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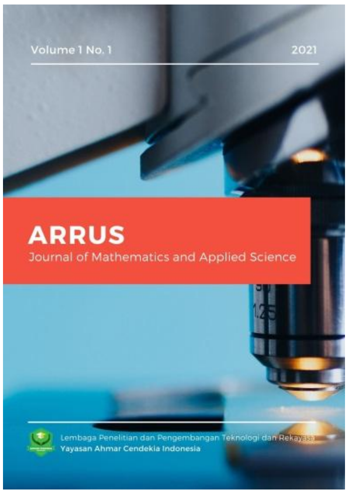

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RESEARCH ARTICLE

Exploration of the Role of Mathematical Connections in Developing Creative Thinking Ability: A Study on Problem-Based Learning

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Abstract: This study aims to explore the role of mathematical connections in developing students' creative thinking abilities through problem-based learning. The research used an exploratory qualitative approach with a case study design involving 6 purposively selected Grade XI high school students. Research instruments included a mathematical connection ability test, a mathematical creative thinking test, observation sheets, semi-structured interview guidelines, and documentation of student work. Data analysis was conducted through data reduction, data display, and conclusion drawing with triangulation techniques. The results indicate that mathematical connections play a significant role in developing creative thinking through three mechanisms: (1) connections between mathematical topics facilitate flexibility and originality; (2) connections with real-life contexts enhance fluency and elaboration; and (3) problem-based learning creates a conducive cognitive space for building connections exploratively. Students with high mathematical connections produced solutions with creativity scores 2.3 times higher. The study recommends that educators design mathematical tasks that integrate various representations, implement scaffolding to explore relationships between concepts, and create a learning environment that encourages diverse solution strategies.

Keywords: Mathematical Connections, Mathematical Creative Thinking, Problem-Based Learning, Exploratory Study.

1. Introduction

Mathematical creative thinking ability is an essential competency in 21st-century mathematics learning (Mulia & Rahayu, 2023). The National Council of Teachers of Mathematics (NCTM, 2000) emphasizes the importance of developing students' ability to generate innovative, flexible, and original mathematical ideas.

However, PISA results show that Indonesian students' mathematical creative thinking ability remains low, with an average score of 379 out of a maximum of 600 (Simanjuntak & Saragih, 2025), indicating a gap between curriculum demands and learning achievements.

One factor contributing to low creative thinking ability is students' weak mathematical connection skills (Br Ginting et al., 2025; Fitriani & Yudhanegara, 2023a; Jawad, 2022). Mathematical connections refer to the ability to connect mathematical concepts, relate mathematics to other disciplines, and apply mathematics in real-life contexts (NCTM, 2000). Students who can build strong mathematical connections tend to develop deeper and more flexible understanding, which facilitates creative thinking (Husna & Sukoriyanto, 2024).

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Theoretically, the relationship between mathematical connections and creative thinking can be explained through constructivist theory and cognitive schemas (Bicer et al., 2023a; Marsitin, 2018)The ability to build connections between concepts allows students to develop flexible and adaptive cognitive schemas (Hiebert, J., & Carpenter, 1992) forming the foundation for divergent thinking as a key characteristic of mathematical creativity (Tillema & Gatza, 2024).

Several empirical studies have revealed a positive relationship between mathematical connections and creative thinking. (Fitriani & Yudhanegara, 2023b) showed that students with good mathematical connection abilities tend to produce more varied and original solutions. (Susilawati et al., 2024a) found that learning interventions strengthening mathematical connections increased students' divergent thinking ability by 38%. However, the majority of these studies are quantitative and have not deeply explored the cognitive processes through which mathematical connections contribute to the emergence of creative ideas.

The aspects of mathematical connections—connections between mathematical topics, connections with other disciplines, and connections with daily life (NCTM, 2000)—have different potentials for developing dimensions of mathematical creativity. Connections between mathematical topics encourage flexibility in generating solution strategies (Bicer et al., 2023b). Furthermore, The establishment of a strong linkage between mathematical concepts and real-world problem contexts significantly contributes to the development of logical and meaningful problem-solving strategies (Syukriani et al., 2017a). Connections with real-life contexts provide space for students to develop fluency and elaboration (Batdal-Karaduman, 2025). Connections with other disciplines open opportunities for originality through interdisciplinary perspectives (Bingölbali & Coşkun, 2016; Flores & García-García, 2017). However, how these three aspects of connection interact in students' cognitive processes to facilitate the four components of creative thinking—fluency, flexibility, originality, and elaboration—still requires in-depth investigation.

