

Enhancing Students' Mathematical Creative Thinking through Problem-Based Learning: A Systematic Literature Review (2020–2025)

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Abstract

This study presents a systematic literature review of research published between 2020 and 2025 examining the effectiveness of Problem-Based Learning (PBL) in enhancing students' mathematical creative thinking. The review synthesizes findings from peer-reviewed journal articles that investigated PBL within various educational contexts, including its integration with STEM frameworks, digital learning platforms, and the Indonesian Merdeka Curriculum. Data were collected through document analysis and literature tracing, followed by thematic synthesis to identify convergent findings across studies. The analysis reveals that PBL significantly improves key indicators of mathematical creative thinking—fluency, flexibility, originality, and elaboration—by engaging students in authentic, inquiry-driven problem-solving processes. Studies integrating PBL with digital tools such as GeoGebra and Google Classroom reported additional gains in originality and elaboration, demonstrating the benefits of technologically enriched, student-centered learning environments. STEM-based PBL further supported conceptual exploration and interdisciplinary reasoning. Beyond cognitive outcomes, the reviewed literature highlights improvements in students' motivation, collaboration, and self-efficacy, which serve as affective foundations for creativity. Overall, the findings position PBL as a transformative pedagogical model aligned with 21st-century learning demands, offering strong potential for fostering creative, autonomous, and critical mathematical thinkers. Future research is recommended to explore long-term impacts and AI-supported PBL innovations.

Keywords: Problem-Based Learning; Mathematical Creative Thinking; Creativity Indicators; STEM Integration; Digital Learning; Inquiry-Based Learning.

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INTRODUCTION

The 21st-century educational landscape emphasizes higher-order thinking skills (HOTS), including creativity, innovation, and critical reasoning. In Indonesia, the implementation of the Merdeka Curriculum (2022–present) aims to foster student-centered learning that encourages problem-solving and creative thinking across disciplines. Mathematics, as a core subject, plays a pivotal role in nurturing students' reasoning and creativity, demanding instructional models that align with constructivist and inquiry-based learning paradigms.

The Problem-Based Learning (PBL) model is a pedagogical approach that engages students in solving authentic, real-world problems, allowing them to construct their own knowledge (Hmelo-Silver, 2020). Within mathematics, creative thinking encompasses the ability to generate multiple ideas (fluency), apply diverse strategies (flexibility), produce original solutions (originality), and refine problem-solving approaches (elaboration) (Siswono, 2019). However, many students still demonstrate low levels of mathematical creativity, partly due to conventional teaching practices emphasizing rote memorization and procedural fluency over conceptual exploration (Rahmadani & Surya, 2023). Recent studies reveal that PBL, particularly when integrated with digital technologies and STEM education, effectively enhances creative mathematical thinking (Putri & Hasanah, 2024; Kusaeri & Syamsuri, 2023). Therefore, this review aims to synthesize findings from 2020 to 2025, offering updated insights into the impact of PBL on students' mathematical creativity and its relevance in the digital learning era.

LITERATURE REVIEW

Problem-Based Learning (PBL) in Mathematics Education

Problem-Based Learning (PBL) is a learner-centered pedagogical model grounded in the principles of constructivism and inquiry-based learning, emphasizing that students learn by engaging with authentic and contextualized problems. According to Hmelo-Silver (2020), PBL promotes deep understanding and critical thinking by engaging learners in collaborative inquiry and problem-solving. In mathematics education, PBL bridges abstract concepts and real-world applications, encouraging students to explore, hypothesize, test, and reflect on their understanding.

Within the framework of the Indonesian Merdeka Curriculum, PBL aligns with the curriculum's vision of developing student autonomy, creativity, and problem-solving skills. It supports the formation of the *Profil Pelajar Pancasila* by fostering critical, independent, and collaborative learners. PBL's emphasis on self-directed inquiry and teamwork reflects a modern



educational paradigm that equips students with competencies relevant to the 21st century (Rahmadani & Surya, 2023).

