



Cognitive barriers in elementary students' mathematical creative thinking on fraction problems: A hierarchical and multidimensional analysis

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Abstract

Background: Mathematical creative thinking is a crucial competency in contemporary mathematics education; however, elementary students often encounter difficulties in developing this ability, particularly in fraction learning. Previous studies have predominantly focused on measuring creative thinking performance, providing limited understanding of the cognitive barriers underlying students' difficulties across different dimensions of creativity.

Aims: This study aims to identify and describe cognitive barriers in sixth-grade students' mathematical creative thinking when solving fraction problems across the dimensions of fluency, flexibility, originality, and elaboration.

Method: A descriptive qualitative-dominant mixed-methods design was employed involving 30 sixth-grade students from an elementary school in Bandung, Indonesia. Data were collected through open-ended mathematical creative thinking tasks and semi-structured interviews. Students were categorized into low-, moderate-, and high-ability groups, and the data were analyzed using the Miles, Huberman, and Saldaña qualitative analysis framework.

Results: The findings revealed that cognitive barriers were hierarchical and multidimensional. Low-ability students experienced representational barriers related to fraction concepts, moderate-ability students demonstrated transitional barriers characterized by dependence on visual representations, and high-ability students exhibited metacognitive barriers affecting precision and originality. Among the creative thinking dimensions, elaboration showed the lowest achievement (12.0%), followed by originality (13.1%), while fraction conceptual understanding remained relatively weak (28.0%).

Conclusion: Mathematical creative thinking difficulties develop hierarchically across ability levels and are strongly interconnected across dimensions. The proposed hierarchical-multidimensional framework offers a foundation for diagnosis-based differentiated instruction in elementary mathematics learning.

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INTRODUCTION

Mathematical creative thinking has become an essential twenty-first-century competency that enables students to address complex problems in an increasingly dynamic and uncertain world (Ibrahim et al., 2024; Schoevers et al., 2020; Shaw et al., 2022). This competency extends beyond procedural fluency and conceptual understanding by involving the ability to generate multiple ideas, construct original solutions, and establish meaningful mathematical connections across diverse contexts (Thompson & Harel, 2021; Wang et al., 2023). In contemporary educational environments, students are expected not only to master mathematical procedures but also to demonstrate creativity when confronted with unfamiliar situations. The rapid advancement of artificial intelligence and

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digital technologies has further increased the importance of creative thinking as routine computational tasks become increasingly automated (Bicer et al., 2021). Consequently, mathematics education has shifted its emphasis toward cultivating higher-order thinking skills that support innovation and adaptability. Mathematical creativity has been associated with effective problem-solving, conceptual reasoning, and the ability to transfer knowledge across different situations. Students who demonstrate strong mathematical creative thinking are generally more capable of exploring alternative strategies and justifying their reasoning in flexible ways. These capabilities are increasingly recognized as important indicators of meaningful mathematical understanding and lifelong learning readiness. As a result, understanding how mathematical creativity develops and identifying factors that hinder its development have become significant concerns in contemporary mathematics education research. Therefore, investigating students' mathematical creative thinking remains an important endeavor for both theoretical advancement and educational practice.

Research in mathematics education has consistently documented that elementary school students experience substantial difficulties in developing mathematical creative thinking, particularly when solving open-ended and non-routine problems. Such difficulties become especially evident in mathematical topics that require flexible conceptual manipulation and multiple representations. Fractions represent one of the most challenging domains in elementary mathematics because they require students to coordinate symbolic, visual, verbal, and procedural knowledge simultaneously (Geary & Xu, 2022). Numerous studies have reported that students struggle to understand fraction magnitude, equivalence, comparison, and operations, even after receiving formal instruction. These conceptual difficulties often limit students' capacity to generate alternative solution strategies and to reason creatively about mathematical situations. Furthermore, students frequently rely on memorized procedures rather than meaningful conceptual understanding when solving fraction problems. Such dependence on routine algorithms may restrict the development of flexibility, originality, and elaboration in mathematical thinking. Previous research has shown that students encounter significant challenges when required to create novel solution methods or explain their reasoning in detail within fraction-related tasks (Flores et al., 2024; Polydoros et al., 2025). Since fractions serve as a foundational concept for advanced mathematical learning, difficulties in this domain may have long-term consequences for students' mathematical development. Therefore, examining mathematical creative thinking within the context of fraction learning provides a valuable opportunity to understand the interaction between conceptual understanding and creative reasoning.

The existing body of research on mathematical creative thinking has predominantly focused on measuring creativity levels through standardized instruments or evaluating the effectiveness of particular instructional approaches designed to enhance creative performance (Suherman & Vidákovich, 2022). While these studies have contributed substantially to the understanding of mathematical creativity, they provide limited insight into the specific difficulties students experience during the creative thinking process. Mathematical creativity is generally conceptualized through the Torrance framework, which consists of four interconnected dimensions: fluency, flexibility, originality, and elaboration. Fluency refers to the ability to generate multiple relevant ideas, flexibility reflects the capacity to use diverse approaches, originality concerns the production of novel solutions, and elaboration involves the ability to develop ideas systematically and comprehensively. Recent educational studies have continued to adopt and refine this framework to understand creative mathematical actions in various learning contexts (Álvarez-Huerta et al., 2022). However, qualitative investigations that specifically identify students' difficulties across these dimensions in fraction learning remain relatively limited. Moreover, previous studies have rarely examined how such difficulties differ according to students' ability levels or how they are associated with underlying cognitive mechanisms. To address this limitation, the present study adopts a

cognitive-barriers perspective grounded in Cognitive Load Theory and metacognitive knowledge theory (Sweller et al., 2019; Toikka et al., 2024). From this perspective, mathematical creative thinking may be constrained by barriers such as functional fixedness, cognitive overload, mental set, insufficient metacognitive monitoring, and representational inflexibility. Despite growing interest in mathematical creativity, little is known about how these cognitive barriers manifest across different dimensions of creativity and across different levels of student ability, thereby indicating a significant gap in the existing literature.