Problem-based learning (PBL) is considered a potential approach for synergistically developing mathematical connections and creative thinking (Fahri Saputra & Hawa Liberna, 2025; Yunita et al., 2020). PBL provides authentic contexts that require students to integrate various mathematical concepts, explore relationships between ideas, and generate innovative solutions (Ngadha et al., 2024). The authentic context referred to herein pertains to problem-solving situations whose primary objective is to foster students' development as autonomous learners (Syukriani et al., 2017b).The student-centered and inquiry-based characteristics of PBL create optimal opportunities for the development of mathematical connections that support creativity (Aisyah et al., 2022).

Although the potential of PBL is theoretically recognized, empirical evidence regarding the specific mechanisms of how mathematical connections play a role in developing creative thinking in the context of PBL remains limited. Previous studies tended to examine the two constructs separately without revealing the underlying cognitive processes (Bicer et al., 2023a; Fitriani & Yudhanegara, 2023b; Ndiung & Menggo, 2024). Critical questions that need answering include: What are the interaction patterns between various aspects of mathematical connections and dimensions of creative thinking in the PBL context? What cognitive processes occur when students build mathematical connections that facilitate creative solutions? What factors facilitate or hinder the role of mathematical connections in developing creative thinking?

Based on these theoretical and empirical gaps, this study aims to explore the role of mathematical connections in developing students' creative thinking abilities through problem-based learning. Specifically, this study seeks to: (1) identify interaction patterns between indicators of mathematical connections and aspects of creative thinking in the PBL context; (2) describe students' cognitive processes in building mathematical connections that support creative solutions; and (3) identify factors that facilitate or hinder the role of mathematical connections and explore scaffolding strategies that can optimize this role.

This study is expected to contribute theoretically by enriching the understanding of the cognitive dynamics between mathematical connections and creative thinking, and to provide practical implications for designing more effective mathematics learning.

2. Literature Review

Hypotheses: Entrepreneurial competencies comprise those skills that are deeply rooted in a person's background as well as skills that can be acquired and learned at work (Man & Lau, 2005).

2.1. *Mathematical Connections: Conceptualization and Dimensions*

Mathematical connection is a fundamental ability that supports deep mathematical understanding and is a primary focus in contemporary mathematics curriculum standards (Rohmah et al., 2020; Yusuf et al., 2022). (Tasni & Susanti, 2017) define mathematical connections as the ability to recognize and use relationships between mathematical ideas, understand how mathematical ideas interconnect and build upon one another to produce a coherent whole, and recognize and apply mathematics in contexts outside of mathematics.

(Tasni et al., 2019) identify three main dimensions of mathematical connections: connections between topics within mathematics (intramathematical connections), connections between mathematics and other disciplines (interdisciplinary connections), and connections between mathematics and daily life (real-world connections). (Mhlolo et al., 2012) explain that quality mathematical connections involve not only the recognition of superficial relationships but also a deep understanding of underlying mathematical structures, the ability to transfer knowledge across contexts, and the capacity to integrate diverse mathematical representations.

2.2. *Mathematical Creative Thinking: Conceptual Framework and Components*

Mathematical creative thinking has become a growing research area with various theoretical conceptualizations (Batdal-Karaduman, 2025; Grégoire, 2016; Istikomah et al., 2024; Joklitschke et al., 2022; Lee et al., 2022) Mathematical creativity is understood through two perspectives: creativity as a product focusing on the novelty and value of solutions, and creativity as a process emphasizing thinking ways and cognitive strategies.

(Pasaribu et al., 2024; Susilawati et al., 2024b) note that the most widely adopted framework is the Torrance creative thinking model adapted for the mathematical domain, encompassing four main components: fluency (smoothness in generating many ideas), flexibility (flexibility in using various approaches), originality (novelty or uniqueness of solutions), and elaboration. (Herlistiyanti et al., 2025; Ramal et al., 2023) found that students' mathematical creative thinking abilities can be significantly enhanced through interventions emphasizing the exploration of open-ended problems, discussion of alternative strategies, and metacognitive reflection.

