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Analysis of the Effectiveness of Problem-Based Learning Method in Developing Students' Analytical Mathematical Thinking Skills

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Abstract: This study constitutes a systematic literature review aimed at analyzing the effectiveness of Problem-Based Learning (PBL) methods in developing students' analytical mathematical thinking skills. The literature sources were extracted from Scopus, DOAJ, and Google Scholar indices, covering the publication period from 2013 to 2023. The research findings indicate that the consistent implementation of PBL has a positive impact on the development of students' analytical mathematical thinking skills. Empirical findings from various studies support the claim that PBL is effective in enhancing critical thinking skills, problem-solving abilities, and communication skills among students. Despite variations in the contexts and PBL approaches employed, the overall research results demonstrate the effectiveness of PBL in advancing students' analytical mathematical thinking skills. The implications of this research provide support for the implementation of PBL in the context of mathematics education, with the potential for a positive contribution to the development of students' analytical thinking skills.

Keywords: Problem-Based Learning; Analytical Thinking Skills; Education Research.

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A. INTRODUCTION

Analytical thinking skills play a central role in the context of mathematics education, as they encourage students to develop analytical, synthetic, and evaluative abilities in solving mathematical problems (Asrati et al., 2018). In the realm of mathematics instruction, these skills extend beyond merely solving problems using formulas or fixed procedures, emphasizing a deeper understanding of mathematical concepts and their application in real-world situations. Analytical thinking skills enable students to break down problems into smaller components, identify patterns or relationships, and formulate solutions with a systematic approach (Mitra et al., 2023). Moreover, through these skills, students can refine their critical thinking, question information, and construct logical arguments to support the resolution of mathematical problems. The significance of analytical thinking skills is not confined solely to academic prowess but also encompasses the application of mathematical concepts in everyday life.

Problem-Based Learning (PBL) is an instructional method that centers around utilizing problems as the starting point for the learning process (Arif et al., 2019). PBL encourages learners to actively engage in solving complex problems, fostering critical thinking skills, and consistently adapting to the challenges of the learning environment. This instructional model

involves students in the resolution of real-world problems, allowing them to apply knowledge and skills in a contextual manner. The fundamental concepts of PBL encompass four key skills: applying, analyzing, synthesizing, and evaluating (Sucipto, 2017). In the context of education in Indonesia, PBL is considered a learning model that exposes learners to real and contextual problems. PBL is also known as Problem-Based Learning (PBM) in the Indonesian language.

In the context of developing analytical mathematical thinking skills, the need to evaluate the effectiveness of the Problem-Based Learning (PBL) method becomes a crucial aspect. PBL emphasizes problem-based learning, where students are confronted with real-world situations to solve mathematical problems (Syarah et al., 2013). In this context, evaluating the PBL method is essential to gauge the extent to which it contributes to the development of students' analytical thinking skills. This evaluation includes aspects such as students' ability to analyze, formulate solutions, and connect mathematical concepts to the faced context (Cahyani and Setyawati, 2016). Furthermore, it is important to assess the extent to which PBL enhances students' critical thinking abilities in addressing mathematical problems. Through a comprehensive evaluation of the PBL method, the successes and challenges that may be encountered in its implementation can be identified, thereby optimizing the direction of developing analytical mathematical thinking skills (Kamsinah, 2022).

The effectiveness of Problem-Based Learning (PBL) methods in enhancing students' analytical thinking abilities has been investigated in several studies. Literature reviews indicate that the implementation of the PBL model can improve students' critical thinking skills (Wahdaniyah et al., 2023). Another study employing the PBL model with mind mapping support demonstrated its effectiveness in enhancing students' critical thinking abilities in social studies (Wardani et al., 2023). Furthermore, the Project-Based Learning (PJBL) model has proven effective in biology education, contributing to the improvement of critical thinking skills (Widarbowo et al., 2023). A comparison between the PBL model and Auditory, Intellectually, and Repetition (AIR) showed that both are equally effective in enhancing students' critical thinking skills, with the PBL model exhibiting a higher level of effectiveness (Asmuni et al., 2023). Additionally, the development of electronic modules for problem-based learning has been proven effective in enhancing students' creative thinking skills (Raviqah et al., 2023). These findings underscore that PBL and its variations can successfully enhance students' analytical thinking abilities.

