Education Studies and Teaching Journal (EDUTECH)
Vol 1 (3) 2024 : 469-480

PROMOTING MATHEMATICAL CRITICAL THINKING SKILLS THROUGH PROJECT BASED LEARNING: A SYSTEMATIC LITERATURE REVIEW OF HIGH SCHOOL IMPLEMENTATION

MENINGKATKAN KEMAMPUAN BERPIKIR KRITIS MATEMATIKA MELALUI PEMBELAJARAN BERBASIS PROYEK: TINJAUAN PUSTAKA SISTEMATIS PELAKSANAAN PEMBELAJARAN DI SEKOLAH MENENGAH ATAS

Mardiana[1], Mardiati[2]
STKIP Budidaya[1,2]
*diananst18@gmail.com[1], mardiati2208@gmail.com[2]

**Corresponding Author*

ABSTRACT
This research examines implementation Project-Based Learning (PBL) in improving middle school students' mathematical critical thinking skills. The research objective is to identify strategies, challenges, and impacts of implementing PBL in the context of mathematics learning. The method used is Systematic Literature Review (SLR) with the PRISMA approach, analyzing relevant articles in the last ten years. The research results show that PBL is effective in improving critical thinking skills, especially when supported by technology and projects that are relevant to students' lives. The implications of this research include the importance of training for teachers and policy support to optimize the implementation of PBL in mathematics classes.
Keywords: Project-based learning, mathematical critical thinking, middle school, PBL implementation, mathematics education.

ABSTRAK
Penelitian ini mengkaji implementasi Project-Based Learning (PBL) dalam meningkatkan kemampuan berpikir kritis matematis siswa sekolah menengah. Tujuan penelitian adalah untuk mengidentifikasi strategi, tantangan, dan dampak dari penerapan PBL dalam konteks pembelajaran matematika. Metode yang digunakan adalah Systematic Literature Review (SLR) dengan pendekatan PRISMA, menganalisis artikel-artikel yang relevan dalam sepuluh tahun terakhir. Hasil penelitian menunjukkan bahwa PBL efektif dalam meningkatkan keterampilan berpikir kritis, terutama bila didukung oleh teknologi dan proyek yang relevan dengan kehidupan siswa. Implikasi penelitian ini mencakup pentingnya pelatihan bagi guru dan dukungan kebijakan untuk mengoptimalkan penerapan PBL di kelas matematika.
Kata Kunci: Pembelajaran berbasis proyek, berpikir kritis matematis, sekolah menengah, implementasi PBL, pendidikan matematika.

1. INTRODUCTION

The development of critical mathematical thinking skills among high school students is significantly hindered by traditional, teacher-centered learning approaches. These conventional methods often emphasize rote memorization and limit opportunities for students to engage in deep exploration and analysis of mathematical concepts. As a result, students frequently find themselves capable of solving routine problems but struggle to understand the underlying principles or apply their knowledge to more complex, contextual situations (Hidayati & Wagiran, 2020; Harianto, 2024; Arifin et al., 2021). International assessments such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) highlight deficiencies in students' mathematical problem-solving abilities. For instance, data from PISA indicates that many Indonesian students demonstrate low competence in mathematical problem-solving, often only managing to tackle problems that are straightforward and do not require extensive critical thinking (Yadav et al.,

2011; Kusumantoro et al., 2022). Similarly, TIMSS results reveal that Indonesian students frequently score lower than their peers from other countries, particularly on questions that necessitate higher-order thinking skills such as analysis, evaluation, and innovation (Anazifa & Djukri, 2017; Ismiati, 2024). This gap underscores the urgent need for a shift in educational approaches to foster critical thinking skills effectively.