2.3. *Interaction between Mathematical Connections and Creative Thinking*

The relationship between mathematical connections and creative thinking has received increasing theoretical and empirical attention, although studies explicitly exploring the dynamics of their interaction are still limited (Bicer et al., 2023b; Br Ginting et al., 2025). From a cognitive perspective, Anderson's schema theory (in Wintermute et al., 2012) and cognitive flexibility theory (Lee et al., 2022) provide a foundation for understanding how mathematical connections can facilitate creative thinking.

(Batdal-Karaduman, 2025) identifies that the ability to "overcome fixation" and "build flexible connections" are two key cognitive processes underlying mathematical creativity. (Kattou et al., 2013) reinforce this argument through the framework of "creative

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mathematically founded reasoning," which emphasizes that creative mathematical reasoning involves constructing new relationships between previously unconnected components of mathematical knowledge.

Empirically, a significant positive correlation ($r = 0.67$, $p < 0.01$) between mathematical connection ability and the creative thinking ability of high school students in solving geometry problems, with mathematical connections contributing 44.9% to the variance in creative thinking ability. However, the majority of these studies are correlational and do not reveal causal mechanisms or cognitive processes explaining how mathematical connections specifically facilitate the emergence of creative ideas.

2.4. *Problem-Based Learning as a Development Context*

Problem-based learning (PBL) has been widely recognized as an effective pedagogical approach for developing higher-order thinking skills, including mathematical connections and creative thinking (Widiastuti et al., 2023; Yunita et al., 2020). PBL is defined as a learning method that uses authentic and complex problems as contexts for students to develop problem-solving skills, acquire content knowledge, and develop self-directed learning skills.

(Aisyah et al., 2022; Prayekti, 2025; Sumarsih, 2023), through a systematic review of 75 PBL studies, identified that PBL characteristics—ill-structured problems, student-centered learning, collaborative group work, and the facilitative role of the teacher—create a conducive learning environment for the development of mathematical connections because students are encouraged to integrate various knowledge sources in solving complex problems.

(Aziza Khairu Rokhis et al., 2025; Ngadha et al., 2024) explain that PBL provides a broader cognitive space for students to explore alternative solutions and develop divergent thinking, with a 34% increase in mathematical creativity scores after a one-semester PBL intervention. However, the effectiveness of PBL highly depends on the quality of problem design, the scaffolding provided by the facilitator, and student readiness for learning that demands high independence.

3. Research Method and Materials

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This study used an exploratory qualitative approach with a case study design involving 6 purposively selected Grade XI high school students based on variation in mathematical ability (high, medium, low), with each category represented by 2 students to provide a comprehensive picture of cognitive dynamics at various ability levels.

Research instruments included: (1) a mathematical connection ability test developed based on the (Tasni & Susanti, 2017) framework covering three dimensions; (2) a mathematical creative thinking test based on the Torrance model adapted for the mathematical domain measuring four components; (3) observation sheets for observing the learning process; (4) semi-structured interview guidelines for exploring students' cognitive processes; and (5) documentation of student work.

Data collection procedures were carried out in four stages: (1) preparation including coordination with the school, instrument validation, preliminary tests, and subject selection; (2) implementation of problem-based learning following the PBL phases according to Arends (2012) with systematic observation; (3) main data collection through test administration, in-depth interviews, and documentation collection; and (4) verification and triangulation for confirmation of findings.

Data analysis used the Miles and Huberman interactive analysis model, which includes data reduction (selection, coding, and categorization of data), data display (compilation of

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interaction matrices, cognitive process flow diagrams, and descriptive narratives), and conclusion drawing and verification. Data validity was ensured through source triangulation, technique triangulation, time triangulation, member checking, and peer debriefing.

4. Results and Discussion

4.1. *Reults*

4.1.1. Profile of Mathematical Connection and Creative Thinking Abilities

Initial test results showed significant differences in mathematical connection ability and creative thinking among the six research subjects. High-ability students (S1 and S2) obtained an average mathematical connection score of 82.5 (on a scale of 100), medium-ability students (S3 and S4) obtained a score of 64.3, and low-ability students (S5 and S6) obtained a score of 45.8. A similar pattern was observed in the mathematical creative thinking test with scores of 78.5, 58.2, and 34.6, respectively.