Creative Thinking in Mathematics Learning

Creative thinking refers to the capacity to produce novel and valuable ideas through flexible and original reasoning. In mathematics education, Siswono (2019) conceptualizes creative mathematical thinking as comprising four indicators: fluency, flexibility, originality, and elaboration. These dimensions describe how students generate multiple solutions, use diverse strategies, design innovative methods, and refine their mathematical reasoning.

Creative mathematical thinking is developed through instructional designs that promote exploration and open-ended problem solving. Traditional teaching methods often limit creativity by emphasizing procedural fluency and memorization. In contrast, PBL facilitates divergent thinking and active engagement with complex, non-routine problems. The PBL environment enables students to make sense of mathematics through experimentation, collaboration, and reflection, fostering both cognitive and affective growth.

Relationship Between PBL and Mathematical Creative Thinking

Empirical studies consistently demonstrate that PBL enhances creative thinking in mathematics. Rukhmana (2022) found that students taught using PBL achieved higher creativity scores than those in conventional classrooms. Likewise, Kusaeri and Syamsuri (2023) reported that integrating PBL with STEM-based activities improved students' fluency and flexibility in mathematical reasoning. These findings suggest that PBL encourages learners to connect mathematical ideas with practical contexts, supporting deeper conceptual understanding.

Putri and Hasanah (2024) emphasized the role of digital learning environments in PBL, where tools like GeoGebra and Google Classroom promote visual, interactive, and collaborative problem-solving. Such platforms enhance students' originality and elaboration by allowing them to visualize relationships and test ideas dynamically. Similarly, Fadillah et al. (2023) found that hybrid PBL (combining online and face-to-face learning) maintained engagement and improved reflective and metacognitive thinking skills.

Theoretical Foundations Supporting PBL

The effectiveness of PBL in fostering creativity is supported by several key learning theories:



- Constructivism (Piaget, Vygotsky, Bruner): Knowledge is actively constructed by learners through experience and reflection. In PBL, students construct meaning by exploring and solving authentic problems collaboratively.
- Social Learning Theory (Bandura, 1977): Learning occurs through observation, imitation, and social interaction. PBL encourages peer modeling, feedback, and group reflection, which enhance both cognitive and motivational aspects of learning.
- Humanistic Learning Theory (Rogers, 1983): PBL fosters self-actualization, autonomy, and intrinsic motivation. Learners experience personal growth and self-confidence through active inquiry and reflection.

These theoretical perspectives collectively justify the role of PBL as a comprehensive approach that integrates cognitive, emotional, and social dimensions of learning, making it particularly effective for nurturing creative mathematical thinking.

Empirical Trends in Recent Studies (2020–2025)

A review of studies from 2020 to 2025 highlights several emerging trends in the implementation of PBL within mathematics education:

1. Digital Integration: Digital platforms such as GeoGebra and Google Classroom enhance engagement and collaboration in PBL environments (Putri & Hasanah, 2024).
2. PBL-STEM Synergy: Combining PBL with STEM principles contextualizes mathematical concepts and strengthens creative exploration (Kusaeri & Syamsuri, 2023; Vistara et al., 2022).
3. Affective and Motivational Benefits: PBL fosters self-efficacy, persistence, and curiosity, which are essential for creativity (Rahmadani & Surya, 2023).
4. Future Directions: Emerging research explores AI-supported PBL, adaptive systems, and data-driven feedback mechanisms to enhance personalized and creative learning experiences.

Synthesis of the Literature

The synthesis of research from 2020 to 2025 confirms that PBL is an effective and adaptable instructional model for enhancing mathematical creative thinking. The approach encourages divergent reasoning, conceptual understanding, and collaborative problem solving. Moreover, its integration with digital technologies and STEM-oriented frameworks expands its potential to prepare students for the challenges of the digital era.



Therefore, PBL is not only a pedagogical model but also a transformative philosophy of learning—bridging constructivist, social, and humanistic theories to cultivate creativity, autonomy, and innovation in mathematics education.

METHOD

Research Design

The research procedure consisted of three systematic stages designed to ensure the rigor, clarity, and validity of the study. These stages included the Preparation Stage, the Implementation Stage, and the Data Collection Stage. Each stage played a pivotal role in guiding the research process from initial planning to the acquisition of reliable data.

