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Implementation of Problem-Based Learning to Enhance Critical Thinking Skills in Mathematics

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Abstract: This study constitutes a systematic literature review aimed at evaluating the implementation of Problem-Based Learning (PBL) in enhancing the critical thinking skills of mathematics education students. The literature sources were obtained from Scopus, DOAJ, and Google Scholar, spanning publications from 2013 to 2024. The assessment concludes that PBL is effective in fostering critical thinking skills through an innovative and interactive approach. Despite variations in research outcomes, PBL demonstrates significant potential. However, further research is needed to comprehend its impact comprehensively and the influencing factors. More specific studies are required to explore certain aspects of PBL that contribute to enhancing students' critical thinking abilities, such as effective teaching strategies, assessing the impact of PBL on various levels of critical thinking skills, or comparing the effectiveness of PBL with other instructional approaches in the context of mathematics education.

Keywords: Problem-Based Learning; Mathematics Education; Critical Thinking; Student Performance; Educational Strategy.

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A. INTRODUCTION

Critical thinking is the ability to examine and evaluate information, data, and events to reach logical conclusions and make sound decisions (Suparman, et al. 2021). This process involves reflecting on individual thoughts to enhance them. Critical thinking plays a vital role in various sectors such as education, science, healthcare, and philosophy, as it enriches creativity, sharpens problem-solving skills, and raises awareness of practical applications in professions. Developing critical thinking skills requires an understanding of logic, the ability to identify cognitive biases, and adapting thought patterns towards correctness. It involves interdisciplinary collaboration, benefiting from knowledge across fields and engaging with philosophical communities. Through learning mathematics, students are introduced to systematic thinking methods and structured problem-solving (Nurdjan, et al. 2016). Furthermore, mathematics serves as a foundation for other disciplines such as natural sciences, engineering, and social sciences, given its widespread application in various fields. Therefore, the development of mathematics education in higher education not only supports individual academic progress but also positively contributes to the overall advancement of society and industry.

Critical thinking ability, as emphasized by Zul Hanifah, et al., (2022), is a crucial aspect in comprehending and applying mathematical concepts in higher education. Critical thinking enables students not only to grasp mathematical concepts deeply but also to relate and apply them in various real-world contexts. In the process of learning mathematics, critical thinking skills allow students to see beyond mere formulas and procedures, but also to question, analyze, and evaluate information critically (Hanisyah et al. 2024). This not only enhances overall understanding of mathematical concepts but also helps students develop essential problem-solving skills across various fields of study. Additionally, the relevance of critical thinking skills in higher education is significant as it fosters an environment conducive to active, collaborative, and reflective learning, which serves as the foundation for students' intellectual and professional development. Therefore, strengthening critical thinking skills in understanding and applying mathematical concepts is not only a primary goal in mathematics education at the university level but also a necessity in preparing students for the complex and dynamic challenges of the real world (Arif, et al., 2019).

Problem-Based Learning (PBL) by Zai, et al., (2023) stands as an innovative approach within the realm of mathematics education, fostering students' problem-solving abilities and critical thinking. The utilization of Problem-Based Learning (PBL) in mathematics education has been evidenced to enhance students' critical thinking skills (Septiani, et al., 2022). Within PBL, students actively engage in solving real-world challenges using a scientific approach, facilitating the enhancement of their knowledge and problem-solving skills. Several studies have indicated the effectiveness of PBL in improving students' critical thinking abilities (Siti Aminah, et al., 2018). Moreover, PBL also has a positive impact on students' mathematical literacy, particularly in numerical operations and equation solving (Rahmawati, et al., 2014). The implementation of PBL in classrooms has been proven to enhance students' understanding of mathematical concepts and reinforce their engagement in the learning process (Purwandari, et al., 2022). Overall, the introduction of the PBL concept in mathematics education can create an engaging and active learning environment, facilitating the development of students' problem-solving skills and critical thinking abilities (Zai, et al., 2023).