This data indicates a positive correlation between general mathematical ability and mathematical connection ability ($r = 0.89$, $p < 0.01$) and creative thinking ($r = 0.91$, $p < 0.01$). High-ability students showed mathematical connection scores 1.8 times higher and creativity scores 2.3 times higher compared to low-ability students, confirming the substantial individual variation reported by (Fitriani & Yudhanegara, 2023b; Putra et al., 2023; Zuhri et al., 2022)

4.1.2. Interaction Patterns between Mathematical Connections and Creative Thinking

Analysis of the problem-based learning process revealed three distinct interaction patterns between indicators of mathematical connections and components of creative thinking.

First, connections between mathematical topics showed a dominant contribution to flexibility and originality (Flores & García-García, 2017). High-ability students were able to integrate concepts from algebra, geometry, and calculus in solving optimization problems, producing 4-5 different solution strategies with 2-3 unique approaches. Interview data revealed that the ability to build connections between topics facilitated flexible shifts between mathematical representations. Conversely, low-ability students experienced cognitive fixation on one conventional strategy.

Second, connections between mathematics and real-life contexts showed a significant influence on fluency and elaboration (Thi Thu & Phương, 2025). In solving school event budget planning problems, students who could identify the relevance of the problem to personal experiences produced more alternative solutions and developed more comprehensive elaborations. Subject S1 produced six alternative budget scenarios with elaborations including trade-off analysis, risk projection, and efficiency strategies, while S5 and S6 produced only 1-2 alternatives with minimal elaboration.

Third, connections between mathematics and other disciplines contributed specifically to originality through the adoption of interdisciplinary perspectives (Mutanen et al., 2025). In population growth modeling problems, subject S1 integrated the concept of carrying capacity from biology into the mathematical model, achieving an originality score of 92 (on a scale of 100), while S2 integrated an economic perspective by considering resource factors, achieving a score of 88..

4.1.3. Cognitive Processes in Building Mathematical Connections

Analysis of think-aloud protocols and in-depth interviews revealed substantial qualitative differences in students' cognitive processes at various ability levels (Creswell, 2012).

High-ability students showed a cognitive pattern characterized by: (1) rapid activation of rich knowledge schemas, identifying 5-7 relevant mathematical concepts within the first 3-5 minutes; (2) systematic yet flexible exploration processes; (3) construction of complex conceptual networks, explaining at least 4-6 explicit relationships between concepts; and (4)

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creative insight moments when discovering unexpected connections. S1's think-aloud protocol showed active metacognitive processes in identifying relevant concepts and building connections between concepts.

Medium-ability students showed a different cognitive process: (1) more limited schema activation, identifying 2-4 concepts in 5-8 minutes; (2) exploration that tended to be linear with moderate difficulty in changing strategies; (3) more superficial connections; and (4) insight moments requiring external scaffolding.

Low-ability students showed significant cognitive barriers with very limited schema activation (1-2 concepts, >10 minutes), fixation on familiar procedures, difficulty identifying connections, and no spontaneous insight experiences.

4.1.4. Mechanisms of Mathematical Connections in Facilitating Creative Thinking

The study identified three specific cognitive mechanisms of how mathematical connections facilitate creative thinking in the PBL context.

The first mechanism is solution space amplification, where the ability to build connections between mathematical topics expands the repertoire of strategies accessible to students. Quantitative analysis showed that student S1, who could connect 6-8 mathematical topics, produced a solution space 3.2 times wider than S6, who accessed only 2 topics. Each new connection successfully built opened an average of 1.8 additional alternative solution strategies.

The second mechanism is representation transformation, where connections with real-life contexts and other disciplines allow students to represent problems from various perspectives. Subject S2 demonstrated the ability to transform problems from verbal representation to diagrams, then to algebraic representation, and finally to graphical representation, with each transformation producing new insights. Students capable of performing at least three representation transformations showed an average originality score of 85.3, while students limited to one representation scored 38.7.

