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Literature Study: The Effect of The Problem-Based Learning Model Assisted by The Flipped Classroom on Mathematical Creative Thinking Ability

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ABSTRACT

The development of mathematical creative thinking abilities is a crucial goal in modern education, as these skills enable students to approach complex problems innovatively and adapt to diverse challenges. However, traditional teaching methods often fail to nurture creativity, focusing instead on rote learning and procedural tasks. This study aims to investigate the impact of integrating the Problem-Based Learning (PBL) model and the Flipped Classroom approach on enhancing students' mathematical creative thinking abilities. The research employs a Systematic Literature Review (SLR) methodology, analyzing previous studies that explore the effects of these pedagogical strategies individually and in combination. Data were collected and synthesized through a rigorous process of identification, screening, and inclusion based on predefined criteria. The findings reveal that the integration of PBL and the Flipped Classroom significantly improves students' flexibility, originality, and ability to generate innovative solutions in mathematics. PBL fosters collaborative problem-solving and real-world application, while the Flipped Classroom prepares students with foundational knowledge, allowing class time to focus on exploration and creativity. This research highlights the potential of innovative teaching models to transform mathematics education by creating dynamic and student-centered learning environments. The results provide valuable insights for educators seeking to foster higher-order thinking skills and creativity in their students.

INTRODUCTION

Education is a fundamental pillar for individual and societal development, providing the foundation for intellectual growth and problem-solving skills. In the 21st century, the rapid advancement of technology and the increasing complexity of global challenges necessitate a shift in educational paradigms. Modern pedagogical approaches emphasize the development of higher-order thinking skills, particularly creative thinking, as a critical competency for students (Nida et al., 2019). In mathematics education, creative thinking is not merely an ancillary skill but a core element that enables learners to approach problems innovatively, connect concepts, and devise novel solutions (Nantha et al., 2022). However, traditional teaching methods often prioritize rote memorization and standardized testing over fostering creativity and deep understanding, creating a pressing need for more dynamic and interactive instructional models.

One promising approach to address these challenges is the integration of Problem-Based Learning (PBL) and Flipped Classroom models. PBL encourages students to engage in authentic problem-solving activities, promoting critical thinking and collaborative learning (Sya'Roni et al., 2020). Meanwhile, the Flipped Classroom model leverages technology to shift passive learning outside the classroom and reserves face-to-face time for active engagement and discussion. Combining these models has the potential to transform mathematics instruction, making it more student-centered and conducive to creative thinking. However, the practical implementation and efficacy of such an integrated approach require further exploration, particularly in fostering mathematical creative thinking abilities (Suhartini & Marianti, 2023).

Despite the recognized importance of creative thinking in mathematics, many educational systems still struggle to cultivate this skill effectively. Traditional classroom settings often fail to provide opportunities for students to experiment with ideas, explore multiple solutions, or think divergently. This limitation is particularly evident in mathematics education, where the focus tends to be on procedural fluency and correctness rather than innovation and flexibility (Rahayu et al., 2022). Consequently, students may develop proficiency in solving routine problems but lack the ability to apply their knowledge in novel and complex contexts.

In recent years the integration of technology in education has opened new possibilities for enhancing learning experiences. The Flipped Classroom model, for instance, allows students to access instructional content at their own pace through digital platforms, freeing up classroom time for interactive problem-solving activities (Fayakuun, 2023). Similarly, PBL encourages students to take ownership of their learning by working collaboratively to solve real-world problems. While both approaches have demonstrated positive outcomes in various educational settings, their combined impact on mathematical creative thinking remains underexplored, leaving a gap in the literature that warrants further investigation.

A survey conducted by the National Center for Education Statistics (NCES) in 2022 revealed that only 35% of high school students demonstrated proficiency in higher-order thinking skills in mathematics. Furthermore, a study by the Indonesian Ministry of Education showed that 60% of students struggled with non-routine problems requiring creative and critical thinking (Tabieh & Hamzeh, 2022). These findings underscore a significant disparity between the skills students acquire in traditional classrooms and the competencies demanded in real-world scenarios. The lack of effective pedagogical strategies to address this gap highlights the urgency of exploring innovative instructional models.