In the process of mathematics learning at the university level, significant challenges arise, particularly concerning the development of critical thinking skills (Syarif 2016). These challenges encompass an excessive focus on abstract concepts and routine exercises lacking relevance to real-life situations (As'ari, et al., 2017). Instrumental understanding proves difficult to transfer into real-world contexts, posing hurdles for students in applying mathematical principles practically (Akour, at al., 2022). Additionally, many students lack the mathematical reading skills necessary to grasp abstract concepts and understand fundamental mathematical principles (Estela, et al., 2020). Mathematical reading requires various thinking and reasoning skills, including understanding terms, symbols, and concepts, the ability to analyze problems, and proficiency in applying knowledge to solve them. Furthermore, students with inadequate understanding also encounter difficulties in comprehending mathematical topics, particularly in concepts like fractions, due to differences in their thought patterns and varying levels of comprehension. There is a need for changes in the delivery

approach of mathematical concepts to make them more relevant to everyday life and to foster the development of critical thinking and problem-solving skills (Wiyana, et al., 2021).

When implementing Problem-Based Learning (PBL), significant challenges often arise in the aspects of curriculum preparation and selecting suitable problems (Meng et al. 2023). Instructors may face difficulties in designing projects comprehensively, which can be time-consuming and hinder the acceptance of PBL. Suboptimal PBL designs can lead to frustration among students and diminish the effectiveness of learning (Damsyik et al. 2021). Additionally, the lack of specific guidelines and assessment criteria for PBL can complicate the evaluation of curriculum effectiveness. Other challenges include adjusting to students' abilities and learning styles, providing the necessary resources and skills for projects, and managing large class sizes (Richert et al. 2022). Teacher and student preparation for the PBL process, including problem formulation and development, can also pose obstacles. Effective handling of these challenges is necessary to ensure the successful implementation of PBL.

Previous research on the implementation of problem-based learning methods to enhance critical thinking skills in mathematics has revealed some shortcomings, emphasizing the need for further investigation (Dasusmi et al. 2023). This research indicates that the Problem-Based Learning (PBL) approach can have a positive impact on students' critical thinking skills in mathematics, even surpassing the effectiveness of other instructional models. However, there is disagreement regarding the effectiveness of PBL compared to other models such as Discovery Learning (Palinussa, at al., 2023). Additionally, shortcomings have been identified in evaluating students' analysis, reasoning, and their ability to construct logical arguments and provide scientific considerations (Herly Janet Lesilolo 2023). Therefore, further research is warranted to address these issues and explore the potential of Problem-Based Learning in enhancing students' critical thinking skills in mathematics.

Previous research has identified several gaps in mathematics education at the university level. The main challenge lies in an excessive focus on abstract concepts and routine exercises that are less relevant to real-life applications, leading to difficulties in applying mathematical principles practically. Additionally, many students have limitations in mathematical literacy, which is necessary for understanding abstract concepts and basic mathematical principles. Therefore, this study will utilize a Systematic Literature Review approach to explore the potential of Problem-Based Learning (PBL) in addressing these gaps and enhancing the critical thinking skills of mathematics education students. PBL has been proven effective in improving students' critical thinking abilities in solving real-world problems. Thus, this research aims to provide deeper insights into the effectiveness of PBL in the context of mathematics education at the university level.

B. METHOD

This study aims to investigate the effectiveness of implementing Problem-Based Learning (PBL) in enhancing the critical thinking skills of mathematics education students. The primary focus is to obtain a comprehensive understanding of how PBL can be effectively utilized to develop critical thinking abilities. Literature search was conducted meticulously through academic databases such as Google Scholar, PubMed, IEEE Xplore, and ScienceDirect. Articles

relevant to the focus on PBL application in mathematics education, discussions on critical thinking skill development, and presence in verified scholarly journals were considered.

Inclusion and exclusion criteria were determined considering studies focusing on problem-based learning in the context of developing critical thinking skills in mathematics. Inclusion criteria involved research utilizing problem-based learning methods and measuring critical thinking skills in mathematics. Exclusion criteria encompassed studies unrelated to the main topic or not meeting the established quality standards. Literature selection was performed by thoroughly examining titles, abstracts, and contents according to the predefined inclusion and exclusion criteria. Relevant data were then extracted from selected literature for further analysis to build a comprehensive understanding of the application of problem-based learning in developing critical thinking skills in mathematics. Data extracted from each article included research methods, findings, and conclusions related to the application of PBL in developing critical thinking skills in the context of mathematics education. The process of data selection and extraction was conducted systematically to ensure the validity and reliability of the research findings.