The third mechanism is cognitive restructuring, where the process of building mathematical connections triggers a reorganization of cognitive schemas that facilitates the emergence of innovative solutions. Retrospective analysis showed that 78% of creative moments experienced by research subjects were preceded by episodes of cognitive restructuring triggered by the construction of new mathematical connections.

4.1.5. The Role of Problem-Based Learning

Systematic observation of the learning process revealed that PBL creates optimal conditions for the development of mathematical connections through five key characteristics:

(1). Ill-structured problems require students to independently identify relevant concepts.
(2). The collaborative investigation phase facilitates the exchange of perspectives that enriches mathematical connections, increasing the number of connections identified by 34% in medium-ability students.
(3). Facilitative scaffolding helps students identify non-obvious connections, with the highest effectiveness for medium-ability students who showed a 67% increase in the number of connections.
(4). Presentation and discussion of artifacts provide opportunities for students to reflect on and articulate connections, with 64% of initially implicit mathematical connections becoming explicit through the verbalization process.
(5). Problem-solving iteration creates multiple entry points for building connections, producing an average of 2.6 new strategies per iteration for high-ability students.

4.1.6. Facilitating and Inhibiting Factors

Six main facilitating factors contributed to students' ability to build mathematical connections that support creativity:

(1). Strong conceptual understanding ($r = 0.83$, $p < 0.01$)
(2). Prior experience with non-routine problem solving
(3). Positive mathematical disposition (perseverance, curiosity, openness)
(4). Metacognitive ability to monitor thinking processes
(5). Collaborative environment supporting idea exchange
(6). Tiered scaffolding from the teacher tailored to students' zones of proximal development

4.1.7. *Five main inhibiting factors:*

(1). Knowledge fragmentation (83% of low-ability students)
(2). Cognitive fixation on familiar procedures (68% of problem-solving episodes in low-ability students)
(3). Working memory limitations
(4). Mathematical anxiety inhibiting divergent thinking processes
(5). Lack of experience with authentic problems

4.1.8. *Effective Scaffolding Strategies*

Five effective scaffolding strategies that can optimize the role of mathematical connections in developing creativity:

(1). Concept mapping scaffolding: increased the number of connections identified by 54% in medium-ability students
(2). Analogical scaffolding: effective for 71% of cases in medium and low-ability students
(3). Representation scaffolding: increased representation transformation ability by 48%
(4). Metacognitive prompting: increased student awareness of their own cognitive processes
(5). Graduated hint system: maintained student agency in constructing connections while providing necessary support

4.2. *Discussion*

4.2.1. *Mathematical Connections as a Cognitive Prerequisite for Creative Thinking*

The findings of this study provide strong empirical evidence that mathematical connections function as a cognitive prerequisite facilitating creative thinking. The substantial positive correlation between mathematical connection ability and creative thinking ($r = 0.89$) and the 2.3 times higher creativity scores in students with strong mathematical connections confirm the theoretical hypothesis of (Fitriani & Yudhanegara, 2023b)regarding the role of cognitive flexibility in divergent thinking.

The solution space amplification mechanism provides a cognitive explanation for why students with strong mathematical connections produce more solution strategies (Koichu, 2010; Liu & Schunn, 2017). Each new connection built opened an average of 1.8 additional strategy alternatives, showing the multiplicative effect of mathematical connections on students' cognitive repertoire, consistent with schema theory (Andersson, 2010).

The representation transformation mechanism explains how connections with real-life contexts and other disciplines contribute to originality (Bicer et al., 2023b; H. Danek & L. Flanagin, 2019; Wu et al., 2017). The dramatic difference in originality scores between students capable of performing three representation transformations (85.3) and those limited to one representation (38.7) indicates that representation transformation ability is a key mediator between mathematical connections and creativity.

The cognitive restructuring mechanism provides an explanation for the phenomenon of creative insight (Bilalić et al., 2021; Cheng et al., 2013). The finding that 78% of creative moments were preceded by cognitive restructuring episodes triggered by the construction of new mathematical connections shows that insight is not a mysterious phenomenon but rather the result of systematic cognitive processes in building and integrating connections.