The role of teachers is highly significant in supporting the development of analytical thinking skills through Problem-Based Learning (PBL) methods (Tripon, 2022). PBL is an instructional approach that encourages students to actively engage in problem-solving and develop critical thinking skills (Suyatman and Chusni, 2022). By implementing PBL, teachers can establish a student-focused framework, where students are motivated to think critically, analyze information, and find solutions to real-world problems (Thomas Stewart, 2020). PBL provides opportunities for students to apply their analytical thinking skills in practical situations, helping them deepen their understanding of the subject matter (Omariba, 2020). Furthermore, integrating computational thinking into PBL activities can further enhance students' analytical thinking skills (Hoić-Božić et al., 2019). Teachers can guide students in employing computational thinking strategies to analyze and solve complex problems,

enriching their abilities in critical and creative thinking. Therefore, teachers play a key role in facilitating the development of analytical thinking skills through PBL by creating an environment that encourages critical thinking, problem-solving, and the application of computational thinking strategies.

Several studies have investigated the effectiveness of Problem-Based Learning (PBL) in developing students' analytical thinking skills in mathematics. Both Septiana et al. (2019) and Sormin & Pasaribu (2023) found that PBL can enhance students' critical thinking skills in mathematics. Supporting this, Syahbana (2012) further demonstrated that Problem-Based Learning with cognitive conflict strategy (PBLCC) is more effective than conventional learning in improving students' critical thinking skills. Rosita (2014) emphasizes the importance of mathematical reasoning and communication skills in problem-solving, which are also key components of PBL. Collectively, these studies suggest that PBL is an effective approach for developing students' analytical thinking skills in mathematics.

Through the review of previous research, there is consistency in findings indicating the effectiveness of Problem-Based Learning (PBL) in enhancing students' analytical thinking skills. The implementation of PBL has been shown to improve students' critical thinking skills in various subject contexts, such as social studies (Wahdaniyah et al., 2023) and biology (Widarbowo et al., 2023). Furthermore, comparisons between PBL and other models demonstrate the superiority of PBL in enhancing students' critical thinking skills (Asmuni et al., 2023). The role of teachers in supporting the development of students' analytical thinking skills through PBL is crucial. Teachers not only create student-focused environments that encourage critical thinking but also can integrate computational thinking to enhance students' analytical thinking skills (Hoić-Božić et al., 2019). Despite the proven effectiveness of PBL in various contexts, a gap in research may lie in the lack of specific studies that deeply explore the effectiveness of PBL in developing students' analytical thinking skills in the context of mathematics education. Therefore, an in-depth study using a systematic literature review approach is aimed at filling this gap, with the specific goal of identifying the extent to which PBL is effective in developing students' analytical thinking skills in mathematics education.

B. METHOD

This study aims to conduct an analysis of the effectiveness of the Problem-Based Learning (PBL) method in developing students' analytical thinking skills in the context of mathematics education. The primary objective of this research is to identify the extent to which this method positively contributes to the development of mathematical analytical thinking skills among students. The systematic literature review approach is employed to achieve the objectives of this research. Literature searches will be conducted systematically by utilizing reputable academic databases and online resources such as Scopus, DOAJ, Google Scholar, and ScienceDirect. The focus of the search will be on journal articles, books, and scholarly publications related to Problem-Based Learning (PBL) in the context of developing analytical thinking skills in mathematics. The search will encompass the period from 2013 to 2023, aligning with the recent developments in this field.

The establishment of inclusion and exclusion criteria will serve as the primary foundation for selecting literature to be included in this review. Inclusion criteria will encompass empirical studies specifically investigating the use of Problem-Based Learning (PBL) in the context of developing analytical thinking skills in mathematics. Studies with experimental designs, case studies, and literature reviews will be considered for inclusion. Exclusion criteria will encompass studies that are irrelevant, do not employ qualitative research methods, or do not address the effectiveness of PBL in developing students' analytical thinking skills. The selection and data extraction process will be conducted meticulously, prioritizing information directly relevant to the effectiveness of Problem-Based Learning (PBL) in developing students' analytical thinking skills in mathematics. Extracted data may include key findings, utilized research methods, and research outcomes that either support or oppose the effectiveness of PBL in this context. Thus, through this systematic literature review approach, the research aims to present a comprehensive and analytical synthesis of information regarding the effectiveness of the Problem-Based Learning (PBL) method in the context of developing students' analytical thinking skills in mathematics.