Although mathematical creative thinking has become one of the most extensively investigated topics in mathematics education, previous studies have primarily focused on measuring students' levels of mathematical creativity, developing assessment instruments, or evaluating the effectiveness of instructional approaches designed to enhance creativity (Bicer et al., 2020; Khalid et al., 2020; Schoevers et al., 2020; Suherman & Vidákovich, 2022). Several studies have also examined the relationships between mathematical creativity and academic achievement, self-efficacy, problem-solving ability, and problem-posing skills, while describing the characteristics of mathematical creativity among elementary school students (Bicer et al., 2021; Sadak et al., 2022; Shaw et al., 2022; Yayuk et al., 2020). In contrast, research on fraction learning has predominantly focused on conceptual difficulties, misconceptions, learning obstacles, and the effectiveness of various interventions aimed at improving students' understanding of fractions (Barbieri et al., 2020; Dyson et al., 2020; Jarrah et al., 2022; Lenz et al., 2020; Sari et al., 2024). Studies on cognitive barriers in mathematics have likewise identified various obstacles that influence students' learning processes and mathematical problem solving, including representational obstacles, cognitive overload, and instructional barriers (Barnes, 2021; Murniasih et al., 2020). However, these lines of research have largely developed independently and have not yet provided a comprehensive understanding of how cognitive barriers influence students' mathematical creative thinking in the context of fraction learning. Furthermore, only a limited number of studies have simultaneously examined difficulties across the four dimensions of mathematical creative thinking fluency, flexibility, originality, and elaboration and explored how these difficulties vary across different levels of student ability. Consequently, there remains a lack of a comprehensive conceptual framework capable of explaining the relationship among fraction conceptual understanding, cognitive barriers, and mathematical creative thinking from a hierarchical and multidimensional perspective. Therefore, this study seeks to address this gap by investigating cognitive barriers in elementary students' mathematical creative thinking on fraction problems through a hierarchical and multidimensional analysis based on students' ability levels.

This study aims to identify and describe the difficulties experienced by sixth-grade elementary school students in mathematical creative thinking within the context of fraction learning. Specifically, the study investigates students' difficulties across the four dimensions of the Torrance framework, namely fluency, flexibility, originality, and elaboration. The study further examines how these difficulties differ among students with low, moderate, and high levels of mathematical ability. To achieve this objective, a descriptive qualitative-dominant mixed-methods approach is employed to capture both the extent and nature of students' difficulties. Through open-ended assessment tasks and in-depth semi-structured interviews, the study seeks to uncover not only what difficulties students encounter but also how and why these difficulties emerge. Particular attention is given to the role of fraction conceptual understanding in shaping students' creative thinking performance. In addition, the study explores how various cognitive barriers contribute to the manifestation of difficulties across different dimensions of mathematical creativity. By adopting a cognitive-barriers framework, the research provides a more comprehensive explanation of students' creative thinking difficulties than traditional performance-based assessments. The study also proposes a hierarchical-multidimensional framework that explains how difficulties progress from conceptual barriers to

strategic-transitional barriers and ultimately to metacognitive-refinement barriers. Ultimately, the findings are expected to contribute to theoretical discussions on mathematical creativity and provide practical guidance for developing diagnosis-based differentiated instruction in elementary mathematics education.

LITERATURE REVIEW

Mathematical creative thinking is widely recognized as a fundamental component of contemporary mathematics education because it enables students to generate innovative ideas and solve unfamiliar problems effectively. Unlike routine mathematical performance, creative thinking involves producing multiple solutions, exploring alternative approaches, and constructing meaningful mathematical relationships. Scholars have argued that mathematical creativity represents a synthesis of domain-specific mathematical knowledge and domain-general creative abilities (Schoevers et al., 2020). This perspective suggests that creativity in mathematics requires both conceptual understanding and cognitive flexibility. Students with strong mathematical creative thinking are generally capable of adapting their knowledge to novel situations and developing unconventional yet mathematically valid solutions. Research has demonstrated positive associations between mathematical creativity and problem-solving performance, academic achievement, and mathematical self-efficacy (Bicer et al., 2021). Furthermore, mathematical creativity contributes to deeper conceptual learning because students actively construct and evaluate their own mathematical ideas. Contemporary educational reforms increasingly emphasize creativity as a critical outcome of mathematics instruction in response to the demands of the twenty-first century. Consequently, understanding the factors that support or inhibit mathematical creative thinking has become an important area of research in mathematics education. Investigating students' creative thinking processes is therefore essential for improving both theoretical understanding and instructional practice.

One of the most influential frameworks for understanding mathematical creativity is derived from Torrance's theory of creative thinking. According to Torrance, creativity consists of four interconnected dimensions: fluency, flexibility, originality, and elaboration. Fluency refers to the ability to generate numerous relevant ideas or solutions when responding to a problem. Flexibility reflects the capacity to shift perspectives and employ diverse strategies when solving mathematical tasks. Originality involves producing uncommon or novel solutions that differ from typical responses. Elaboration concerns the ability to develop, refine, and explain ideas in a systematic and detailed manner. These four dimensions collectively provide a comprehensive framework for evaluating creative thinking in educational settings. Previous studies have demonstrated that students often display varying levels of achievement across these dimensions, indicating that creativity is not a single homogeneous construct (Lassig, 2020; Zabelina et al., 2022; Zhang et al., 2021). Research further suggests that weaknesses in one dimension may influence performance in other dimensions because the creative process requires continuous interaction among multiple cognitive functions. Therefore, examining students' difficulties through the lens of the Torrance framework offers a structured approach to understanding the complexity of mathematical creative thinking.

Fractions have long been recognized as one of the most challenging topics in elementary mathematics because they require students to coordinate multiple representations and conceptual relationships simultaneously. Understanding fractions involves more than performing calculations; it requires reasoning about part-whole relationships, proportionality, equivalence, and magnitude (Pedersen & Bjerre, 2021; Schadl & Ufer, 2023). Numerous studies have shown that students frequently experience misconceptions when comparing fractions, identifying equivalent fractions, and performing arithmetic operations involving fractions (Geary & Xu, 2022). These conceptual

difficulties often persist across grade levels and may hinder students' future mathematical development. Researchers have also reported that many students rely on procedural rules without fully understanding the underlying concepts of fractions (Lenz et al., 2020). Such procedural dependence may limit students' ability to think creatively because creative problem solving requires conceptual flexibility rather than mere algorithmic execution. In addition, fraction problems frequently require students to move between symbolic, visual, and verbal representations. Difficulties in coordinating these representations may reduce students' ability to generate multiple solution pathways and justify their reasoning effectively. Because fraction understanding serves as a foundation for later mathematical learning, identifying the nature of students' difficulties in this domain is of considerable educational importance. Consequently, fraction learning provides an appropriate context for investigating the relationship between conceptual understanding and mathematical creative thinking.

The concept of cognitive barriers offers a useful theoretical perspective for understanding why students experience difficulties in mathematical learning and creative problem solving. Cognitive barriers refer to internal obstacles that restrict students' ability to process information, construct understanding, and apply knowledge effectively in unfamiliar situations. Drawing from Cognitive Load Theory, excessive cognitive demands may overwhelm working memory capacity and limit students' ability to engage in higher-order thinking processes (Sweller et al., 2019). Similarly, metacognitive theories suggest that students may encounter difficulties when they fail to monitor, evaluate, or regulate their own thinking effectively (Toikka et al., 2024). Previous studies have identified several forms of cognitive barriers, including functional fixedness, mental set, cognitive overload, representational inflexibility, and insufficient metacognitive monitoring. Functional fixedness occurs when students become trapped in familiar procedures and struggle to generate alternative approaches. Mental set refers to the tendency to rely repeatedly on previously successful strategies even when they are not suitable for new situations. Representational inflexibility emerges when students cannot transition effectively between symbolic, visual, and verbal forms of mathematical representation. These barriers may significantly constrain students' performance across the dimensions of fluency, flexibility, originality, and elaboration. Therefore, understanding cognitive barriers is essential for explaining the underlying mechanisms that impede mathematical creative thinking.