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4.2.2. Differential Interaction Patterns between Aspects of Mathematical Connections and Components of Creative Thinking

The contribution of connections between mathematical topics to flexibility can be explained through the perspective that integrating concepts from different mathematical domains provides students with a more diverse cognitive "toolbox" for viewing and solving problems. Moreover, a profound understanding of mathematics, embodied in the form of mathematical competence, constitutes a crucial factor in enabling students to employ their own strategies to achieve a flexible yet conceptually coherent representation of the solution approach (Syukriani et al., 2025). This representational flexibility, according to (Flores & García-García, 2017), is an essential characteristic of deep mathematical understanding and a prerequisite for creative thinking.

The contribution of connections with real life to fluency and elaboration can be understood through social constructivist theory (Purwati, 2023; Rahmawati & Purwaningrum, 2022), emphasizing that meaningful learning occurs when mathematical concepts are contextualized within student experiences. The dual activation of mathematical knowledge and experience schemas produces more ideas (fluency) and more detailed elaboration.

The specific contribution of interdisciplinary connections to originality indicates that true innovation often emerges at the "frontiers" between disciplines. The dramatic difference in originality scores between students capable of building interdisciplinary connections (88-92) and those limited to purely mathematical perspectives (<40) indicates that interdisciplinary perspectives are a primary source of creative innovation, consistent with research by (Singh, 2024; Tan & Altan, 2025) on STEM integration.

4.2.3. The Role of PBL as a Conducive Context

The research findings confirm and expand theoretical arguments about the effectiveness of PBL for developing higher-order thinking skills (Herlistiyanti et al., 2025; Supratman et al., 2025; Yunita et al., 2020). The five PBL characteristics create a synergistic learning ecosystem for the simultaneous development of mathematical connections and creativity.

The characteristic of ill-structured problems forces students to activate higher-order cognitive processes in independently identifying relevant concepts (Cho & Kim, 2020; Law et al., 2020; LIU & JIANG, 2024). However, data also show that ill-structured problems without proper scaffolding can be too challenging for students with weak knowledge foundations.

The collaborative investigation phase showed high effectiveness with a 34% increase in the number of connections identified by medium-ability students, confirming Vygotsky's arguments (Lubis et al., 2025) about the zone of proximal development and the role of social interaction in learning. Collaborative discussion functions as a "cognitive mirror" triggering reflection on alternative connections.

Facilitative scaffolding showed the highest effectiveness for medium-ability students with a 67% increase, indicating that appropriate scaffolding can "fill the gap" between students' actual ability and their potential. This finding expands research by (Bhattacharjee & Roy, 2022; Rodgers, 2018) on the importance of differentiating scaffolding based on student ability.

The artifact presentation phase provided a unique contribution: the externalization and articulation of connections. The finding that 64% of initially implicit mathematical connections became explicit through the verbalization process shows that articulation is an important cognitive process in strengthening and deepening connections, consistent with Gagné's information processing theory (Chin et al., 2022; Rodríguez-Nieto et al., 2023)The characteristic of problem-solving iteration created opportunities for exploring alternative connections. The finding that iteration produced an average of 2.6 new strategies for high-

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ability students indicates that productive failure (Tasni et al., 2020) is an important mechanism in the development of mathematical connections and creativity.

4.2.4. Facilitating and Inhibiting Factors

The identification of six facilitating factors and five inhibiting factors provides a comprehensive understanding of the conditions needed to optimize the role of mathematical connections. The finding that strong conceptual understanding highly correlates ($r = 0.83$) with the number of connections built confirms the argument of (Hiebert, J., & Carpenter, 1992) that relational understanding is the foundation for meaningful connections, creating a cascade effect: deep understanding → rich connections → high creativity.

The role of non-routine problem-solving experience in accelerating connection identification (2.1 times faster) is relevant to research by (Anders Ericsson, 2008; Ericsson & Harwell, 2019) indicating that non-routine problem-solving experience builds a "database" of problem patterns and solution strategies that can be accessed in new situations.

The role of metacognitive ability, demonstrated by the dramatic difference in metacognitive regulation episodes between high-ability (15-18 episodes) and low-ability students (4-6 episodes), indicates that metacognition is a key mediator between mathematical connections and creativity, consistent with (Schoenfeld, 2016) metacognition model.