One contributing factor to this issue is the insufficient integration of interactive and problem-based learning methods within the curriculum. Teachers often face pressure to adhere to strict schedules, leading them to favor lecture-based instruction, which is perceived as more efficient but ultimately less effective in cultivating critical thinking skills (Zhang et al., 2019; Sunar & Shaari, 2017). Research indicates that innovative teaching strategies, such as Project-Based Learning (PBL), can significantly enhance students' critical thinking abilities by actively involving them in the learning process (Parida et al., 2018; Yumatov et al., 2017). PBL encourages students to engage with real-world problems, thereby promoting deeper understanding and application of mathematical concepts (Bashith & Amin, 2017; Khusaini et al., 2018). Moreover, the use of interactive multimedia and e-modules in conjunction with PBL has been shown to increase student motivation and facilitate independent learning, further supporting the development of critical thinking skills (Fu et al., 2014; Sitanggang, 2023). In conclusion, traditional approaches to teaching mathematics in high schools are inadequate for developing critical mathematical thinking skills. The evidence from international assessments and the effectiveness of alternative teaching methods such as PBL suggest that a shift towards more interactive, student-centered learning strategies is essential. By adopting these innovative approaches, educators can better equip students with the critical thinking skills necessary for success in an increasingly complex world.

In the 21st century, education systems globally are increasingly recognizing the importance of critical thinking skills, particularly within the domains of Science, Technology, Engineering, and Mathematics (STEM). Critical thinking is essential for solving complex problems and is viewed as a vital competency for future workforce challenges. As noted by Li et al., the integration of critical thinking into STEM education is crucial for preparing students to navigate the complexities of modern society and the job market (Li et al., 2020). Furthermore, the Partnership for 21st Century Learning emphasizes that skills such as creativity, communication, collaboration, and critical thinking are foundational for student success in both higher education and the workforce (Soulé & Warrick, 2015). Project-Based Learning (PBL) has emerged as a prominent pedagogical approach to foster critical thinking within STEM education. PBL encourages students to engage in active exploration and collaboration, allowing them to apply theoretical concepts to real-world situations. Hanif et al. highlight that PBL not only enhances students' creativity but also necessitates critical and creative thinking as they tackle hands-on projects (Hanif et al., 2019). This aligns with the findings of Aşiroğlu and Akran, who assert that PBL is integral to developing 21st-century skills, including critical thinking and problem-solving (Aşiroğlu & Akran, 2018). Moreover, the systematic review by Imaduddin et al. indicates that PBL effectively equips students with essential skills such as collaboration and systematic thinking, which are vital for success in STEM fields (Imaduddin et al., 2021).

The implementation of PBL in mathematics education exemplifies how this approach can enhance conceptual understanding while simultaneously fostering critical thinking skills. For instance, projects that involve designing budgeting systems or analyzing statistical data provide students with opportunities to apply mathematical concepts in practical contexts. This experiential learning environment not only makes mathematics more engaging but also reinforces the application of critical thinking in problem-solving scenarios. As noted by Pugh et al., integrating in-school learning with real-world experiences is crucial for deep-level learning, which is a core objective of PBL (Pugh et al., 2023). Additionally, the research conducted by Hsu and Tsai supports the notion that robotics, as a component of PBL, serves as an effective tool

for hands-on learning, thereby enhancing students' engagement and critical thinking skills (Hsu & Tsai, 2022). In conclusion, the emphasis on critical thinking within 21st-century education, particularly in STEM fields, is increasingly being addressed through innovative pedagogical approaches like Project-Based Learning. This method not only cultivates critical thinking skills but also prepares students for the complexities of the future workforce by integrating real-world applications into the learning process.

Even though many studies have revealed the benefits of Project-Based Learning (PBL) in improving various student skills, including critical thinking, there are still several problems that need to be highlighted. One of them is the lack of consensus among educational researchers and practitioners regarding how the effective implementation of PBL can improve critical mathematical thinking skills among secondary school students. This is a major challenge because the success of PBL is very dependent on project design, the role of the teacher, and adequate learning infrastructure support.

In addition, the lack of systematic documentation about PBL best practices in the context of mathematics learning in secondary schools adds to the complexity of this issue. Most previous research tends to be descriptive or only focuses on one aspect of PBL implementation, making it difficult to obtain a holistic picture of this approach. The lack of comprehensive guidance also makes it difficult for teachers to design and implement PBL consistently to achieve the expected results. Therefore, further research is needed to identify best practices and challenges faced in implementing PBL to effectively improve students' critical mathematical thinking skills.