Recent developments in mathematics education have emphasized the importance of examining students' difficulties from multidimensional and developmental perspectives rather than treating learning difficulties as isolated phenomena. Emerging evidence suggests that students' difficulties in mathematical creativity may differ according to their levels of conceptual understanding, cognitive maturity, and problem-solving experience. Students with lower ability levels often experience fundamental conceptual difficulties that prevent them from generating valid mathematical ideas. In contrast, students with moderate ability levels may demonstrate partial understanding but struggle to apply their knowledge flexibly across different contexts. High-ability students frequently possess adequate conceptual knowledge but may encounter difficulties related to metacognitive regulation, originality, and refinement of ideas. These findings indicate that cognitive barriers may develop hierarchically, progressing from conceptual obstacles to more sophisticated metacognitive challenges. However, empirical studies that explicitly examine such hierarchical patterns remain limited, particularly in the context of fraction learning. Furthermore, little is known about how cognitive barriers interact across multiple dimensions of mathematical creative thinking. A hierarchical and multidimensional perspective therefore provides a promising framework for understanding the complexity of students' creative thinking difficulties. Such a perspective may also contribute to the development of diagnosis-based differentiated instruction that addresses the specific needs of learners at different ability levels.

METHOD

Research Design

This study employed a descriptive qualitative-dominant mixed-methods design to investigate elementary students' difficulties in mathematical creative thinking within the context of fraction learning. The qualitative component served as the primary approach because the study sought to explore the nature, characteristics, and underlying mechanisms of students' difficulties across different dimensions of creative thinking. Quantitative data were used to support the classification of students' ability levels and to provide descriptive information regarding their performance. The selection of a qualitative-dominant approach was based on the need to understand complex cognitive processes that cannot be fully captured through numerical data alone. This design enabled the researchers to examine not only the extent of students' difficulties but also how and why such difficulties emerged during problem-solving activities. The study focused on the dimensions of fluency, flexibility, originality, and elaboration as conceptualized within the Torrance framework of creative thinking. Furthermore, the research adopted a cognitive-barriers perspective to interpret the difficulties identified across different ability levels. Through the integration of qualitative and quantitative evidence, the study aimed to provide a comprehensive understanding of mathematical creative thinking difficulties in fraction learning.

Participants

The study was conducted at SDN 212 Harapan Bandung, Indonesia, in December 2025. Participants consisted of 30 sixth-grade students selected through purposive sampling. The selection criteria included comparable instructional experiences, similar class sizes, equivalent academic backgrounds, and the absence of acceleration programs to ensure relatively homogeneous learning conditions. The participants represented a typical elementary school population engaged in formal fraction instruction. Ethical considerations were observed throughout the research process. Approval to conduct the study was obtained from the school administration prior to data collection. Informed consent was secured from both students and their parents or guardians. Participation was voluntary, and students were informed of their right to withdraw from the study at any stage without consequences. To protect confidentiality, all participant identities were anonymized and replaced with initials in all research records and publications.

Instruments and Data Collection

Data were collected using two complementary instruments: a diagnostic test and semi-structured interviews. The diagnostic test consisted of 15 items, including ten multiple-choice items, one short-answer item, and four essay items designed to assess students' fraction conceptual understanding and mathematical creative thinking. The test was constructed based on the Torrance framework and covered four dimensions of creativity: fluency, flexibility, originality, and elaboration. In addition, the instrument included items measuring conceptual understanding of fractions because conceptual knowledge was considered an important prerequisite for creative thinking. The test items covered cognitive levels ranging from C1 to C5 and were distributed across five domains: conceptual understanding, fluency, flexibility, originality, and elaboration. Multiple-choice items were scored dichotomously, while open-ended items were assessed using an analytic rubric designed to evaluate the quality and completeness of students' responses. Content validity was established through a detailed test blueprint aligning each item with specific learning objectives, cognitive levels, and assessment domains. Following the written assessment, semi-structured interviews were conducted to obtain deeper insights into students' cognitive processes and difficulties. The interviews enabled the researchers to investigate not only the outcomes of students' thinking but also the reasoning, strategies, and cognitive barriers underlying their responses.

Data Analysis

Data analysis was conducted using the interactive model proposed by Miles, Huberman, and Saldaña (2014), consisting of data condensation, data display, and conclusion drawing and verification. Quantitative test scores were first analyzed descriptively to determine students' achievement levels and to classify participants into ability categories. Based on the distribution of total test scores, students scoring 14 or below were categorized as low-ability, students scoring between 15 and 17 were categorized as moderate-ability, and students scoring 18 or above were categorized as high-ability. These categories subsequently guided the purposive selection of interview participants. Qualitative data from students' written responses and interview transcripts were coded and analyzed thematically to identify patterns of difficulty across the dimensions of creative thinking. Particular attention was given to identifying the cognitive barriers underlying students' performance. To enhance credibility, findings were triangulated across multiple data sources, including test responses, written work, and interview data. Dependability and confirmability were strengthened through expert review, in which interpretations and coding decisions were examined and discussed among the researchers. An audit trail documenting coding procedures, analytical decisions, and interpretation processes was maintained throughout the study to ensure transparency and trustworthiness.

Research Procedure

The study was conducted through several sequential stages. The first stage involved the development and validation of the diagnostic test and interview protocols based on the theoretical framework of mathematical creative thinking and cognitive barriers. The second stage involved selecting participants and obtaining ethical approval and informed consent. The third stage consisted of administering the diagnostic test to all participating students to assess fraction conceptual understanding and mathematical creative thinking. Following the completion of the test, students' responses were scored and categorized into low-, moderate-, and high-ability groups. The fourth stage involved selecting representative participants from each ability category for in-depth interviews. During the interviews, students were asked to explain their reasoning processes, solution strategies, and difficulties encountered while solving fraction problems. The fifth stage involved transcribing and organizing the qualitative data obtained from interviews and written responses. Subsequently, quantitative and qualitative data were analyzed using the Miles, Huberman, and Saldaña framework. Finally, the findings were synthesized to develop a hierarchical and multidimensional explanation of cognitive barriers in mathematical creative thinking and to formulate implications for diagnosis-based differentiated instruction in elementary mathematics education. To provide a clear overview of the study procedure, the sequence of activities is summarized in Figure 1.