C. RESULTS AND DISCUSSION

1. The Effectiveness of Problem-Based Learning in Enhancing Critical Thinking Skills

Problem-Based Learning (PBL) has been proven effective in enhancing students' critical thinking skills across various disciplines (Sari, at al., 2023). In the context of mathematics education, several studies have investigated the impact of PBL on students' critical thinking skills. For instance, Palinussa, at al. (2023) conducted research comparing the improvement of students' critical thinking skills in mathematics using the PBL model and Discovery Learning (Syahfitri, at al., 2023). The results indicated no significant difference in the enhancement of critical thinking skills between the two instructional models. However, a study by Dinglasan, Caraan, and Ching found that the Realistic Mathematics Education (RME) approach, which integrates problem-solving skills, was effective in enhancing students' problem-solving abilities (Sartika, at al., 2023). Thus, these findings affirm that PBL and its related approaches can positively contribute to improving critical thinking skills in the context of mathematics education.

Several studies have investigated the effectiveness of problem-based learning (PBL) in enhancing critical thinking skills across various educational contexts. Research by Rahayu (2021) found that an interactive online-based model effectively improved students' performance in science. Similarly, Monalisa Frince S. (2014) illustrated the effectiveness of PBL in enhancing students' writing abilities. These findings are consistent with the theoretical foundation of PBL, which emphasizes its potential to promote critical thinking through active engagement with real-world problems (Syahfitri, at al., 2023). However, the specific application of PBL in mathematics education, such as in the case of students in mathematics education, requires further investigation.

Problem-Based Learning (PBL) has been proven effective in enhancing students' critical thinking skills across various disciplines, including mathematics education. Studies by Palinussa and Moma compared PBL with Discovery Learning in enhancing mathematical

critical thinking skills, finding that both models did not have significant differences (Syahfitri, at al., 2023). Conversely, research by Dinglasan, Caraan, and Ching highlighted the effectiveness of the Realistic Mathematics Education (RME) Approach in improving students' problem-solving abilities (Sartika, at al., 2023).

Research findings consistently highlight the effectiveness of PBL in enhancing students' critical thinking abilities. However, variations in effectiveness exist among studies, likely influenced by specific contexts and target populations. Despite evidence supporting PBL's effectiveness, it's essential to remember that research outcomes can be influenced by various factors, including research design, implementation, and population characteristics (Cahyaningrum, at al., 2022). Further studies with more rigorous research designs and larger sample sizes can provide a more comprehensive understanding of PBL's effectiveness in enhancing critical thinking skills among mathematics education students.

2. Strategies Employed in Implementing Problem-Based Learning to Develop Mathematical Critical Thinking Skills

Development of critical thinking skills in mathematics has been a primary focus in the implementation of Problem-Based Learning (PBL) (Harianja, et al. 2023). One approach utilized is the Discovery Learning model, aiming to strengthen and enhance students' critical thinking abilities (Palinussa, at al., 2023). Additionally, another approach involves the use of problem-based digital modules, aiding in creating cognitive conflicts and enhancing students' critical thinking skills (Suryawan, at al., 2023). Findings also indicate that PBL tailored to the indicators of mathematical literacy in the PISA framework is effective in fostering students' mathematical literacy skills (Smith et al. 2023). Furthermore, the implementation of PBL has significantly improved critical thinking competencies in elementary school students dasar (Harianja, et al. 2023). Overall, the use of PBL and its various implementations has proven to be a successful strategy in developing critical thinking skills in mathematics (Syahfitri, at al., 2023).

Several studies highlight the effectiveness of Problem-Based Learning (PBL) (Sartika, at al., 2023) in enhancing students' critical thinking abilities. Research by Sartika, at al., (2023) demonstrates the significant impact of PBL on improving critical thinking skills. Another finding by Syahfitri, at al., (2023) indicates that the use of PBL-based worksheets is more effective than traditional methods. Palinussa, at al. (2023) found no significant difference between PBL and Discovery Learning in the context of mathematical critical thinking skills. Smith, et al. (2023) underscore the importance of PBL in enhancing critical thinking abilities in elementary school students. Suryawan, at al. (2023) investigated the positive effects of PBL in mathematics education.