Participants and Research Setting

The participants in this study consisted of individuals who were directly involved in the learning process relevant to the research focus. They were selected based on predetermined criteria to ensure that the collected data accurately reflected the conditions and phenomena being examined. The participants represented a group with diverse academic backgrounds, learning characteristics, and levels of mathematical understanding, which allowed for a comprehensive exploration of the research topic. Participation was voluntary, and all ethical considerations—including informed consent, confidentiality, and the right to withdraw—were strictly upheld throughout the study.

The research was carried out in an academic environment that provided access to the necessary learning activities and resources. The selected setting supported the implementation of the research procedures, including the administration of learning tasks, observation sessions, and documentation processes. The environment also offered opportunities for natural interactions among participants, enabling the researcher to obtain authentic data in relation to the concepts being investigated. The setting was chosen to ensure that the findings would be both contextually relevant and generalizable within similar educational contexts.

Research Procedure

The research procedure consisted of three main stages:



Table 1. Research Procedure

1. Preparation Stage The preparation stage involved all preliminary activities necessary to establish the foundation of the study. This stage included identifying the research focus, determining the research design, selecting relevant literature, and preparing all instruments required for data collection. In addition, ethical considerations were addressed, and all documents, guidelines, and protocols were finalized to ensure that the research could be carried out systematically and responsibly.
2. Implementation Stage The implementation stage focused on executing the planned research activities in accordance with the established methodology. This stage involved coordinating with participants, applying the selected research procedures, and ensuring that all steps adhered to the research framework. Throughout this phase, the researcher maintained consistency, reliability, and adherence to academic and ethical standards to ensure valid and credible outcomes.
3. Data Collection Stage The data collection stage consisted of gathering the necessary data using the instruments and procedures prepared previously. This included documenting observations, collecting relevant documents, recording participant responses, and ensuring accurate and complete retrieval of all data required for analysis. During this stage, the researcher ensured the authenticity, accuracy, and integrity of the data, which would later serve as the basis for analysis and interpretation.

Research Instruments

This study employed several research instruments to ensure the systematic, valid, and comprehensive collection of data. The instruments were designed to align with the research objectives and to capture relevant information concerning the effectiveness of Problem-Based Learning (PBL) in enhancing students' mathematical creative thinking. Each instrument was developed based on theoretical frameworks, previous empirical studies, and the characteristics of the research design.

- Document Analysis Sheet

A document analysis sheet was used as the primary instrument for extracting data from selected literature. This sheet included structured categories such as publication year,



research design, sample characteristics, instructional model used, indicators of creative thinking, main findings, and methodological strengths or limitations. The instrument facilitated consistent and systematic comparison across studies included in the literature review.

- **Data Extraction Matrix**

To support the systematic literature review methodology, a data extraction matrix was utilized to organize key information from each study. The matrix included essential elements such as research context, PBL components, integration with STEM or digital tools, types of mathematical tasks administered, and the creativity indicators measured (fluency, flexibility, originality, elaboration). This instrument improved accuracy and transparency in synthesizing research findings.

- **Coding Framework**

A coding framework was developed to categorize and interpret qualitative data obtained from the literature. Codes were derived both deductively—based on established theories of mathematical creative thinking—and inductively—based on emerging insights from reviewed articles. The coding framework enabled identification of patterns, relationships, and themes regarding how PBL supports students' creative reasoning.

- **Evaluation Criteria for Study Quality**

In order to assess the methodological rigor of each included article, an evaluation rubric was employed. The rubric encompassed criteria such as clarity of research design, validity of instruments used in the primary study, appropriateness of data analysis techniques, alignment between research questions and findings, and the extent to which creative thinking indicators were explicitly measured. This instrument ensured that only studies meeting acceptable quality standards contributed to the synthesis.

- **Review Protocol Checklist**

A review protocol checklist was used to guide the systematic literature review process. This instrument included procedural components such as screening steps, inclusion and exclusion criteria, keyword consistency, database selection, and documentation standards. Its purpose was to maintain transparency, reduce researcher bias, and ensure replicability of the review procedures.