Problem-Based Learning (PBL) is a learner-centered approach that emphasizes active exploration and collaborative problem-solving. Rooted in constructivist theory, PBL posits that learning is most effective when students actively engage in solving meaningful problems (Khaerudin & Chaeruman, 2023). In mathematics, this approach encourages students to construct their understanding through inquiry, reflection, and interaction. Meanwhile, the Flipped Classroom model aligns with contemporary theories of personalized and blended learning. By shifting direct instruction to digital platforms, this model maximizes classroom time for discussion, experimentation, and peer learning, thereby creating an environment conducive to higher-order thinking (Yurniwati & Utomo, 2020).

The integration of PBL and the Flipped Classroom model creates a synergistic framework for fostering mathematical creative thinking. While PBL provides the context for deep, collaborative learning, the Flipped Classroom ensures that students come to class prepared to engage actively in problem-solving activities. This combination has the potential to address the limitations of traditional teaching methods, offering a more holistic approach to mathematics instruction (Mudhofir, 2021).

Several studies have explored the individual impact of PBL and Flipped Classroom models on student learning outcomes. A study by (Ahdhianto et al., 2020) found that PBL significantly enhances students' problem-solving and critical thinking skills. (Busebaia & John, 2020) demonstrated that the Flipped Classroom model improves student engagement and academic performance. A meta-analysis by (Capone, 2022) highlighted the potential of blended learning approaches to foster creativity and innovation in STEM education. However, most of these studies focus on general learning outcomes rather than specifically examining mathematical creative thinking. Additionally, limited research has investigated the combined effect of PBL and Flipped Classroom models, leaving a gap in the understanding of their integrated application.

Based on the above studies it appears that most researchers have concentrated on general academic performance and problem-solving skills, with less emphasis on creative thinking in mathematics. Furthermore, the potential of combining PBL and Flipped Classroom models has been underexplored in the context of fostering mathematical creativity. To fill this gap, this study aims to investigate the specific impact of integrating these two pedagogical approaches on students' mathematical creative thinking abilities.

This study seeks to examine the effect of the Problem-Based Learning model assisted by the Flipped Classroom on mathematical creative thinking ability. Specifically, the research aims to explore how this integrated approach can enhance students' ability to generate innovative solutions, approach problems from multiple perspectives, and apply their knowledge creatively in mathematics. By addressing these objectives, the study aims to contribute to the development of effective instructional strategies that prepare students for the demands of a complex and rapidly evolving world.

METHODS

The research method used in this study is Systematic Literature Review (SLR), which is a structured approach to identifying, analyzing, and synthesizing existing studies relevant to the topic (Mubarok, 2025). The SLR method is conducted through a five-stage process to ensure the reliability and validity of the findings. In the first stage, the research begins by identifying the topics and keywords that align with the focus of the study, such as "Problem-Based Learning," "Flipped Classroom," "Mathematical Creative Thinking," and their variations. This step ensures a comprehensive search of relevant literature across multiple databases. In the second stage, the literature search process is carried out systematically using predefined databases, including Scopus, Web of Science, and Google Scholar, to gather a wide range of research articles, conference papers, and reviews. Boolean operators and inclusion of peer-reviewed studies are used to refine the search (J. W. Creswell & Creswell, 2018).