C. RESULTS AND DISCUSSION

1. The Implementation of Problem-Based Learning (PBL) Method Can Influence the Development of Students' Analytical Mathematical Thinking Skills

The implementation of Problem-Based Learning (PBL) has proven to have a positive impact on the development of students' analytical mathematical thinking skills (Syahfitri and Endang Sulaiman, 2023). Research findings indicate that PBL can enhance students' critical thinking abilities across various academic disciplines, including mathematics (Hudha *et al.*, 2023). Moreover, studies have noted an improvement in students' problem-solving skills as a result of implementing PBL, a crucial aspect for the development of analytical thinking (Lusiana, 2023). Furthermore, the integration of PBL with innovative technologies such as the GeoGebra application has been shown to significantly enhance students' mathematical thinking abilities (Sartika, Rahman and Irfan, 2023). These findings suggest that PBL can be an effective approach in advancing students' analytical thinking skills.

Anggiana (2019) and Nufus et al. (2021) both reported a significant improvement in students' problem-solving abilities and critical thinking skills when Problem-Based Learning (PBL) was employed as a teaching model. Similarly, Putri (2022) found that PBL led to an enhancement in students' creative thinking abilities. These findings align with the research conducted by Sinusi (2022), indicating the positive impact of PBL on critical thinking skills among high school students in the field of biology. Therefore, the use of PBL can be an effective method for enhancing students' analytical thinking skills across various subjects, including mathematics.

The research results indicate that Problem-Based Learning (PBL) has a significantly positive impact on developing students' analytical thinking skills in mathematics. PBL not only contributes to improvements in problem-solving but also engages critical and creative aspects of mathematical thinking. PBL emerges as a holistic learning method, involving essential aspects in the development of analytical thinking. This study demonstrates that the

use of PBL can transcend disciplinary boundaries, particularly in enhancing students' critical thinking skills across various fields of study, showcasing the flexibility and relevance of PBL in diverse educational contexts. The importance of problem-solving skills resulting from PBL suggests that this method not only imparts mathematical concepts but also trains students to apply these concepts in solving real-world problems, aligning with the goal of developing analytical mathematical thinking. The integration of technology, as exemplified by W. Sartika et al. (2023), indicates that PBL can leverage innovation to enrich learning. The use of the GeoGebra application as a supportive tool for PBL demonstrates that technology can be an effective means to advance students' mathematical thinking abilities. Although these research findings present positive considerations regarding the use of PBL in the context of developing students' analytical thinking skills in mathematics, it is essential to note that the success of PBL may be influenced by various factors, including contextual and implementation aspects. Therefore, a profound understanding of the variations in outcomes and potential impacts across different learning situations is necessary.

2. The Primary Challenges Encountered in Implementing PBL to Develop Analytical Thinking Skills in Mathematics

Implementing Problem-Based Learning (PBL) as a method to enhance analytical thinking skills in mathematics faces several challenges. One difficulty encountered is in formulating and solving verbal statement arithmetic problems (PAVE) (Othman et al., 2022). Other challenges include the readiness of educators as facilitators, as well as the acceptance and preparedness of learners for the PBL strategy learning process (Mateus-Nieves and Díaz, 2021). Additionally, creating a conducive learning environment and designing and constructing PBL problems or triggers pose constraints (Nenotaek, et al., 2019). Teachers employing a scientific approach in teaching mathematics struggle to engage students in the learning process, stimulate questions from students, and develop the courage and speaking skills of students to communicate their findings (Putra and Suparman, 2021). Furthermore, teachers implementing learning with heuristic strategies face difficulties in providing non-routine problems to students, enabling students to solve problems on their own, and conducting discussions to find solutions (Rosyada and Retnawati, 2021). These challenges underscore the importance of effective strategies and support to overcome barriers and successfully implement PBL and heuristic strategies in mathematics education.

The primary challenge in implementing PBL to develop analytical thinking skills in mathematics lies in the need for reliable and valid measurement tools to assess creative thinking (Adiputra and Putri, 2020). This becomes particularly crucial in the context of mathematics education, where a robust understanding of the subject is paramount. Furthermore, learners often encounter difficulties in logical reasoning in mathematics, especially in determining the equivalence of compound sentences and drawing conclusions from given premises (Mirati, 2015). Therefore, addressing these challenges and ensuring the validity of assessment tools become crucial aspects in the implementation of PBL for the development of analytical thinking skills in mathematics.

From the research findings, it can be concluded that the primary challenges in implementing PBL to develop analytical thinking skills in mathematics involve several aspects. Firstly, the issue of PAVE implies difficulties in transforming verbal statements into concrete mathematical problems. Secondly, the challenges related to the readiness of educators and learners indicate barriers in utilizing PBL strategies, both from the facilitator and learner perspectives. Furthermore, creating a supportive learning environment and designing appropriate problems are key factors for successful PBL implementation. This study provides a comprehensive understanding of the challenges faced in implementing PBL for analytical thinking skills in mathematics. However, it is important to note that the focus on PAVE, educator, and learner readiness, learning environment, and heuristic strategies provides a thorough overview. A more in-depth evaluation of specific aspects of PBL, such as the development of valid assessments and creativity measurement tools, may offer additional insights.