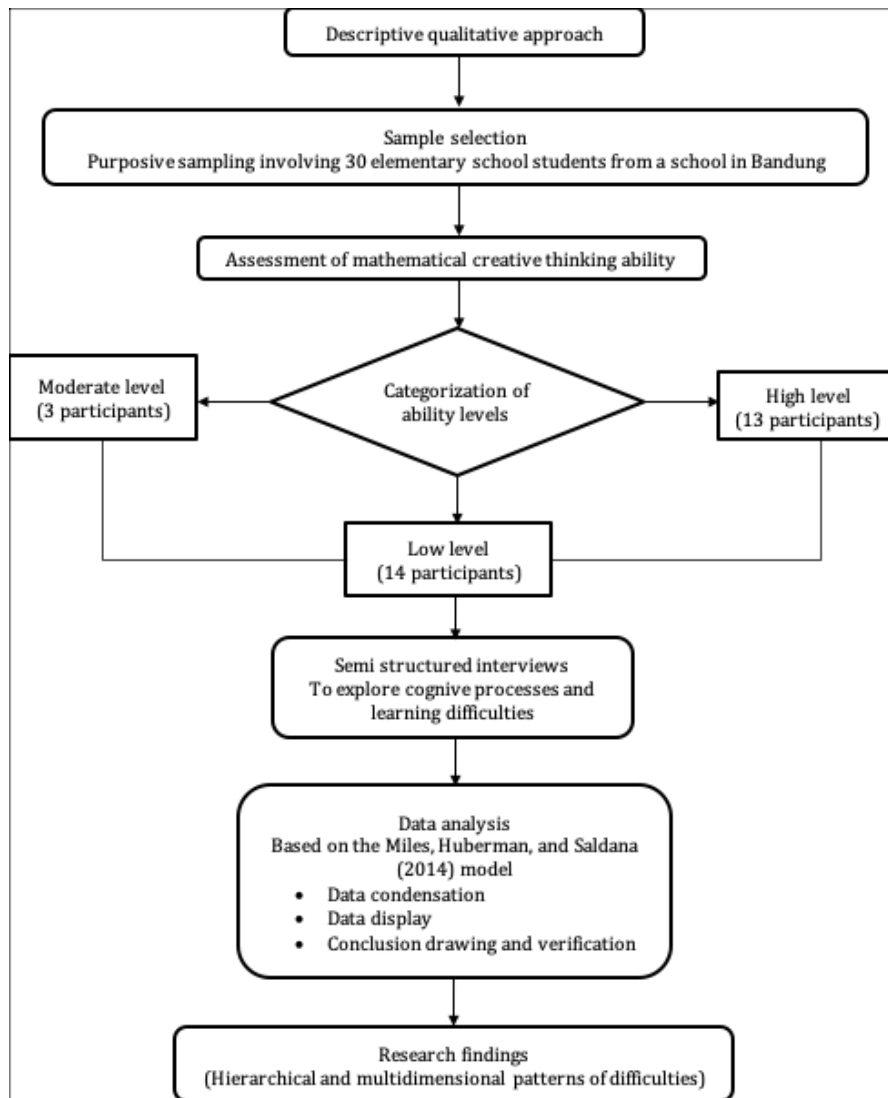


Figure 1. Research Procedure

RESULTS AND DISCUSSION

Results

Descriptive statistical analysis revealed a mean score of 17.47 with a standard deviation of 10.99, indicating heterogeneity of ability within a single class. Throughout the analysis, achievement scores serve as quantitative indicators of the relative difficulty of each dimension, whereas the interview and document analysis characterise the nature of those difficulties; lower achievement is therefore interpreted as evidence of greater difficulty rather than equated with it. Based on categorization, 14 students (46.7%) were classified in the low-ability category, 3 students (10.0%) in the moderate-ability category, and 13 students (43.3%) in the high-ability category.

Table 1. Distribution of Mathematical Creative Thinking Ability

Category	Frequency	Percentage
Low	14	46.7%
Moderate	3	10.0%
High	13	43.3%
Total	30	100%

Beyond the overall categorisation, the conceptual-understanding items revealed a fragile foundation: students reached only 28.0% achievement on these items. The most basic tasks were the weakest identifying and naming a fraction from a shaded diagram succeeded for only 3.3% of students whereas recognising equivalent fractions was comparatively well mastered (76.7%). Conceptual-understanding scores were positively associated with performance on the creative-thinking items (Spearman's $\rho = 0.51$): students with weak conceptual scores averaged 12.0% on the creative-thinking items, compared with 21.0% among those with stronger conceptual scores, and half of the students (15 of 30) scored zero on all four creative-thinking essay items. This pattern indicates that limited conceptual understanding of fractions is closely intertwined with—and plausibly underlies the observed difficulties in creative thinking, consistent with the cascading relationship discussed below.

Thematic analysis of interview transcripts identified distinct patterns of difficulty across each dimension. Regarding conceptual understanding and *fluency*, high-ability students generally comprehended the concepts of numerator and denominator but made errors due to carelessness in reading visual information. As student AR articulated: “Fractions are numbers that represent parts of a whole... But it turned out I misread the problem; I identified the shaded part instead of the unshaded one.” Moderate- and low-ability students exhibited more fundamental conceptual difficulties, such as the inability to connect visual representations with symbolic forms.

The *fluency* dimension showed the highest achievement among the four dimensions at 45.4%, falling within the “Moderate” category. Nevertheless, this achievement remained below 50% and thus cannot be considered satisfactory. In the *fluency* dimension, high-ability students were able to generate more than one solution strategy, although they still encountered difficulties with simplification. Moderate-ability students produced only one dominant strategy, while low-ability students demonstrated limitations in generating ideas, tending to fixate on a single mechanical procedure.

The *originality* dimension showed the second-lowest achievement, at 13.1%, classified as “Very Low.” This finding indicates that students experienced significant difficulty in generating unique and unconventional ideas or solutions, particularly when asked to create word problems that were both original and mathematically logical. The *flexibility* dimension showed higher achievement than originality and elaboration, at 23.4%, classified as “Low”. Regarding the *flexibility* and *originality* dimensions, high-ability students were capable of transitioning between representations and constructing word problems aligned with fraction operations. One of the open-ended items assessed the *originality* dimension: “Create a word problem about activities at home using the operation $2\frac{1}{4} + \frac{2}{3} - 1.5$!” The following is the response of one high-ability student:

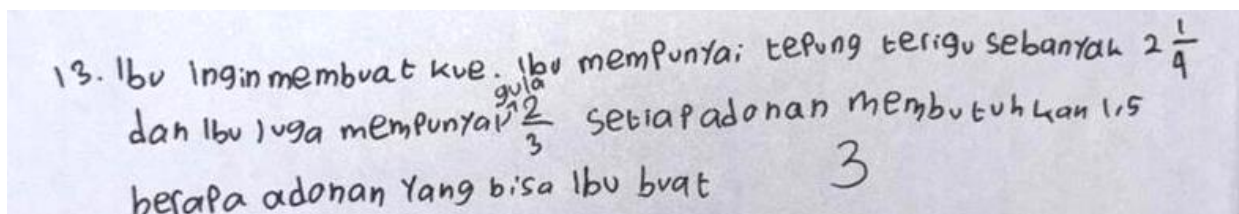


Figure 2. Response of a high-ability student on the item assessing the *originality* dimension

Figure 2. Response of a high-ability student on the originality task. The student was able to formulate a contextual problem using the provided numerical values but showed evidence of metacognitive barriers, as the constructed situation did not accurately reflect the required operation $2\frac{1}{4} + \frac{2}{3} - 1,5$

15 berapa liter susu yang harus diminum? $2\frac{7}{2}$

$$10 \times 11 = 5\frac{11}{10} = 2\frac{1}{4} = 3\frac{10}{6}$$

$$5\frac{1}{2} \times 2 = 10\frac{1}{1} = 10\frac{1}{1}$$

$$3\frac{10}{6} = 1\frac{3}{4} = 2\frac{7}{2}$$

Figure 3. Response of a moderate-ability student on the item assessing the *elaboration* dimension

Figure 3. Response of a moderate-ability student on the elaboration dimension. Although the student attempted to explain the solution process, the response demonstrates transitional cognitive barriers characterized by inconsistent fraction manipulation and difficulty maintaining procedural coherence throughout the problem-solving process.

From this student's response, the researcher found that the student experienced difficulty in connecting mathematical operations with logically coherent real-world situations. The student also demonstrated metacognitive barriers, including fixation on conventional word problem patterns, difficulty "breaking away" from standard procedures, and an inability to evaluate the reasonableness of self-constructed word problems. This phenomenon can be explained through *Cognitive Load Theory* (Sweller et al., 2019): students were overly focused on "insert all the numbers" into a word problem, neglecting logical validation of whether the story context made sense, resulting in *fixation* on familiar procedural patterns.

The *elaboration* dimension showed the lowest achievement of all four at only 12.0%, classified as "Very Low." Moderate- and low-ability students exhibited a high dependence on visual representations and experienced difficulty when visual contexts were unavailable. In the *elaboration* dimension, high-ability students provided relatively coherent explanations but still struggled with finding common denominators and simplifying fractions. Moderate-ability students produced inconsistent explanations, while low-ability students provided fragmentary explanations.

Table 2. Synthesis of Difficulty Patterns by Ability Category

Dimension	High-Ability	Moderate-Ability	Low-Ability
Conceptual Understanding	Carelessness errors	Representational confusion	Unable to comprehend fraction meaning
Fluency	≥ 2 strategies; simplification difficulties	Limited to one strategy	Unable to generate alternatives
Flexibility	Employed multiple representations	Dependent on visual aids	Inflexible
Originality	Capable of creating contextual problems	Difficulty initiating ideas	Unable to generate ideas
Elaboration	Coherent explanations; simplification difficulties	Inconsistent explanations	Fragmentary explanations

The findings demonstrated that cognitive barriers play a central role in students' difficulties with mathematical creative thinking. The identified cognitive barriers can be categorized into three principal types according to student ability level. First, representational barriers experienced by low-ability students, manifested as an inability to connect visual and symbolic representations, indicating

insufficiently developed cognitive schemata. Second, transitional barriers in moderate-ability students, characterized by excessive dependence on concrete visual representations, resulting in difficulty transitioning to abstract thinking. Third, metacognitive barriers in high-ability students, manifested as *fixation* on standard procedures that impeded the generation of original ideas. This pattern indicates that cognitive barriers develop hierarchically in accordance with students' increasing ability levels, ranging from barriers at the basic information processing level to barriers at the metacognitive regulation level.

A focused analysis of the constructed-response (essay) items, which most directly elicit creative thinking, revealed difficulties considerably more pronounced than the aggregate per-dimension scores suggested. On these open-ended items, achievement reached only 29.3% for *fluency* (Item 11), 7.5% for *flexibility* (Item 12), 9.2% for *originality* (Items 13–14 combined), and 10.7% for *elaboration* (Item 15), with between 73% and 80% of students scoring zero on Items 12 through 15. Notably, *flexibility*—which appeared comparatively higher (23.4%) at the aggregate level—collapsed to 7.5% on the open-ended item, indicating that the recognition-format (multiple-choice) items had partially masked the depth of students' difficulties with genuine creative thinking. This pattern reinforces the interpretation that the observed difficulties are pervasive rather than confined to a single dimension.

Discussion

The finding that low-ability students experienced comprehensive conceptual difficulties provides empirical evidence that basic fraction conceptual understanding constitutes a critical foundation for the development of mathematical creative thinking ability. The inability to connect visual representations with symbolic forms indicates insufficiently developed cognitive schemata necessary for building creative thinking (Winata et al., 2025). Regarding the *fluency* dimension, low-ability students struggled not only with generating multiple ideas but also with producing a single valid idea, which subsequently exerted a cascading effect on *flexibility* and *originality* (Kholid & Ahadiyahati, 2022; Weiss & Wilhelm, 2022). The difficulty patterns of moderate-ability students indicate a transitional phase from procedural to creative thinking that has not yet stabilized. These students possessed emerging conceptual understanding but encountered significant barriers when required to generate alternative strategies or original ideas. The high dependence on visual representations suggests that their understanding remains at the concrete level and has not yet progressed to the abstract stage (Star et al., 2022). Students were aware of possible alternatives but lacked adequate metacognitive strategies to explore them.

High-ability students, despite possessing relatively strong creative thinking ability, still exhibited difficulties in precision, simplification, and consistency of elaboration. This finding affirms that mathematical creative thinking is not static but requires continuous *refinement* (Beaty & Johnson, 2021; Forthmann et al., 2020). Errors attributable to carelessness indicate the need for developing *monitoring* and *evaluating* skills in the problem-solving process (Fyfe et al., 2022; Toikka et al., 2024). A noteworthy finding of this research is the presence of metacognitive barriers among high-ability students when confronted with the *originality* dimension. This phenomenon can be explained through the perspective of *Cognitive Load Theory* (Sweller et al., 2019) and reinforces that excessively rigid metacognitive knowledge of particular procedures can constrain students' flexibility in seeking alternative solutions (Toikka et al., 2024). The inability of students to “break away” from standard patterns (*fixation*) demonstrates that high proficiency in fraction content does not necessarily correlate positively with lateral thinking ability, thus necessitating more intensive *guided inquiry* interventions (Wang et al., 2023). This finding constitutes a *novelty* of this study, contributing to the understanding that metacognitive barriers can serve as a *bottleneck* for

mathematical creativity development among high-ability students (Jiang et al., 2023; Rajadurai & Ganapathy, 2023).