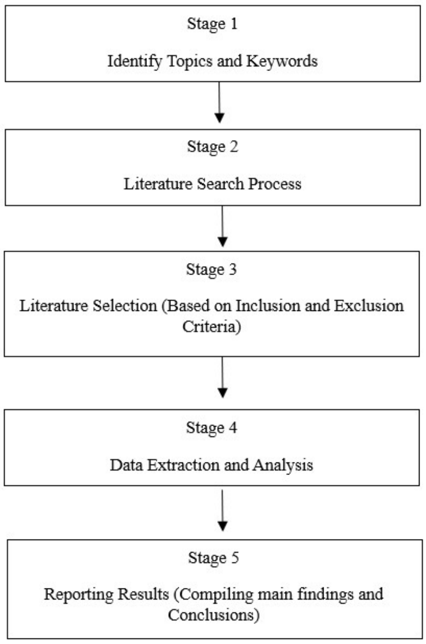

Figure 1. Systematic Literature Review Research Process

In the third stage the literature selection process is conducted based on inclusion and exclusion criteria, such as relevance to the topic, publication year (e.g., within the last ten years), and methodological rigor. Articles that do not address the integration of Problem-Based Learning and Flipped Classroom or their impact on mathematical creative thinking are excluded. In the fourth stage, data extraction and analysis are performed, focusing on key information such as research objectives, methodologies, findings, and conclusions from the selected studies. This step ensures that only pertinent data contribute to the synthesis process (J. Creswell, 2017). Finally, in the fifth stage, the findings are compiled, categorized, and synthesized into a coherent framework, providing insights into the effect of the combined learning models on fostering mathematical creative thinking. The results are reported with a clear emphasis on addressing research gaps and proposing future directions (J. Creswell, 2016).

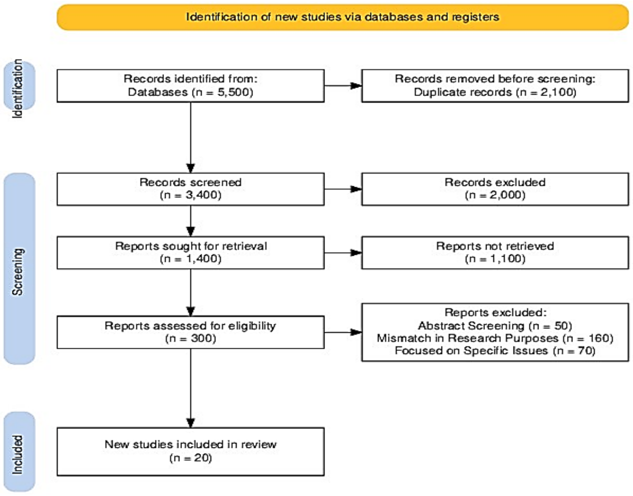

Figure 2. Prism Table
Source: Generated from PRISMA 2024 database

The PRISMA diagram presented in Figure 2 illustrates the systematic process of identifying, screening, and including studies for the literature review, generated from the PRISMA 2024 database. Initially, 5,500 records were identified from various databases, of which 2,100 duplicate records were removed before screening. During the screening phase, 3,400 records were reviewed for relevance, with 2,000 being excluded based on their lack of alignment with the study's objectives. Subsequently, 1,400 reports were sought for retrieval, but 1,100 could not be retrieved due to access limitations or incomplete data. Of the 300 reports assessed for eligibility, 50 were excluded due to superficial abstract screening, 160 due to mismatches in research purposes, and 70 because they focused on specific issues outside the study's scope. Ultimately, 20 studies were deemed eligible and included in the review, forming the foundation for the analysis and synthesis of findings in this research. This meticulous selection process ensures the reliability and comprehensiveness of the data used to draw meaningful conclusions.

RESULTS AND DISCUSSION

The review of previous studies highlights the positive impact of the Problem-Based Learning (PBL) model in fostering critical and creative thinking skills. (Silma et al., 2023) found that PBL enhances students' abilities to tackle complex problems through collaboration and active exploration. Similarly, (Azizah, 2024) demonstrated that students engaged in PBL tend to develop stronger creative problem-solving skills as they are required to generate innovative solutions to open-ended tasks. In mathematics education, PBL has been shown to encourage divergent thinking, enabling students to approach mathematical challenges with greater creativity and flexibility.

The Flipped Classroom model has also been extensively researched with findings emphasizing its role in promoting student-centered learning environments. (Andargeery et al., 2024) showed that students performed better academically when they had access to instructional materials outside the classroom, allowing more time for interactive and practical application during class sessions. (Cevikbas & Kaiser, 2022) further reported that the Flipped Classroom approach enhances students’ engagement and participation by enabling personalized learning experiences. When applied to mathematics, this model has been effective in helping students develop a deeper understanding of concepts, as it provides ample time for active problem-solving during class.