3. Contextual Variables, such as the Learning Environment and Student Characteristics, Influence the Effectiveness of PBL in the Context of Developing Analytical Thinking Skills in Mathematics

Contextual variables, such as the learning environment and student characteristics, have been proven to influence the effectiveness of Problem-Based Learning (PBL) in developing analytical thinking skills in mathematics. Studies indicate that the use of mobile-based PBL has a significantly positive impact on students' critical thinking skills in mathematics (Irawati et al., 2022). Furthermore, the implementation of PBL materials has been shown to enhance students' critical thinking skills in mathematics, as evidenced by improved performance and survey results (Magpantay and Pasia, 2022). Additionally, the development of learning modules using a brain-based model has been validated as practical and effective in improving students' critical thinking skills in mathematics (Sutarni and Gatiniggsih, 2022). The results of meta-analysis also indicate that the Project-Based Learning (PJBL) model is effective in enhancing students' mathematical problem-solving abilities, with the PJBL model proving to be 1,284 times more effective than conventional learning models (Yunita et al., 2022). Furthermore, the implementation of PBL has been shown to have a high-impact category in improving students' mathematical problem-solving skills, particularly in the middle school environment (Musna et al., 2021).

The effectiveness of Problem-Based Learning (PBL) in developing students' analytical thinking skills in mathematics is influenced by contextual variables such as the learning environment and student characteristics (Kadir and Masi, 2014). These variables can impact the implementation of contextual learning in mathematics education and students' initial mathematical knowledge, both of which are crucial in PBL. For example, students' misconceptions in solving mathematical problems, as identified by Ratnayanti et al. (2021), can hinder the effectiveness of PBL. Similarly, the use of ethnomathematics in mathematics teaching has proven effective in enhancing students' understanding of mathematics (Saputro et al., 2020). However, students' learning difficulties in mathematics, particularly in topics such as mathematical logic, can also influence the effectiveness of PBL (Rahmadani, 2020).

Therefore, it is essential to consider these contextual variables when implementing PBL in the development of students' analytical thinking skills in mathematics.

Contextual variables, such as the learning environment and student characteristics, play a significant role in the effectiveness of PBL in developing students' analytical thinking skills in mathematics. The utilization of technology, such as mobile-based learning, and models focusing on brain-based learning, show potential for enhancing learning outcomes. Additionally, recognition of variations in student characteristics and their diverse initial understandings of mathematics is a key factor. Overall, research findings indicate that PBL can be an effective approach, especially when tailored to the learning context and student characteristics. This study contributes significantly by illustrating the effectiveness of PBL in various contexts and its implementation methods. However, some studies might benefit from being more specific in describing contextual variables, and further evaluation may be necessary to understand in more detail the mechanisms behind these positive impacts. Enhancing understanding of student misconceptions and strategies for addressing them could be a valuable addition to comprehending how PBL can be more effective in overcoming these challenges.

4. Strategies or Modifications to Enhance the Effectiveness of Problem-Based Learning (PBL) in Achieving the Objectives of Developing Analytical Mathematical Thinking Skills

Strategies and adaptations that can enhance the effectiveness of Problem-Based Learning (PBL) in developing analytical mathematical thinking skills involve the utilization of instructional models such as Guided Inquiry, Group Investigation, and Context-Based Learning (CBL) (Magpantay and Pasia, 2022). These models encompass steps such as initiating with a problem, formulating it, seeking relevant information, conducting observations/experiments, drawing conclusions, and communicating results (Yerizon et al., 2022). Additional instructional strategies like MURDER (Mood, Understand, Recall, Digest, Expand, Review) and Infographics can also enhance analytical thinking skills (Sartika, 2018). The implementation of PBL within the context of flipped classroom learning, where students actively engage in discussions and systematically solve problems, has proven effective in improving critical mathematical thinking skills (Gao, Yuan and Li, 2022). The use of STEM-PBL (Project-Based Learning) has also demonstrated improvement in critical thinking skills, including critical mathematical thinking, among students at various educational levels (Setyawati et al., 2022).