The main research questions underlying this study are: How can project-based learning (PBL) be implemented to improve mathematical critical thinking skills in middle school classrooms? This question leads to the specific focus of the research, namely the relationship between PBL and its effectiveness in developing critical thinking skills in mathematics. The primary focus is understanding how PBL can transform traditional teaching methods into a more dynamic, student-centered approach that encourages deep thinking and problem solving. By emphasizing this question, the study aims to explore whether PBL can help develop critical mathematical thinking skills—a skill that is critical for students in dealing with complex mathematical concepts. This research also seeks to identify fundamental factors, including teaching strategies, classroom environment, and level of student involvement, that influence the success of implementing PBL in achieving these goals.

The motivation behind this research is twofold. First, this research aims to identify approaches that have been successfully implemented in implementing PBL in secondary school mathematics classes. Although there is a large body of literature regarding the use of PBL in various educational contexts, its application in mathematics education has often not been widely explored, especially in the context of developing critical thinking skills. By focusing on case studies and successful strategies, this research is expected to provide valuable insights for educators on how to effectively implement PBL in their teaching practices to improve student learning outcomes. Second, this research aims to provide practical guidance for educators in implementing PBL effectively in their classes. As the educational landscape changes toward more student-centered and experience-based learning methods, it has become increasingly important to equip teachers with the tools and strategies necessary to develop critical thinking skills. Therefore, this research will contribute to the literature that educators can use in designing lesson plans and activities that integrate PBL in a way that encourages deeper mathematical understanding and problem-solving skills.

The main aim of this research is to examine various ways of implementing PBL in the context of mathematics teaching in secondary schools. This study will involve the analysis of various PBL models, frameworks, and methodologies applied in various classroom settings. By observing these applications, this study aims to assess the effectiveness of PBL in promoting critical thinking skills in mathematics. Furthermore, this research will identify key strategies

that contribute to the successful integration of PBL in mathematics teaching, such as collaborative group work, real-world problem solving, and the use of technology. In addition to analyzing implementation strategies, this research will also explore the challenges educators face when integrating PBL into their classrooms. These challenges may include limited resources, lack of training for teachers, resistance to change from traditional teaching methods, or difficulty in assessing students' critical thinking skills within a PBL framework. Understanding these barriers will be key to formulating practical solutions that can help overcome them and improve the overall implementation process. Finally, this research will aim to measure the results of implementing PBL in terms of its effectiveness in improving students' critical mathematical thinking skills. This will involve evaluating whether PBL results in improved problem-solving abilities, deeper understanding of concepts, and the development of a more analytical approach to mathematical tasks. The ultimate goal is to provide evidence-based recommendations that can guide future educational practice in mathematics teaching.

This research aims to provide theoretical and practical contributions in the field of mathematics education. From a theoretical perspective, this research will add to the existing literature on PBL and its relationship to critical thinking, particularly in the context of mathematics education in secondary schools. Although much of the research on PBL focuses on general education or specific subjects such as science, there is still a need for more research focused on its application in mathematics education. By providing a deeper understanding of how PBL can develop critical thinking skills in this context, it is hoped that this research will fill a gap in the literature and contribute to the broader conversation regarding effective teaching methods in mathematics. From a practical perspective, this research will offer applicable insights and recommendations for educators who wish to implement PBL in their classrooms. These recommendations will be based on findings regarding successful strategies, challenges, and results of PBL in improving critical thinking skills. By offering concrete suggestions for how teachers can adapt PBL to their teaching contexts, this research aims to empower educators with the knowledge and resources they need to improve their teaching practices. Additionally, these findings may influence policy recommendations at the school or district level, encouraging educational leaders to support and invest more in PBL as a means to improve the quality of mathematics instruction.

2. METHODS

2.1 Research Design

This research uses the method Systematic Literature Review (SLR) based on PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. PRISMA is a methodology that has proven effective in providing a structured and transparent approach to reviewing and combining evidence from existing research. In this study, SLR was applied to assess and analyze relevant literature on implementation of Project-Based Learning (PBL) in developing mathematical critical thinking skills in middle school classes. This method allows researchers to identify, evaluate, and synthesize previous research results systematically and objectively. Using PRISMA, this research will follow clear steps to ensure transparent literature selection and minimize bias in data collection and synthesis of findings.