The findings of this study revealed several cognitive factors that impede students' mathematical creativity. First, *functional fixedness*, which causes students to become entrapped in a single familiar solution method without being able to perceive alternatives. This barrier was clearly evident among high-ability students who, despite mastering fraction operation procedures, were unable to apply them in the context of original word problems. Second, *cognitive overload*, which occurs when students must simultaneously process conceptual and procedural information, thereby limiting cognitive capacity for creative thinking. Third, *mental set*, or the tendency to employ previously successful strategies even when they are inappropriate for new problems. Fourth, insufficient *metacognitive monitoring*, which renders students unable to evaluate the reasonableness of their solutions, as evidenced by mathematically illogical word problem responses that went unnoticed by students. Fifth, *representational inflexibility*, or the inability to transition between representations (visual, symbolic, verbal), which restricts exploration of alternative solutions. Understanding these creativity-impeding factors is essential as a foundation for designing targeted instructional interventions for each student ability category.

The distinct characteristics of difficulties affirm that mathematical creative thinking is hierarchical and multidimensional in nature. The hierarchy is evident in a pattern that progresses from comprehensive-conceptual to strategic-transitional to metacognitive-refinement. Multidimensionality is reflected in the close interdependencies among dimensions, whereby difficulties in one dimension impact others, indicating that the four dimensions constitute integrated components within a cognitive system (Rawlings et al., 2025). These findings reinforce the notion that developing mathematical creative thinking requires a holistic approach that considers the interrelationships among dimensions and students' levels of cognitive development.

A closer reading of the essay responses clarified the mechanisms underlying these difficulties, with two cross-cutting patterns proving particularly salient. First, moderate- and low-ability students exhibited a marked dependence on visual representations: on the fraction-comparison task they relied exclusively on the relative length of bar models and reported having no symbolic fallback strategy once the visual was withdrawn (for example, stating that without a picture they were unable to proceed), whereas high-ability students could resort to common denominators or decimal conversion. Second, a shared procedural bottleneck equalising denominators and simplifying results was reported as the most difficult step across all three ability levels and recurred across the *flexibility* and *elaboration* items. This converging evidence substantiates the proposed cascading relationship, whereby limited operational fluency with fractions constrains students' capacity to generate alternative strategies and to develop complete, justified solutions. A representative instance is shown in Figure 3, in which a moderate-ability student attempted the multi-step elaboration item but carried out the successive subtractions in a procedurally inconsistent manner, reflecting both an unstable grasp of mixed-number notation and the difficulty of sustaining a coherent chain of steps once the denominators differed.

The *originality* item proved especially diagnostic of metacognitive barriers among high-ability students. Rather than failing to generate ideas, these students produced superficially plausible word problems that nonetheless did not faithfully or coherently represent the prescribed operation ($2\frac{1}{4} + \frac{2}{3} - 1.5$) for instance, embedding the given numbers in a narrative while reframing the required computation, or accepting a mathematically incorrect equivalence as valid without recognising the mismatch (see Figure 2). This indicates that their limitation lay not in idea generation but in the evaluative, self-regulatory monitoring that *originality* demands, confirming that strong procedural proficiency in fractions does not automatically confer the capacity to assess the reasonableness of one's own creative product.

Implications

The findings of this study have important theoretical, methodological, and pedagogical implications for mathematics education, particularly in the development of mathematical creative thinking among elementary school students. From a theoretical perspective, the study demonstrates that mathematical creative thinking should not be viewed as a single cognitive construct but rather as a hierarchical and multidimensional system in which difficulties evolve according to students' levels of mathematical ability. The proposed hierarchical-multidimensional framework extends existing creativity literature by explaining how cognitive barriers progress from representational difficulties to transitional constraints and ultimately to metacognitive challenges. The findings further highlight the strong interdependence among fluency, flexibility, originality, and elaboration, indicating that weaknesses in one dimension may negatively influence performance in other dimensions. From a methodological standpoint, the integration of diagnostic testing and qualitative interviews provides a comprehensive approach for identifying not only the extent of students' difficulties but also the cognitive mechanisms underlying those difficulties. The study also demonstrates the value of employing a cognitive-barriers perspective to complement traditional assessments of mathematical creativity, thereby enabling a deeper understanding of students' thinking processes. In practical terms, the results suggest that instructional interventions should be differentiated according to students' specific difficulty profiles rather than relying on uniform teaching approaches. For low-ability students, instruction should prioritize strengthening conceptual understanding of fractions through multiple representations and concrete learning experiences. For moderate-ability students, scaffolding strategies should focus on facilitating the transition from visual and procedural reasoning toward more flexible and abstract forms of mathematical thinking. For high-ability students, learning activities should emphasize metacognitive regulation, reflective reasoning, and opportunities to generate and evaluate original mathematical ideas. Furthermore, the framework developed in this study may serve as a diagnostic tool for teachers to identify students' cognitive barriers more accurately and design targeted interventions that support the progressive development of mathematical creative thinking in elementary mathematics classrooms.

Limitations and Suggestions for Future Research

Several limitations should be considered when interpreting the findings of this study and determining their applicability to broader educational contexts. First, the study involved only 30 sixth-grade students from a single elementary school, which limits the transferability of the findings to other student populations, educational settings, and cultural contexts. Although the qualitative-dominant design enabled an in-depth exploration of students' cognitive barriers, the relatively small sample size restricts broader generalization of the identified hierarchical patterns. Second, the investigation focused exclusively on fraction content, and therefore the proposed hierarchical-multidimensional framework may not fully capture the characteristics of mathematical creative thinking difficulties in other domains such as geometry, algebra, measurement, or statistics. Third, the study primarily examined cognitive barriers and did not explicitly investigate the influence of affective variables, including motivation, self-efficacy, mathematical anxiety, or learning engagement, which may also contribute to creative thinking performance. Fourth, the cross-sectional nature of the study captured students' difficulties at a single point in time and was therefore unable to reveal how cognitive barriers evolve throughout students' mathematical development. Fifth, the unequal distribution of participants across ability categories, particularly the limited number of moderate-ability students, may have reduced the representativeness of the identified transitional difficulty patterns. Future research should therefore involve larger and more diverse samples drawn from multiple schools and educational contexts to enhance the robustness and transferability of the

findings. Longitudinal studies are also recommended to examine how cognitive barriers and mathematical creative thinking develop over time and across different stages of schooling. Further investigations may extend the framework to other mathematical topics to determine whether similar hierarchical and multidimensional patterns emerge across content domains. In addition, future studies should integrate cognitive, affective, and instructional variables to provide a more comprehensive explanation of students' creative thinking difficulties. Experimental and quasi-experimental research evaluating diagnosis-based differentiated instruction may also help determine the effectiveness of targeted interventions designed to address specific cognitive barriers identified within each ability category. Such efforts will contribute to refining the proposed framework and advancing both theoretical understanding and practical strategies for fostering mathematical creative thinking in elementary mathematics education.