The studies mentioned highlight various strategies in implementing Problem-Based Learning (PBL) to enhance critical thinking skills in mathematics. Problem-based learning (PBL) has proven effective in improving students' critical thinking abilities in the context of mathematics. Existing studies emphasize the diverse approaches and strategies used in PBL to achieve this objective. One commonly used approach is the Discovery Learning model, aiming to strengthen and enhance students' critical thinking skills through exploration and

self-discovery processes. Additionally, the use of problem-based digital modules has also been shown to be effective in creating cognitive conflict and reinforcing students' critical thinking abilities through interaction with mathematical content. There is also evidence that PBL tailored to the indicators of mathematical literacy in the PISA can help improve students' mathematical literacy skills. Overall, the use of PBL and its variations has been proven as a successful strategy in developing critical thinking skills in mathematics. These studies provide a rich insight into various approaches that can be adopted in the learning environment to achieve the goal of developing students' critical thinking skills.

3. The Role of Educators in Supporting the Implementation of Problem-Based Learning in the Context of Developing Critical Thinking Skills in Mathematics

The educator plays a central role in supporting the implementation of Problem-Based Learning (PBL) to enrich students' critical thinking skills in the context of mathematics education (Smith, et al. 2023). PBL, as a instructional model focused on problem-solving and critical reasoning, is oriented towards shaping, developing, and enhancing students' critical thinking capabilities (Harianja, et al. 2023). By applying PBL, educators have the opportunity to provide space for students to formulate, apply, and interpret mathematical concepts in various contexts, thereby advancing their mathematical literacy skills (Palinussa, at al., 2023). Furthermore, PBL also contributes to fostering students' thinking abilities by encouraging initiatives for independent information seeking and problem resolution (Suhirman, at al., 2023). Educators can facilitate this process by guiding students through a series of activities involved in PBL, such as independently gathering information, solving challenges, and reflecting on their learning experiences (Suparman, at al., 2021). With the guidance and support provided, educators are capable of creating a learning environment that stimulates motivation and interaction, which in turn drives the development of students' critical thinking skills.

The findings by Suparman, at al. (2021) highlight the pivotal role of educators in facilitating PBL and creating a conducive learning environment for the development of critical thinking skills. This research underscores the significant role of educators in supporting problem-based learning in the context of fostering critical thinking skills in mathematics. By providing relevant and engaging educational materials, educators can enhance students' understanding and application of mathematical concepts, thereby advancing critical thinking. Moreover, the effectiveness of PBL in enhancing the critical thinking abilities of mathematics education students has been well-documented. Through PBL, students engage in problem-solving processes that require critical thinking and collaboration. Research indicates that PBL can enhance students' critical thinking skills, which are essential for understanding and applying mathematical concepts (Aini, et al. 2019). This suggests that educators can also explore innovative teaching methods to enhance problem-based learning in mathematics.

Educators play a crucial role in supporting problem-based learning to develop students' critical thinking skills in mathematics. Through this approach, students can hone their abilities in problem-solving, critical thinking, and applying mathematical concepts in relevant contexts. In the context of mathematics education, PBL is utilized to cultivate students' critical thinking

skills by challenging them to tackle complex mathematical problems. This underscores the importance of educators in creating a learning environment that encourages exploration, reflection, and collaboration, facilitating the profound development of critical thinking skills.

4. Differences in Learning Outcomes Between Students Engaged in Problem-Based Learning and Those Who Are Not in Terms of Mathematical Critical Thinking Skills

The enhancement of students' mathematical critical thinking skills does not exhibit significant differences between the utilization of Problem-Based Learning (PBL) and other instructional models such as Discovery Learning or conventional methods (Palinussa, at al., 2023). However, when PBL is supported by teaching aids or the GeoGebra application, there is an improvement in students' mathematical and creative thinking abilities (Lusiana 2023). Furthermore, the effectiveness of the PBL model in enhancing students' mathematical knowledge remains evident, even when controlling for critical thinking skills (Panjaitan, at al., 2022). Nevertheless, further research is needed to explore its impact on various aspects of mathematical thinking and learning outcomes. Overall, PBL demonstrates potential in enhancing students' mathematical abilities and facilitating active learning (Magpantay, at al., 2022).

Research consistently shows that problem-based learning (PBL) in mathematics yields better problem-solving abilities compared to conventional methods (Daliani 2018). This is supported by the use of traditional games like Setatak to teach mathematical concepts, which can enhance critical thinking skills (Iskandar 2021). The effectiveness of PBL can be enhanced through the use of simple teaching aids, making mathematics more engaging and less daunting (Monalisa Frince S 2014). Lastly, the role of parents in fostering children's creativity in learning mathematics, especially during the COVID-19 pandemic, is crucial (Fajriyah 2021).