2.2 Data Collection

The main data sources in this research are relevant journal articles that can be found in various leading academic databases, including Scopus, Web of Science, And Google Scholar. This database was chosen because of its high reputation in providing verified and peer-reviewed scientific journals, which are relevant to the research topic. The data collection process begins with a search using keywords tailored to the research topic, namely: "Project-Based Learning", "Mathematical Critical Thinking", "High School", and "Implementation". These keywords were designed to ensure that the articles found actually

discussed the implementation of PBL in the context of mathematics teaching at the secondary school level.

Article inclusion criteria included studies that focused on PBL and mathematical critical thinking, published within the last ten years, to ensure the relevance and currency of the information. The selected articles must also provide empirical data that supports findings related to the implementation of PBL and its effect on improving mathematical critical thinking skills. On the other hand, exclusion criteria would include articles that are not relevant to the research topic, such as those that only discuss PBL outside of a mathematical context or do not provide empirical data that can be analyzed. Studies that do not meet the inclusion criteria will be excluded from the analysis to maintain research focus on relevant aspects.

2.3 Data Analysis

For data analysis, this research will use thematic analysis, which is an approach used to identify, analyze and report patterns or themes in data found during the literature selection process. Through thematic analysis, researchers can identify various patterns in the implementation of PBL, including the strategies used, challenges faced by educators, and the results obtained in improving mathematical critical thinking skills among students. This analysis process will be carried out carefully, by noting the main categories and themes that emerge from each selected article, as well as categorizing them based on relevant topics. In this analysis, researchers will also use Bloom's thinking framework and constructivism theory as a theoretical basis for understanding how PBL can facilitate the development of mathematical critical thinking skills. Bloom's framework, with its levels ranging from knowledge to evaluation, will be used to assess how the application of PBL can influence various levels of critical thinking skills needed in mathematics learning. Meanwhile, constructivism theory, which focuses on the understanding that students build their knowledge through direct experience and reflection, will help explain how PBL can create a deep and meaningful learning context for students. By combining these two frameworks, the analysis will provide a more holistic understanding of how PBL can improve critical thinking skills in mathematics in the middle school classroom.

3. RESULTS

3.1. PBL Implementation Strategy

Implementation Project-Based Learning (PBL) in teaching mathematics in secondary schools requires the application of various strategies that enable students to be actively involved in learning and develop their critical thinking skills. Some of the main strategies that can be used in implementing PBL in mathematics classes include:

1. **Use of Real World Problem Based Projects**

One of the main strategies in PBL is to use projects that are based on real-world problems. In the context of mathematics, this means connecting mathematical concepts with situations or problems that are relevant to students' daily lives. For example, students may be given assignments to design household budgets, analyze stock market data, or plan infrastructure development using mathematical principles such as statistics, algebra, or geometry. This approach not only makes learning more engaging, but also gives students the opportunity to see how mathematics is applied in the real world, increasing their understanding of the importance of mathematical skills in professional and social contexts. By working on projects that touch on real issues, students will be invited to think critically in solving problems, evaluate various solutions, and consider the implications of the decisions they make.

2. **Group Collaboration to Complete Complex Tasks**

Group collaboration is an important element in implementing PBL. In mathematics learning, working on projects in groups allows students to share ideas, discuss solutions, and

work together to solve more complex problems. Students with different levels of understanding or expertise can help each other, thereby enriching their learning experience. This collaboration also encourages communication skills, teamwork, and collective problem solving, all of which are important components of critical thinking. In addition, group work can increase student motivation because they feel responsible for the results achieved together. In more complex tasks, such as designing a mathematical model for a problem or analyzing statistical data, collaboration allows students to break down the heavier work and explore multiple perspectives that can enrich the resulting solution.