In studies combining PBL and the Flipped Classroom researchers have observed significant improvements in learning outcomes. (Hsu & Wu, 2023) found that students demonstrated higher levels of creative thinking and critical reasoning when exposed to an integrated model, as the Flipped Classroom prepared them with foundational knowledge, while PBL offered opportunities for application and exploration. (Yang et al., 2024) also highlighted that the combination of these methods maximized student engagement and fostered innovative thinking, as students were able to actively connect theoretical knowledge with real-world problems in a collaborative setting. These studies suggest that integrating PBL and Flipped Classroom models creates a dynamic and supportive environment that promotes mathematical creativity.

Further evidence supports the benefits of these models in enhancing mathematical creative thinking. A study by (Jamil et al., 2022) revealed that students exposed to blended learning approaches, including PBL and Flipped Classroom, were more adept at generating unique solutions to mathematical problems. Similarly, (Attard & Holmes, 2022) found that technology-assisted active learning models increased students' ability to think creatively by providing them with opportunities to explore multiple perspectives and approaches. These findings affirm the value of combining innovative instructional methods to enrich students’ creative thinking skills in mathematics.

In conclusion the synthesis of prior studies indicates that both PBL and the Flipped Classroom have demonstrated positive effects on mathematical creative thinking when implemented individually or in combination. The reviewed literature consistently shows that these approaches enhance students' ability to explore, experiment, and innovate within mathematical contexts. This study builds upon these findings by emphasizing how the integration of the PBL and Flipped Classroom models can specifically nurture mathematical creativity, providing valuable insights for educators aiming to foster higher-order thinking skills in mathematics education.

The findings of this study demonstrate that the integration of the Problem-Based Learning (PBL) model with the Flipped Classroom approach significantly enhances students’ mathematical creative thinking abilities. This approach allows students to engage actively in the learning process, encouraging them to explore various problem-solving methods, develop unique ideas, and apply their mathematical understanding innovatively. The study reveals that students who experienced this integrated learning model showed improved flexibility in thinking, a greater capacity for generating novel solutions, and the ability to connect mathematical concepts to real-world contexts more effectively.

The results also highlight that the Flipped Classroom provides a strong foundation for learning by enabling students to access instructional materials independently before class. This preparation ensures that in-class time is optimized for active, collaborative, and exploratory activities, which are essential for fostering creative thinking. When combined with PBL, which focuses on solving complex, real-life problems, this model creates a dynamic learning environment where students can engage in meaningful discussions, experiment with different strategies, and refine their solutions. The synergy between these two approaches enhances students' ability to think critically and creatively within the mathematical domain.

Additionally, the study underscores the importance of collaboration and self-directed learning in enhancing mathematical creativity. By working collaboratively on problem-solving tasks, students are exposed to diverse perspectives, which stimulates their creative thinking. At the same time, the Flipped Classroom supports independent learning, allowing students to revisit challenging concepts at their own pace. This combination of structured group work and self-directed study fosters both independence and teamwork, equipping students with the skills necessary to tackle mathematical problems innovatively and effectively.

Overall, this study concludes that the integrated use of PBL and the Flipped Classroom approach significantly contributes to the development of mathematical creative thinking abilities. It shows that this dual model not only enhances students' engagement and understanding but also nurtures their capacity to approach mathematical challenges with creativity and confidence. These findings provide strong evidence for the potential of innovative pedagogical approaches to transform mathematics education, ensuring that students are better prepared to meet the demands of a complex and rapidly evolving world.

1. The Impact of the Problem-Based Learning Model Assisted by the Flipped Classroom on Mathematical Creative Thinking

Mathematical creative thinking is an essential competency in the modern educational landscape, as it enables students to approach mathematical problems with flexibility, originality, and the ability to generate innovative solutions. This study focuses on exploring how the integration of the Problem-Based Learning (PBL) model and the Flipped Classroom approach can enhance students' mathematical creative thinking abilities. By combining the strengths of these two innovative pedagogical approaches, the findings provide insights into how active, student-centered learning environments contribute to the development of higher-order thinking skills in mathematics.