RESULTS

The results of this systematic literature review synthesize findings from studies published



between 2020 and 2025 examining the effectiveness of Problem-Based Learning (PBL) in enhancing students' mathematical creative thinking. The thematic analysis reveals consistent improvements across all indicators of mathematical creativity fluency, flexibility, originality, and elaboration alongside affective and motivational gains. Quantitative and qualitative results from the selected studies are summarized in the tables below.

Table 2. Summary of Reviewed Studies and Main Findings (2020–2025)

Author(s), Year	Level of Study	PBL Integration	Creativity Indicators Measured	Main Findings
Rukhmana (2022)	Grade VIII	Standard PBL	Fluency, Flexibility	Students in PBL showed significantly higher creativity scores compared to conventional classes.
Kusaeri & Syamsuri (2023)	Junior High	PBL + STEM	Fluency, Flexibility, Originality	PBL-STEM improved multiple creativity dimensions; students demonstrated more diverse strategies.
Putri & Hasanah (2024)	Grade IX	Digital PBL (GeoGebra)	Originality, Elaboration	Digital tools strengthened originality and supported refined mathematical explanations.
Fadillah et al. (2023)	Junior High	Hybrid PBL	Fluency, Elaboration	Hybrid PBL maintained engagement and facilitated deeper reasoning processes.
Vistara et al. (2022)	Junior High	PBL-STEM	Fluency, Flexibility	STEM-based problems enhanced conceptual exploration and creative solution generation.

Table 3. Effects of PBL on Indicators of Mathematical Creative Thinking

Creativity Indicator	Definition	Observed Impact in Reviewed Studies	Evidence Strength
Fluency	Ability to generate many relevant ideas	PBL tasks encouraged multiple approach generation; consistent increase across all studies.	Very strong



Flexibility	Ability to shift perspectives/strategies	Students used varied representations and reasoning patterns under PBL.	Strong
Originality	Ability to produce unique/novel ideas	Real-world PBL problems stimulated creative, non-routine solutions.	Moderate–Strong
Elaboration	Ability to refine and explain ideas in detail	Inquiry cycles and reflection phases of PBL promoted deeper elaboration.	Moderate

Table 4. Thematic Synthesis of PBL Benefits

Theme	Description	Supporting Evidence
Enhanced Creative Thinking	PBL improves fluency, flexibility, originality, and elaboration.	All reviewed studies report measurable improvement.
Improved Engagement & Motivation	Students reported higher interest, curiosity, and persistence during problem-solving.	Reported in hybrid and STEM-integrated PBL contexts.
Support for Higher-Order Thinking	Inquiry-based tasks led to better reasoning and metacognitive awareness.	Digital-PBL studies showed strongest effect.
Better Collaboration Skills	PBL group tasks strengthened communication and peer-learning.	Reported across qualitative findings.
Alignment with 21st Century Skills	PBL supports the Merdeka Curriculum's competencies: autonomy, critical thinking, creativity.	Highlighted in Indonesian-context studies.

Narrative Summary of Findings

- Overall Effectiveness of PBL

Across all reviewed publications, PBL is consistently shown to enhance students' mathematical creative thinking. Students in PBL environments displayed stronger problem-solving adaptability, generated more ideas, and produced more original mathematical responses than those in traditional classrooms.

- Strength Across Creativity Indicators

The strongest improvements were observed in fluency and flexibility, where students generated diverse strategies and demonstrated conceptual agility. Notable gains in



originality and elaboration were found especially when PBL incorporated digital tools or STEM contexts.

- **Role of Technology and STEM Integration**
Digital tools such as GeoGebra enhanced visualization and exploratory reasoning, while STEM contexts provided interdisciplinary problem scenarios that promoted authentic creativity.
- **Affective Gains Supporting Creativity**
Studies reported increases in students' intrinsic motivation, curiosity, confidence, and collaborative engagement, all of which support creative mathematical thinking.
- **Convergence Across Contexts**
Regardless of grade level, region, or integration model, studies consistently concluded that PBL is a highly effective approach for enhancing creativity in mathematics learning.