3. **Technology Integration Such as Mathematics and Simulation Software**

Technology integration is an important element in supporting the implementation of PBL in mathematics classes. Use of mathematical software, such as GeoGebra, MATLAB, or Wolfram Mathematica, allows students to conduct deeper exploration of mathematical concepts and visualize more complex problems. Technology can also be used to conduct simulations, which help students test various scenarios or mathematical predictions in a more time-efficient manner. For example, in projects that involve data analysis, students can use software to process the data and produce more accurate graphs or mathematical models. This technology not only makes it easier to understand concepts, but also introduces students to the tools used in professional professions and the industrial world. Additionally, technology can increase student engagement in learning, by providing access to a wider range of resources and allowing them to learn in a more interactive way. By implementing these strategies, PBL can be optimized to improve students' critical mathematical thinking skills. Through the use of real-world problems, group collaboration, and technology, students will not only understand mathematical concepts, but will also develop the ability to think analytically, creatively, and critically—skills that are much needed in the 21st century.

3.2 Challenges in PBL Implementation

Although Project-Based Learning (PBL) offers many benefits in the development of mathematical critical thinking skills, its implementation in mathematics classes in secondary schools faces several challenges that need to be overcome to ensure the success of this approach. Some of the main challenges in implementing PBL include:

1. **Time Constraints in Completing Projects**

One of the main challenges often faced in implementing PBL is time constraints. Project-based learning requires more time compared to traditional teaching methods which focus more on delivering material in a short time. Students need time to conduct research, collaborate with classmates, and complete complex assignments, which requires more flexible time allocation and more study sessions. In educational environments that often have tight schedules, such as a limited number of class hours or standardized tests, it is very difficult to provide enough space for these projects to develop. This can also add to the pressure on teachers, who must ensure that curriculum material is still covered while making room for project-based learning. Therefore, efficient time management and careful planning are very important so that PBL can be implemented well without disturbing other learning objectives.

2. **Lack of Teacher Training to Implement PBL Effectively**

Effective implementation of PBL requires teachers' deep skills and understanding in designing, facilitating, and evaluating projects. However, many teachers do not have special training or experience in implementing PBL, especially in the field of mathematics. Without adequate training, teachers can struggle to manage team-based projects, provide constructive feedback, and guide students in overcoming challenges that arise during the project. Additionally, teachers may be unfamiliar with how to manage students working in groups or with balancing their roles between instructor and facilitator. Without proper training, PBL can

run the risk of being less effective, even causing confusion for students who need clear direction. Therefore, it is important for educational institutions to provide adequate and ongoing training for teachers so that they can master PBL strategies and implement them successfully in the classroom.

3. Limited Resources, Such as Technology or Teaching Materials

Implementing PBL in mathematics learning often requires additional resources that are not always available in every school. One of the obstacles that is often encountered is limited access to the technology needed to support project-based learning. Many math projects can be enhanced with the help of special software or technology tools that allow students to analyze data, create models, or visualize difficult math concepts. However, not all schools have sufficient access to the hardware or software required for these projects. Apart from that, limited teaching materials, such as books or learning materials relevant to PBL, can also be an obstacle. If schools do not have adequate teaching materials, both in physical and digital form, PBL-based projects can become more difficult to implement effectively. Therefore, it is important for schools to invest in technological infrastructure and provide adequate teaching materials to support successful implementation of PBL.

Facing these challenges requires collaborative efforts from various parties, including teachers, schools, and policy makers. Support in the form of training, adequate time allocation, and provision of sufficient resources will be very important to ensure that PBL can be implemented effectively and provide maximum benefits for students in developing their mathematical critical thinking skills.