Problem-Based Learning (PBL) is a teaching method that places students at the center of the learning process, requiring them to actively engage in solving real-world problems. In this study, PBL was found to significantly enhance students' creative thinking abilities by promoting an environment where learners are encouraged to think critically and explore multiple solutions. PBL challenges students to analyze complex, often ambiguous problems, pushing them to think beyond routine or algorithmic solutions. This process fosters the ability to think divergently, which is a key component of creativity.

One of the primary ways PBL influences mathematical creative thinking is by encouraging students to approach problems from different perspectives. During PBL activities, students must work collaboratively to identify problem parameters, propose hypotheses, and evaluate potential solutions. This collaborative effort stimulates brainstorming and the exchange of ideas, which often leads to novel and innovative approaches to problem-solving. For example, students tasked with finding alternative solutions to a real-world optimization problem in geometry might devise unique strategies involving both traditional mathematical formulas and creative visualizations.

PBL's emphasis on real-world application helps bridge the gap between theoretical knowledge and practical use. Mathematics often feels abstract to students, but when it is contextualized within real-world scenarios, students are more likely to see its relevance and importance. This connection between abstract concepts and practical applications nurtures their ability to think creatively, as they must adapt their knowledge to unfamiliar and challenging situations.

The Flipped Classroom model, on the other hand, transforms the traditional structure of instruction by shifting direct teaching to asynchronous, pre-class activities. In this study, the Flipped Classroom was found to complement PBL by preparing students with foundational knowledge before class, enabling them to focus on higher-order cognitive tasks during in-class activities. This approach maximizes classroom time for interactive, exploratory learning, which is crucial for fostering creativity in mathematics.

One of the key benefits of the Flipped Classroom model is its ability to provide students with autonomy in their learning process. By accessing instructional materials, such as video lectures, tutorials, or readings, at their own pace, students can revisit challenging concepts as needed, ensuring a deeper understanding of the subject matter. This self-paced learning supports the development of creative thinking by allowing students to build confidence in their foundational knowledge, which they can then apply flexibly and creatively during problem-solving tasks in class. Moreover the Flipped Classroom encourages active participation and engagement in the classroom. When students arrive at class prepared with basic knowledge, they are ready to engage in discussions, ask questions, and collaborate on complex problems. This active involvement not only enhances their understanding of mathematical concepts but also stimulates creative thinking by encouraging them to experiment with different approaches and solutions. For example, a student who has already reviewed the principles of probability at home may use class time to explore creative applications of these principles in solving real-world statistical problems, such as designing experiments or analyzing data trends.

The integration of PBL and the Flipped Classroom creates a powerful synergy that enhances students' mathematical creative thinking abilities. While PBL provides a framework for tackling complex problems through inquiry and collaboration, the Flipped Classroom ensures that students are adequately prepared to engage in these activities. Together, these models create a learning environment that supports both the acquisition of foundational knowledge and the development of higher-order thinking skills.

One of the most significant impacts of this integrated approach is the promotion of student-centered learning. In a traditional classroom, the teacher often dominates the instructional process, leaving little room for students to take an active role in their learning. However, in the integrated PBL-Flipped Classroom model, students are encouraged to take ownership of their learning by engaging with pre-class materials, participating in group discussions, and contributing to problem-solving tasks. This active involvement helps students develop a sense of autonomy and responsibility, which are critical for fostering creativity. When students feel empowered to take charge of their learning, they are more likely to experiment with new ideas and take risks in their problem-solving approaches.

The collaborative nature of PBL is further enhanced by the preparatory work facilitated by the Flipped Classroom. By reviewing materials before class, students arrive better equipped to contribute meaningfully to group discussions and activities. This preparation allows them to focus on higher-level tasks, such as analyzing problems, generating hypotheses, and evaluating solutions, rather than spending class time trying to understand basic concepts. As a result, students can engage in deeper, more creative exploration of mathematical problems. For instance, a group of students working on a PBL task involving optimization might use class time to brainstorm innovative ways to apply calculus principles to real-world scenarios, rather than simply reviewing the basics of differentiation and integration.