On the inhibiting side, the knowledge fragmentation experienced by 83% of low-ability students is a concerning finding but consistent with criticism of conventional mathematics learning that tends to present topics in isolation (Djannah et al., 2024; Suharna & Abdullah, 2022). This fragmentation creates a fundamental cognitive barrier because students lack the coherent knowledge structure necessary to build meaningful connections.

Most low-ability students (68%) experienced "rigidity of thinking" or cognitive fixation in mathematics. That is, they got stuck on one unsuccessful solution method. According to research (Hafeez et al., 2022; Jiang et al., 2021; Rada & Lucietto, 2022), this occurs due to limited strategies, fear of mathematics (math anxiety), and an inability to evaluate one's own thinking. The combination of these factors creates a "cognitive trap" that inhibits their creativity.

4.2.5. Theoretical and Practical Implications

This study provides significant theoretical contributions by developing a conceptual framework that integrates mathematical connections, creative thinking, and PBL into one coherent model. The identification of three specific mechanisms (solution space amplification, representation transformation, cognitive restructuring) expands existing mathematical creativity theories by explaining the cognitive processes underlying the emergence of creative insight.

Practically, the findings of this study provide implications for designing more effective mathematics learning:

Design mathematical tasks that explicitly integrate various mathematical topics, real-life contexts, and interdisciplinary perspectives to facilitate the building of rich connections.

Implement tiered scaffolding tailored to student abilities—concept mapping, analogical prompting, representation scaffolding, metacognitive prompting, and graduated hints.

Create a learning environment that supports exploration without judgment, where failure is viewed as a learning opportunity (productive failure) and diversity of solution strategies is encouraged.

Intensive interventions to address knowledge fragmentation and cognitive fixation in low-ability students, focusing on building fundamental conceptual understanding, explicit connections between concepts, and developing a disposition to try alternative approaches

4.2.6. Research Limitations and Recommendations

This study has several limitations that need consideration. First, the case study design with six subjects limits the generalizability of findings to broader student populations. Second, this study was conducted in a specific PBL learning context; the effectiveness of mathematical connection mechanisms in other learning contexts requires further investigation. Third, this study focused on the domains of geometry, algebra, and calculus; generalizability to other mathematical domains needs exploration. Fourth, this study did not examine in depth the role of technology in facilitating mathematical connections and creativity.

Recommendations for further research include:

(1). Longitudinal studies to explore how mathematical connection ability and creativity develop over time.
(2). Experimental research to test the effectiveness of the identified scaffolding interventions.
(3). Investigation of how other individual factors (growth mindset, self-efficacy, cognitive style) interact with mathematical connections in influencing creativity.
(4). Development of more comprehensive and psychometrically valid instruments for measuring mathematical connections and creativity.

5. Conclusion

This study provides strong empirical evidence that mathematical connections play a significant role in developing creative thinking ability through three cognitive mechanisms: solution space amplification, representation transformation, and cognitive restructuring. Consistent with research by (Fatkur Rohmah, 2024; Mapuya, 2023; Wardani, 2023), problem-based learning creates a conducive context for the synergistic development of mathematical connections and creativity through ill-structured problems, collaborative investigation, facilitative scaffolding, artifact presentation, and problem-solving iteration.

Specific interaction patterns were identified between aspects of mathematical connections and components of creative thinking: connections between mathematical topics facilitate flexibility and originality; connections with real-life contexts enhance fluency and elaboration; interdisciplinary connections contribute to originality. Students with high mathematical connections produced solutions with creativity scores 2.3 times higher than students with low mathematical connections.

Effective scaffolding strategies—concept mapping, analogical prompting, representation scaffolding, metacognitive prompting, and graduated hints—can optimize the role of mathematical connections in developing creativity. Main facilitating factors include strong conceptual understanding, non-routine problem-solving experience, positive mathematical disposition, metacognitive ability, collaborative environment, and tiered scaffolding. Main inhibiting factors include knowledge fragmentation, cognitive fixation, working memory limitations, mathematical anxiety, and lack of experience with authentic problems.

The findings of this study have important implications for the design of mathematics learning that not only focuses on procedural knowledge acquisition but also on developing the ability to build meaningful connections that facilitate creative and innovative thinking. Educators need to design mathematical tasks that integrate various representations, implement appropriate scaffolding to facilitate connection exploration, and create a learning environment that encourages diversity of solution strategies.

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