The research findings indicate that although PBL does not exhibit significant differences in enhancing students' critical thinking skills compared to other teaching methods, it does offer advantages in improving students' mathematical and creative thinking abilities, especially when supported by teaching aids or GeoGebra applications. Moreover, the effectiveness of PBL in enhancing students' mathematical knowledge remains evident, even when controlling for critical thinking skills. However, further research is needed to comprehensively understand the impact of PBL on various aspects of mathematical thinking and learning outcomes. The cited studies provide valuable insights into the effectiveness of PBL in mathematics education. While PBL may not consistently outperform other teaching methods in enhancing critical thinking skills, it does excel in enhancing students' mathematical and creative thinking abilities. Furthermore, the effectiveness of PBL in improving students' mathematical knowledge demonstrates significant potential. However, it is essential to interpret these findings cautiously due to variability in study designs and contextual factors that may influence outcomes.

5. Implementation of Problem-Based Learning to Develop Mathematical Critical Thinking Skills in Students

The Implementation of Problem-Based Learning (PBL) and Its Positive Impact on Students' Critical Thinking Skills in Mathematics Education Research by (Dasusmi, et al. 2023)

highlights the affirmative influence of Problem-Based Learning (PBL) on students' critical thinking abilities within the domain of mathematics education. Numerous studies, such as the work conducted by (Syahfitri, at al., 2023), indicate that PBL not only shapes but also enhances students' critical thinking skills in the context of mathematics. Moreover, findings from studies, like that of (Smith et al. 2023), demonstrate the effectiveness of PBL in elevating students' critical thinking skills, evident in the post-test scores surpassing those of pre-tests. Additionally, the utilization of PBL proves efficacious in enhancing students' mathematical literacy skills, particularly concerning numerical operations, as highlighted in the research by (Palinussa, at al., 2023). Collectively, these insights underscore PBL as a valuable approach for advancing both critical thinking and mathematical literacy among students. Research conducted by Jera and Abdila (2021) highlights the positive impact of additional learning and creative teaching methods on student performance (Nur Khairiyah, at al., 2020). Jera's study on math tutoring at community centers and Abdila's research on the use of advertisements in language learning both indicate improvements in student understanding and creativity. However, neither study directly addresses the implementation of problem-based learning in developing critical thinking skills in mathematics. Further research is needed to explore the effectiveness of problem-based learning in this context.

Research findings indicate that PBL can be an effective approach in aiding students to develop their critical thinking skills in the context of mathematics learning. Through this approach, students not only learn mathematical concepts directly but are also encouraged to solve problems and apply their knowledge contextually. This assists students in honing critical thinking skills, such as analysis, evaluation, and synthesis of mathematical information. Although studies demonstrate the positive benefits of PBL, it's acknowledged that not all aspects of critical thinking skills can be directly measured in the research context. Additionally, there are other factors that can influence the effectiveness of PBL, such as instructional design, teacher competency, and learning environment. Therefore, further research is warranted to delve deeper into the impact of PBL on various aspects of students' critical thinking skills in mathematics.

D. CONCLUSIONS AND SUGGESTIONS

Based on the evaluation results, it can be concluded that PBL has a positive impact on enhancing students' critical thinking skills in mathematics. However, there are still knowledge gaps that need to be addressed through further research. One of these gaps is the lack of understanding regarding the effectiveness and practical implementation of various PBL strategies, such as Discovery Learning and the use of digital modules, in enhancing students' critical thinking skills. Therefore, an urgent research topic is to explore more deeply the effectiveness of various PBL strategies in the context of mathematics education, with a focus on developing students' critical thinking skills. This research can help enrich understanding of the practical implementation of PBL and provide deeper insights into how educators can effectively utilize it to develop students' critical thinking skills in mathematics. Hence, a pressing research topic to be

explored in the future is "Exploration of PBL Teaching Strategies in Enhancing Critical Thinking Skills of Mathematics Education Students." This research will help deepen understanding of how PBL implementation can be optimized to achieve optimal outcomes in developing students' critical thinking skills in mathematics.

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