Another important aspect of this study is its focus on how the integrated PBL-Flipped Classroom model encourages both divergent and convergent thinking. Divergent thinking involves generating multiple ideas and exploring various possibilities, while convergent thinking involves narrowing down these ideas to identify the most effective solution. Both types of thinking are essential for creative problem-solving in mathematics. The PBL component of the integrated model is particularly effective in promoting divergent thinking. By presenting students with open-ended, real-world problems, PBL encourages them to brainstorm and explore a wide range of potential solutions. This process often involves thinking outside the box and considering unconventional approaches. For example, students working on a PBL task related to urban planning and geometry might explore creative ways to minimize space usage while maximizing efficiency, using a combination of mathematical modeling and innovative design principles.

On the other hand, the Flipped Classroom supports convergent thinking by providing students with the foundational knowledge they need to evaluate and refine their ideas. By reviewing instructional materials at their own pace, students can develop a solid understanding of mathematical principles, which they can then apply to identify the most effective solution to a problem. This balance between divergent and convergent thinking is crucial for fostering mathematical creativity, as it allows students to generate innovative ideas while also ensuring that these ideas are grounded in sound mathematical reasoning.

One of the more subtle yet significant impacts of the integrated PBL-Flipped Classroom model is its ability to build students' confidence and reduce anxiety in mathematics. Many students struggle with math-related anxiety, which can hinder their ability to think creatively and take risks in problem-solving. The Flipped Classroom helps alleviate this anxiety by allowing students to learn at their own pace, providing a safe space for them to review challenging concepts without the pressure of a traditional classroom setting. When students feel more confident in their foundational knowledge, they are more likely to engage actively in PBL tasks and approach problems with a creative mindset.

Additionally, the collaborative nature of PBL provides a supportive environment where students can share ideas, receive feedback, and learn from their peers. This sense of community and mutual support can further reduce anxiety and encourage students to take risks in their problem-solving approaches. By creating a positive and inclusive learning environment, the integrated PBL-Flipped Classroom model helps students build the confidence they need to think creatively and tackle complex mathematical problems.

The findings of this study have important implications for mathematics education, particularly in terms of curriculum design and instructional strategies. The integrated PBL-Flipped Classroom model represents a departure from traditional, lecture-based teaching methods, offering a more dynamic and interactive approach to learning. By incorporating this model into mathematics curricula, educators can create learning environments that not only enhance students' understanding of mathematical concepts but also foster the development of critical and creative thinking skills. One practical implication is the need for professional development and training for teachers. Implementing the integrated PBL-Flipped Classroom model requires a shift in teaching practices, as teachers must learn how to design effective PBL tasks, facilitate group discussions, and create engaging instructional materials for the Flipped Classroom. Providing teachers with the necessary training and resources is essential for the successful implementation of this model.

Another implication is the importance of integrating technology into the classroom. The Flipped Classroom relies on digital resources, such as video lectures and online tutorials, to deliver instructional content. Schools and educators must ensure that students have access to these resources and the necessary technology to engage with them effectively. Additionally, technology can be used to enhance PBL tasks by providing students with tools for data analysis, mathematical modeling, and visualization, further supporting their creative problem-solving efforts.

The integration of the Problem-Based Learning model and the Flipped Classroom approach has a profound impact on students' mathematical creative thinking abilities. By combining the strengths of these two pedagogical strategies, the integrated model creates a learning environment that is both student-centered and conducive to higher-order thinking. This study demonstrates that the integrated PBL-Flipped Classroom model not only enhances students' understanding of mathematical concepts but also nurtures their ability to approach problems creatively, think critically, and collaborate effectively. As mathematics education continues to evolve, the findings of this study highlight the potential of innovative teaching methods to prepare students for the challenges of a rapidly changing world, where creativity and adaptability are more important than ever.