CONCLUSION

This study concludes that elementary school students' difficulties in mathematical creative thinking on fraction problems are hierarchical and multidimensional in nature, reflecting variations in cognitive barriers across different levels of mathematical ability. The findings demonstrate that students' difficulties cannot be explained solely by differences in performance outcomes but must also be understood through the underlying cognitive processes that shape creative thinking. Low-ability students predominantly experienced representational barriers characterized by limited conceptual understanding of fractions and difficulties connecting visual and symbolic representations. Moderate-ability students exhibited transitional barriers manifested in their dependence on visual representations and their inability to flexibly transfer knowledge to more abstract problem-solving contexts. High-ability students, although demonstrating stronger conceptual understanding and procedural competence, encountered metacognitive barriers that constrained originality, self-monitoring, and the evaluation of creative solutions. Among the four dimensions of mathematical creative thinking, elaboration and originality emerged as the most challenging dimensions, while fluency showed relatively higher achievement despite remaining below desirable levels. The findings further indicate that weaknesses in fraction conceptual understanding are closely associated with reduced performance across all dimensions of creative thinking. In addition, the results reveal strong interrelationships among fluency, flexibility, originality, and elaboration, suggesting that difficulties in one dimension may generate cascading effects on other dimensions. Based on these findings, the study proposes a hierarchical-multidimensional framework that explains the progression of cognitive barriers from conceptual difficulties to metacognitive constraints as students' ability levels increase. This framework contributes to the literature by integrating perspectives from mathematical creativity, fraction learning, and cognitive barrier theories into a coherent explanatory model. The study also highlights the importance of adopting diagnostic approaches that identify students' specific difficulty profiles rather than relying solely on conventional assessments of achievement. Ultimately, the findings provide both theoretical insights and practical guidance for the development of diagnosis-based differentiated instruction aimed at fostering mathematical creative thinking in elementary mathematics education.

AUTHOR CONTRIBUTIONS STATEMENT

Yoani Mbipi conceptualised and designed the study, developed the research instruments, collected and analysed the data, and drafted the manuscript. Tatang Herman supervised the research, contributed to the study design and the theoretical framework, validated the analysis and

interpretation of the findings, and critically reviewed and revised the manuscript for important intellectual content. Both authors read and approved the final version of the manuscript.

REFERENCES

- Álvarez-Huerta, P., Muela, A., & Larrea, I. (2022). Disposition toward critical thinking and creative confidence beliefs in higher education students: The mediating role of openness to diversity and challenge. *Thinking Skills and Creativity*, 43, 101003. <https://doi.org/10.1016/j.tsc.2022.101003>
- Barbieri, C. A., Rodrigues, J., Dyson, N., & Jordan, N. C. (2020). Improving fraction understanding in sixth graders with mathematics difficulties: Effects of a number line approach combined with cognitive learning strategies. *Journal of Educational Psychology*, 112(3), 628–648. <https://doi.org/10.1037/edu0000384>
- Barnes, A. (2021). Enjoyment in learning mathematics: Its role as a potential barrier to children's perseverance in mathematical reasoning. *Educational Studies in Mathematics*, 106(1), 45–63. <https://doi.org/10.1007/s10649-020-09992-x>
- Beaty, R. E., & Johnson, D. R. (2021). Automating creativity assessment with SemDis: An open platform for computing semantic distance. *Behavior Research Methods*, 53(2), 757–780. <https://doi.org/10.3758/s13428-020-01453-w>
- Bicer, A., Chamberlin, S., & Perihan, C. (2021). A meta-analysis of the relationship between mathematics achievement and creativity. *The Journal of Creative Behavior*, 55(3), 569–590. <https://doi.org/10.1002/jocb.474>
- Bicer, A., Lee, Y., Perihan, C., Capraro, M. M., & Capraro, R. M. (2020). Considering mathematical creative self-efficacy with problem posing as a measure of mathematical creativity. *Educational Studies in Mathematics*, 105(3), 457–485. <https://doi.org/10.1007/s10649-020-09995-8>
- Dyson, N. I., Jordan, N. C., Rodrigues, J., Barbieri, C., & Rinne, L. (2020). A fraction sense intervention for sixth graders with or at risk for mathematics difficulties. *Remedial and Special Education*, 41(4), 244–254. <https://doi.org/10.1177/0741932518807139>
- Flores, M. M., Hinton, V. M., & Schweck, K. B. (2024). Using CRA-I to teach fraction and decimal concepts to students with learning disabilities. *Learning Disability Quarterly*, 47(1), 44–58. <https://doi.org/10.1177/07319487231176545>
- Forthmann, B., Szardenings, C., & Holling, H. (2020). Understanding the confounding effect of fluency in divergent thinking scores: Revisiting average scores to quantify artifactual correlation. *Psychology of Aesthetics, Creativity, and the Arts*, 14(1), 94–112. <https://doi.org/10.1037/aca0000196>
- Fyfe, E. R., Byers, C., & Nelson, L. J. (2022). The benefits of a metacognitive lesson on children's understanding of mathematical equivalence, arithmetic, and place value. *Journal of Educational Psychology*, 114(6), 1292–1306. <https://doi.org/10.1037/edu0000715>
- Geary, D. C., & Xu, K. M. (2022). Evolution of self-awareness and the cultural emergence of academic and non-academic self-concepts. *Educational Psychology Review*, 34(4), 2323–2349. <https://doi.org/10.1007/s10648-022-09669-2>
- Ibrahim, I., Khalil, I. A., & Prahmana, R. C. I. (2024). Mathematics learning orientation: Mathematical creative thinking ability or creative disposition? *Journal on Mathematics Education*, 15(1), 253–276. <https://doi.org/10.22342/jme.v15i1.pp253-276>
- Jarrah, A. M., Wardat, Y., & Gningue, S. (2022). Misconception on addition and subtraction of fractions in seventh-grade middle school students. *Eurasia Journal of Mathematics, Science and Technology Education*, 18(6), Article em2115. <https://doi.org/10.29333/ejmste/12070>
- Jiang, C., Wang, Y., Wang, S., Zou, Y., Ouyang, J., Jia, D., & Zhou, Y. (2023). *Rational design of compact ceramic coating on SiCp/Al composites by tailoring soft sparking discharge of plasma electrolytic oxidation*. *Surface and Coatings Technology*, 466, 129578.
- Khalid, M., Saad, S., Hamid, S. R. A., Abdullah, M. R., Ibrahim, H., & Shahrill, M. (2020). Enhancing creativity and problem solving skills through creative problem solving in teaching mathematics. *Creativity Studies*, 13(2), 270–291. <https://doi.org/10.3846/cs.2020.11027>

