to capture reasoning quality beyond answer correctness [10,12].

Critically, however, the limitations of open-ended tasks must be acknowledged. Open-ended problems create opportunity structures, not guaranteed outcomes. Student habituation to procedural learning produces cognitive, motivational, and dispositional barriers that a single task format cannot overcome [20,21]. Moreover, classroom culture factors, including praise patterns, grading norms, and peer comparison dynamics, shape whether students feel safe to generate novel or unconventional solutions [5]. Where correctness and procedural conformity remain the primary values communicated in the classroom, students have little incentive to deviate from expected approaches regardless of task format. Addressing these barriers requires not only redesigned tasks but a sustained shift in instructional culture toward mathematical inquiry, where exploration, justification, and creative deviation are treated as central rather than peripheral mathematical competencies [5,7].

4. CONCLUSION

This study demonstrates that mathematical ability plays a meaningful but non-deterministic role in shaping the emergence of creative thinking indicators during open-ended problem solving, with originality and reasoning depth identified as the most persistently underdeveloped indicators across all ability levels. This pattern reflects the broader influence of procedurally oriented instructional habits rather than cognitive limitations alone. These findings carry significant implications for mathematics education practice: teachers must move beyond task format innovation toward sustained instructional redesign that explicitly cultivates divergent thinking, written justification, and reflective reasoning as core mathematical competencies across all ability groups. Nevertheless, this study acknowledges several important boundaries. The use of six purposively selected participants from a single school in Kota Jambi limits the transferability of the findings, as the results reflect a specific instructional context and cannot be generalized to broader populations; the qualitative nature of the study, while yielding rich process-level insights, also means that the findings are interpretive and context-dependent rather than statistically representative. Future research is encouraged to expand the participant sample across multiple schools and regional contexts to test the consistency of these patterns, to employ longitudinal designs that track the development of creative thinking indicators across instructional interventions, and to investigate the specific role of teacher facilitation strategies and classroom discourse quality in activating originality and reasoning depth within open-ended learning environments. This study contributes to the broader public understanding of mathematics education by highlighting that developing students' creative thinking requires not only well-designed tasks but a fundamental cultural shift in how mathematical competence is defined, practiced, and assessed in everyday classroom settings.

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