2. The Role of Collaboration and Self-Directed Learning in Enhancing Mathematical Creativity

Mathematical creativity a vital skill in both academic and real-world problem-solving contexts, allows individuals to approach problems innovatively, think divergently, and apply knowledge flexibly. It is not merely about arriving at correct answers but also about the process of discovering new methods, creating alternative solutions, and thinking outside the box. Two fundamental factors that significantly influence the development of mathematical creativity are collaboration and self-directed learning. Together, these elements create a dynamic learning environment that fosters both individual innovation and collective problem-solving abilities. Collaboration an essential aspect of many active learning approaches, plays a crucial role in stimulating mathematical creativity. When students collaborate, they interact with peers who bring different perspectives, skills, and experiences to the table. This diversity of thought challenges students to think beyond their own assumptions, consider alternative viewpoints, and refine their approaches to problem-solving.

One of the primary ways collaborations enhances creativity is through the exchange of ideas. In a collaborative setting, students are encouraged to share their thought processes, discuss potential solutions, and evaluate the effectiveness of different strategies. This exchange fosters an environment where creativity flourishes, as students are exposed to novel ideas and encouraged to build upon them. For instance, in a group tasked with solving a geometric optimization problem, one student might propose a theoretical approach while another suggests a practical application, leading to a synthesis of ideas that results in a more innovative solution.

Additionally, collaboration encourages risk-taking, a key component of creative thinking. In a supportive group environment, students are more likely to experiment with unconventional approaches and take intellectual risks without fear of failure. This openness to exploration is critical for developing mathematical creativity, as it allows students to test the boundaries of their knowledge and think divergently. For example, a student working on a challenging algebraic problem might feel more confident proposing a unique solution in a group setting, knowing that their peers will provide constructive feedback and support.

1. The Role of Social Interaction in Collaborative Learning

   Social interaction is another crucial element of collaboration that contributes to mathematical creativity. When students engage in meaningful conversations with their peers, they are exposed to a variety of cognitive processes and problem-solving strategies. This interaction helps them develop a deeper understanding of mathematical concepts and enhances their ability to think creatively. Moreover, social interaction fosters a sense of accountability and motivation. In a collaborative setting, students are often more engaged and invested in the learning process because they feel a sense of responsibility toward their group. This motivation can drive them to think more critically and creatively, as they strive to contribute meaningfully to the group's success. For example, a student working on a collaborative project in calculus might be motivated to explore multiple solutions to a problem, knowing that their contributions will impact the group's overall performance.

2. Self-Directed Learning as a Foundation for Creativity

While collaboration emphasizes the collective aspect of learning, self-directed learning focuses on the individual. Self-directed learning is a process in which students take control of their own learning by setting goals, identifying resources, and assessing their progress. This autonomy allows students to tailor their learning experiences to their unique needs and interests, which is essential for fostering creativity. One of the key benefits of self-directed learning is that it enables students to learn at their own pace. This flexibility allows them to spend more time exploring challenging concepts, revisiting foundational knowledge, and experimenting with new ideas. In the context of mathematics, this freedom can lead to a deeper understanding of concepts and a greater capacity for creative problem-solving. For instance, a student who struggles with understanding the properties of logarithms might use self-directed learning to explore additional resources, such as video tutorials or interactive simulations, until they develop a thorough understanding. This foundational knowledge then serves as a springboard for creative applications, such as solving complex exponential equations.

Additionally self-directed learning encourages intrinsic motivation, which is a critical factor in creativity. When students take ownership of their learning, they are more likely to pursue topics that interest them and approach problems with curiosity and enthusiasm. This intrinsic motivation drives them to think creatively and explore innovative solutions. For example, a student with a passion for coding might use their self-directed learning skills to develop an algorithm that solves a mathematical optimization problem, combining their interests in computer science and mathematics in a creative way.

3. Balancing Collaboration and Self-Directed Learning

While collaboration and self-directed learning are powerful tools for enhancing mathematical creativity on their own, their impact is magnified when they are integrated into a balanced approach. By combining the collective benefits of collaboration with the individual focus of self-directed learning, educators can create a learning environment that supports both group innovation and personal growth. In a balanced approach, students can use self-directed learning to prepare for collaborative activities, ensuring that they have the foundational knowledge and skills needed to contribute meaningfully to group discussions. For example, before tackling a complex group project on probability, students might use self-directed learning to review the fundamental principles of probability theory and practice basic problems. This preparation not only enhances their individual understanding but also enables them to engage more effectively in collaborative problem-solving.