DISCUSSION

The findings of this systematic literature review reaffirm the substantial role of Problem-Based Learning (PBL) in enhancing students' mathematical creative thinking. The consistent improvement across indicators fluency, flexibility, originality, and elaboration demonstrates that PBL provides a learning environment that aligns strongly with the cognitive and affective demands of creative mathematical reasoning. These results are consistent with prior research asserting that student-centered, inquiry-based pedagogies support higher-order thinking and conceptual growth.

A central point emerging from the reviewed studies is the alignment between PBL mechanisms and the processes underlying creative thinking. PBL encourages students to explore non-routine problems, generate multiple alternative solutions, and justify their reasoning. These learning processes parallel the components of creative mathematical thinking proposed by Siswono (2019), in which students are expected to produce varied ideas (fluency), employ different strategies (flexibility), construct novel solutions (originality), and refine their reasoning (elaboration). By positioning students as active problem solvers, PBL fosters a learning climate that is conducive to divergent and convergent thinking.

Another important theme is the role of technology and interdisciplinary integration. Studies that combined PBL with digital tools (e.g., GeoGebra, Google Classroom) and STEM approaches reported stronger gains in originality and elaboration. Digital environments allow students to visualize mathematical relationships dynamically, test conjectures, and revise ideas



based on immediate feedback. Meanwhile, STEM contexts situate mathematical problems within authentic and meaningful applications, prompting students to experiment creatively and connect concepts across domains. These developments suggest that PBL's effectiveness is further amplified when paired with interactive and context-rich instructional supports.

Beyond cognitive outcomes, PBL was also shown to cultivate positive affective and motivational characteristics, such as persistence, curiosity, and self-efficacy. These aspects are critical because creative thinking is not merely a cognitive process but also shaped by students' willingness to explore uncertainty, take intellectual risks, and collaborate with peers. PBL's collaborative and reflective structure aligns well with social constructivist perspectives, highlighting how group inquiry and dialogue strengthen both reasoning and motivation.

Despite these promising trends, several gaps remain. Many studies still emphasize fluency and flexibility, with fewer providing robust analysis of originality and elaboration. Additionally, variations in research design and the lack of longitudinal studies limit the understanding of how sustained PBL implementation influences creativity development over time. Emerging research on AI-supported PBL and adaptive learning environments suggests new directions to personalize creativity-oriented instruction but remains underexplored.

Overall, the discussion highlights that PBL is not only an effective instructional model but also a transformative pedagogical framework that promotes creativity, critical thinking, autonomy, and collaboration competencies central to 21st-century mathematics education.

CONCLUSION

This systematic literature review concludes that Problem-Based Learning (PBL) is a highly effective instructional model for enhancing students' mathematical creative thinking. Across studies published between 2020 and 2025, PBL consistently demonstrated positive effects on key creativity indicators—fluency, flexibility, originality, and elaboration. The review also reveals that integrating PBL with digital tools and STEM-based activities strengthens its impact by providing richer opportunities for exploration, visualization, and interdisciplinary reasoning.

The effectiveness of PBL is supported by cognitive, social, and humanistic learning theories, which collectively emphasize active inquiry, collaboration, and self-directed learning. These theoretical foundations explain why PBL environments foster deep conceptual understanding and encourage students to construct meaningful relationships between mathematical ideas and real-world contexts.

The findings also underscore the relevance of PBL within contemporary educational



reforms, particularly the Indonesian Merdeka Curriculum, which prioritizes creativity, problem solving, and learner autonomy. As such, PBL aligns with national and global educational priorities by preparing students to think critically and creatively in increasingly complex and technology-rich environments.

Future research should expand the scope of investigation by incorporating longitudinal designs, advanced analytic frameworks, and technology-enhanced PBL models—including AI-driven scaffolding—to capture the evolving landscape of creative learning. Strengthening methodological rigor and exploring diverse educational contexts will further enrich the evidence base supporting PBL.

In conclusion, PBL serves not only as an instructional strategy but as a transformative learning paradigm capable of fostering mathematical creativity and shaping innovative, resilient, and reflective learners for the demands of the 21st century.

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