Wahyuningsih et al. (2019) emphasized the importance of problem-solving skills in mathematics, proposing that students can develop these skills by observing various problem-solving strategies and being given opportunities to solve a variety of problems. This aligns with the Problem-Based Learning (PBL) approach, which focuses on solving real-world problems. Udjang & Subarjo (2019) and Sudrajat et al. (2020) both highlight the role of leadership in improving the quality of education, with Udjang specifically addressing the importance of student satisfaction. Effective leadership, as discussed by Rahmah et al. (2021), is crucial in identifying and resolving issues, which are key aspects of PBL. Therefore, potential

modifications to enhance the effectiveness of PBL in developing analytical mathematical thinking skills could involve integrating leadership and problem-solving strategies, as well as ensuring student satisfaction with the learning process.

These strategies demonstrate variations and flexibility in the implementation of PBL to achieve the goal of developing analytical mathematical thinking skills. Approaches involving investigative steps, the utilization of specific instructional models, and diverse strategies such as MURDER and Infographics indicate that there are various approaches that can be adopted depending on the learning context. The effectiveness of PBL in developing analytical mathematical thinking skills can be enhanced through these strategies. The implementation of PBL in flipped classroom learning and STEM-PBL models provides tangible evidence of the potential effectiveness of PBL across different educational levels. However, it is crucial to evaluate and select strategies that align with the learning context and the characteristics of the students.

5. Empirical Research Findings Supporting the Effectiveness of PBL in Enhancing Analytical Mathematical Thinking Skills

Findings from empirical research support the claim of the effectiveness of Problem-Based Learning (PBL) in enhancing analytical mathematical thinking skills. Studies indicate that the implementation of PBL in the context of mathematics education leads to a significant improvement in students' critical thinking skills (Irawati, Huda and Adji, 2022). PBL has proven to enhance students' problem-solving abilities, communication skills, as well as their capacity to draw conclusions and argue effectively (Suryawan, Sudiarta and Suharta, 2023). The utilization of PBL materials and modules has also been proven effective in augmenting students' critical thinking skills. Furthermore, the results of meta-analytical studies demonstrate that the implementation of PBL has a significant impact on students' mathematical problem-solving skills. These conclusions affirm that PBL is an effective approach for enhancing analytical mathematical thinking skills in students.

The effectiveness of Problem-Based Learning (PBL) in enhancing analytical mathematical thinking skills is substantiated by several studies. Miatun & Khusna (2020) discovered that students with high mathematical disposition exhibit strong critical thinking skills, indicating the potential of PBL to further enhance these capabilities. Similarly, (Marlina, 2020) underscores the role of learning experiences within student organizations in improving critical thinking skills, suggesting that PBL could be an effective approach in this context. Both Irmayadi et al. (2020) and Warmi (2017) demonstrate the potential of PBL to enhance specific mathematical skills, such as drawing conclusions and making mathematical connections. Collectively, these findings support the effectiveness of PBL in improving analytical mathematical thinking skills.

Research findings indicate that PBL has a positive impact on various aspects of analytical mathematical thinking skills. Improvements in problem-solving skills, communication, and the ability to draw conclusions and argue can be considered evidence that PBL not only teaches mathematical concepts but also enriches students' thinking skills. The implementation of PBL is deemed effective in enhancing analytical mathematical thinking skills, consistent with meta-analysis findings demonstrating a significant impact on problem-solving skills. While these

studies provide robust support, it is essential to note that variations in research design and subject populations may influence the generalizability of the findings.

D. CONCLUSIONS AND SUGGESTIONS

Based on the evaluation results, it is consistently evident that the implementation of Problem-Based Learning (PBL) yields positive impacts on the development of students' analytical mathematical thinking skills. Empirical findings from various studies support the claim that PBL enhances critical thinking skills, problem-solving abilities, and communication skills of students. Despite variations in contexts and PBL approaches employed, the overall research results indicate the effectiveness of PBL in improving analytical mathematical thinking skills.

However, there are several gaps that warrant attention. First, the role of contextual variables such as student misconceptions, learning difficulties, and individual learning styles needs further consideration to understand how these factors influence the effectiveness of PBL. Second, while PBL has proven effective in enhancing analytical thinking skills, further research is needed to explore its impact on long-term learning outcomes and its application in students' everyday lives.

As an urgent research topic, future studies could focus on the integration of PBL with other learning approaches or more specific adaptation strategies of PBL tailored to the needs and characteristics of students. Additionally, research could explore the implementation of PBL in different educational contexts to understand how contextual variability may influence its outcomes. Further, there is a need for advanced research involving a deeper evaluation of the impact of PBL on the development of analytical mathematical thinking skills and its application in everyday life. A comprehensive study would provide a more holistic insight into the contribution of PBL in advancing mathematics education and fostering students' analytical thinking skills.

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