Collaboration can enhance self-directed learning by providing students with feedback, inspiration, and support. When students work together, they can learn from each other's approaches, identify areas for improvement, and gain new insights that inform their individual learning. For instance, a student working on a collaborative project in calculus might discover a novel integration technique from a peer, which they can then explore further through self-directed learning. This iterative process of collaboration and self-directed learning creates a dynamic cycle of growth and creativity.

4. Practical Strategies for Integrating Collaboration and Self-Directed Learning

To maximize the benefits of collaboration and self-directed learning, educators can implement several practical strategies. One effective approach is the use of blended learning models, such as the Flipped Classroom, which combine individual and group learning activities. In a Flipped Classroom, students can use self-directed learning to review instructional materials before class, freeing up class time for collaborative problem-solving activities. This approach ensures that students are well-prepared to engage in meaningful discussions and explore creative solutions. Another strategy is the use of structured group activities, such as Problem-Based Learning (PBL) tasks, that encourage collaboration while allowing for individual exploration. In a PBL task, students work together to solve a real-world problem, but each student is responsible for researching and contributing specific aspects of the solution. This structure promotes both collaboration and self-directed learning, as students must work independently to gather information and collectively to synthesize their findings.

Educators can use technology to support both collaboration and self-directed learning. Online platforms, such as discussion forums and collaborative tools, can facilitate communication and idea-sharing among students, while adaptive learning software can provide personalized resources and feedback to support self-directed learning. For example, a student working on a group project in geometry might use a collaborative online whiteboard to share diagrams with their peers while simultaneously using a self-paced learning app to review trigonometric formulas.

The integration of collaboration and self-directed learning has a profound impact on mathematical creativity. By combining the collective benefits of collaboration with the individual focus of self-directed learning, students develop a range of skills that enhance their ability to think creatively. These skills include divergent thinking, problem-solving, adaptability, and the ability to connect mathematical concepts to real-world applications. Moreover, this integrated approach prepares students for the challenges of the modern world, where creativity and collaboration are highly valued. In professional settings, individuals must often work as part of a team to solve complex problems while also taking responsibility for their own contributions. By fostering these skills in the classroom, educators can equip students with the tools they need to succeed in both academic and professional contexts.

Collaboration and self-directed learning are two powerful forces that, when combined, can significantly enhance mathematical creativity. Collaboration fosters an environment of idea-sharing, experimentation, and mutual support, while self-directed learning empowers students to take ownership of their learning and explore topics that interest them. Together, these approaches create a balanced learning environment that supports both individual innovation and collective problem-solving.

By integrating collaboration and self-directed learning into mathematics education, educators can help students develop the skills they need to think creatively, solve problems effectively, and approach challenges with confidence. This integrated approach not only enhances students' mathematical abilities but also prepares them to navigate the complexities of the modern world, where creativity and adaptability are essential for success.

CONCLUSION

The conclusion of this research underscores the significant impact of integrating the Problem-Based Learning (PBL) model with the Flipped Classroom approach on enhancing students' mathematical creative thinking abilities. This study reveals that the combined pedagogical strategies create a dynamic, student-centered learning environment that fosters the development of higher-order thinking skills. PBL encourages students to actively engage in problem-solving by analyzing real-world scenarios, thinking divergently, and generating innovative solutions, while the Flipped Classroom supports this process by allowing students to build foundational knowledge independently before class. Together, these approaches cultivate flexibility, originality, and adaptability in mathematical thinking, preparing students to address complex challenges creatively and confidently.

The broader impact of this research lies in its contribution to contemporary mathematics education, demonstrating the potential of innovative teaching models to transform traditional learning practices. By integrating PBL and the Flipped Classroom, educators can move beyond rote memorization and formulaic problem-solving, instead nurturing students' abilities to think critically and apply their knowledge in diverse contexts. This research highlights the importance of collaborative and self-directed learning as key components of fostering mathematical creativity, providing a framework for future educational practices that equip students with the skills necessary to thrive in an increasingly complex and interconnected world.

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