- Kholid, M. N., & Ahadiyati, A. (2022). Students' metacognition in solving non-routine problems. *Al-Jabar: Jurnal Pendidikan Matematika*, 13(1), 125–138. <https://doi.org/10.24042/ajpm.v13i1.11776>
- Lassig, C. (2020). A typology of student creativity: Creative personal expression, boundary pushing and task achievement. *Thinking Skills and Creativity*, 36, 100654. <https://doi.org/10.1016/j.tsc.2020.100654>
- Lenz, K., Dreher, A., Holzäpfel, L., & Wittmann, G. (2020). Are conceptual knowledge and procedural knowledge empirically separable? The case of fractions. *British Journal of Educational Psychology*, 90(3), 809–829. <https://doi.org/10.1111/bjep.12333>
- Murniasih, T. R., Sa'dijah, C., Muksar, M., & Susiswo. (2020). Fraction sense: An analysis of preservice mathematics teachers' cognitive obstacles. *Center for Educational Policy Studies Journal*, 10(2), 27–47. <https://doi.org/10.26529/cepsj.742>
- Pedersen, P. L., & Bjerre, M. (2021). Two conceptions of fraction equivalence. *Educational Studies in Mathematics*, 107(1), 135–157. <https://doi.org/10.1007/s10649-021-10030-7>
- Polydoros, G., Artikis, C., & Voudouri, A. (2025). Optimizing fraction learning for elementary students with learning difficulties in mathematics: EdTech-based educational settings. *International Journal of Educational Reform*. Advance online publication. <https://doi.org/10.1177/10567879251355557>
- Rajadurai, R., & Ganapathy, H. (2023). Effect of use of metacognitive instructional strategies in promoting mathematical problem solving competence amongst undergraduate students in facing competitive examination. *Cogent Social Sciences*, 9(1), 2173103. <https://doi.org/10.1080/23311886.2023.2173103>
- Rawlings, B. S., Chetwynd-Talbot, D., Husband, E., Nuttall, A., Quinn, E., Taggart, R., & Roome, H. E. (2025). Divergent thinking is linked with convergent thinking: Implications for models of creativity. *Thinking & Reasoning*, 31(4), 586–608. <https://doi.org/10.1080/13546783.2025.2485059>
- Sadak, M., Incikabi, L., Ulusoy, F., & Pektas, M. (2022). Investigating mathematical creativity through the connection between creative abilities in problem posing and problem solving. *Thinking Skills and Creativity*, 45, 101108. <https://doi.org/10.1016/j.tsc.2022.101108>
- Sari, A. D., Suryadi, D., & Dasari, D. (2024). Learning obstacle of probability learning based on the probabilistic thinking level. *Journal on Mathematics Education*, 15(1), 207–226. <https://doi.org/10.22342/jme.v15i1.pp207-226>
- Schadl, C., & Ufer, S. (2023). Beyond linearity: Using IRT-scaled level models to describe the relation between prior proportional reasoning skills and fraction learning outcomes. *Child Development*, 94(6), 1642–1658. <https://doi.org/10.1111/cdev.13954>
- Schoevers, E. M., Kroesbergen, E. H., & Kattou, M. (2020). Mathematical creativity: A combination of domain-general creative and domain-specific mathematical skills. *The Journal of Creative Behavior*, 54(2), 242–252. <https://doi.org/10.1002/jocb.361>
- Shaw, S. T., Luna, M. L., Rodriguez, B., Yeh, J., Villalta, N., & Ramirez, G. (2022). Mathematical creativity in elementary school children: General patterns and effects of an incubation break. *Frontiers in Education*, 7. <https://doi.org/10.3389/educ.2022.835911>
- Star, J. R., Tuomela, D., Joglar-Prieto, N., Hästö, P., Palkki, R., Abánades, M. Á., Pejlare, J., Jiang, R. H., Li, L., & Liu, R.-D. (2022). Exploring students' procedural flexibility in three countries. *International Journal of STEM Education*, 9(1), 4. <https://doi.org/10.1186/s40594-021-00322-y>
- Suherman, S., & Vidákovich, T. (2022). Assessment of mathematical creative thinking: A systematic review. *Thinking Skills and Creativity*, 44, 101019. <https://doi.org/10.1016/j.tsc.2022.101019>
- Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. *Educational Psychology Review*, 31(2), 261–292. <https://doi.org/10.1007/s10648-019-09465-5>
- Thompson, P. W., & Harel, G. (2021). Ideas foundational to calculus learning and their links to students' difficulties. *ZDM—Mathematics Education*, 53(3), 507–519. <https://doi.org/10.1007/s11858-021-01270-1>

- Toikka, S., Eronen, L., Atjonen, P., & Havu-Nuutinen, S. (2024). Combined conceptualisations of metacognitive knowledge to understand students' mathematical problem-solving. *Cogent Education*, 11(1), 2357901. <https://doi.org/10.1080/2331186X.2024.2357901>
- Wang, T., Zhang, L., Xie, Z., & Liu, J. (2023). How does mathematical modeling competency affect the creativity of middle school students? The roles of curiosity and guided inquiry teaching. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.1044580>
- Weiss, S., & Wilhelm, O. (2022). Is flexibility more than fluency and originality? *Journal of Intelligence*, 10(4). <https://doi.org/10.3390/jintelligence10040096>
- Winata, W., Widiyasari, R., Pramuditya, S. A., Anwar, H., & Ramadhanty, K. P. (2025). Difficulties in learning mathematics: Qualitative studies using NVivo 15. *Educational Process: International Journal*. <https://doi.org/10.22521/edupij.2025.17.397>
- Yayuk, E., Purwanto, P., As'ari, A. R., & Subanji, S. (2020). Primary school students' creative thinking skills in mathematics problem solving. *European Journal of Educational Research*, 9(3), 1281–1295. <https://doi.org/10.12973/eu-jer.9.3.1281>
- Zabelina, D. L., Zaonegina, E., Revelle, W., & Condon, D. M. (2022). Creative achievement and individual differences: Associations across and within the domains of creativity. *Psychology of Aesthetics, Creativity, and the Arts*, 16(4), 618–636. <https://doi.org/10.1037/aca0000439>
- Zhang, Z. S., Hoxha, L., Aljughaiman, A., Arënliu, A., Gomez-Arizaga, M. P., Gucyeter, S., Ponomareva, I., Shi, J., Irueste, P., Rogl, S., Nunez, M., & Ziegler, A. (2021). Social environmental factors and personal motivational factors associated with creative achievement: A cross-cultural perspective. *The Journal of Creative Behavior*, 55(2), 410–432. <https://doi.org/10.1002/jocb.463>