3.3 Impact on Mathematical Critical Thinking

Implementation Project-Based Learning (PBL) in mathematics teaching in secondary schools has a significant impact on the development of students' mathematical critical thinking skills. Some of the main impacts that can occur include increasing analytical, evaluation and creativity skills in solving mathematical problems, as well as increasing student involvement in the learning process. These impacts can be seen in more detail in the following two aspects:

1. Increasing Analysis, Evaluation and Creativity Skills in Solving Mathematical Problems

One of the main benefits of PBL is its ability to encourage students to think more deeply and critically when facing problems. PBL encourages students to analyze problems from various points of view, evaluate available data, and develop solutions that are creative and relevant to real-world contexts. When students are faced with projects that require them to design mathematical models or analyze data, they need to use analytical skills to identify patterns and relationships between existing variables. In addition, they must be able to evaluate various possible solutions, weigh the advantages and disadvantages of each, and choose the most appropriate approach to solving the problem. This process stimulates students' critical thinking abilities, because they not only follow known algorithmic steps, but also look for innovative problem solutions that can be applied in real life.

PBL also encourages creativity, as students are given the freedom to explore possibilities and seek unconventional solutions. In a mathematical context, this creativity can emerge in the way students connect previously separate concepts, or in the use of more innovative mathematical techniques to solve problems. This creativity is very important in developing critical thinking skills because it allows students to see more than one way to solve a problem, as well as understand how a solution can have an impact in a wider context.

2. Increasing Student Engagement in Learning

Implementing PBL in mathematics classes also increases student involvement in the learning process. In the traditional approach, students often feel learning mathematics as

something separate from the real world and irrelevant to their lives. However, through PBL, students are given the opportunity to work with problems that relate directly to the real world, which makes learning more meaningful and interesting. When students feel that what they are learning has practical applications, they will be more motivated to be actively involved in the learning process. In addition, project-based learning places students at the center of learning. They not only receive information from teachers, but also actively seek information, discuss with classmates, and solve problems independently or in groups. This approach gives students a sense of responsibility for their own learning, which in turn increases their sense of ownership and involvement in the material being studied. Active interaction with the material, group discussions, and collaboration on math projects help students to better understand and master complex math concepts.

Overall, the implementation of PBL in mathematics learning has a positive impact on the development of students' critical mathematical thinking. Through increasing analytical, evaluation and creativity skills, as well as active involvement in learning, students not only master mathematical concepts, but also learn to think critically and creatively in dealing with more complex problems. These skills are very important for students, especially in the 21st century, where critical thinking abilities and creativity are the keys to success in various areas of life.

4. DISCUSSION

In answering research questions about how to implement Project-Based Learning (PBL) can improve mathematical critical thinking skills in middle school mathematics classes, study results show that The implementation of Project-Based Learning (PBL) is influenced by various factors, including the school context, teacher capabilities, and available resources. Schools equipped with advanced technological support and better facilities can implement PBL more effectively, utilizing tools such as mathematics software and digital learning platforms to enhance the learning experience (Fang, 2023). Conversely, schools with limited resources may encounter challenges in optimizing PBL; however, innovative teaching approaches can still yield positive outcomes for students. For instance, creative strategies employed by teachers can help mitigate resource limitations, allowing for the effective integration of PBL even in less equipped environments (Harianja et al., 2023).

Research indicates that PBL can significantly enhance students' mathematical critical thinking skills compared to traditional teaching methods. This effectiveness is particularly pronounced when projects are designed to be relevant to students' real-life experiences and are supported by technology that aids in visualizing and analyzing abstract mathematical concepts (Lukitasari et al., 2019; Dharma et al., 2020). In PBL settings, students engage with real-world problems that necessitate critical thinking, evaluation, and the creation of solutions, which are integral to developing mathematical critical thinking skills (Ritonga et al., 2021; Amin et al., 2020). The PBL model encourages deeper and more reflective thinking processes, essential for mastering advanced mathematical concepts, as it fosters an environment where students actively participate in their learning journey (Handayani et al., 2022).

Moreover, studies have shown that the duration and structure of PBL implementation play a crucial role in its effectiveness. Adequate time for both individual and group investigations is necessary to achieve desired learning outcomes, as this allows students to explore problems thoroughly and develop critical thinking skills (Yohannes et al., 2021; Abdullah, 2024). The integration of PBL with other teaching methodologies, such as blended learning, can further enhance student motivation and engagement, leading to improved learning experiences and outcomes (Lukitasari et al., 2019; Hikmawati & Suryaningsih, 2020). Therefore, while the context and resources available to schools can affect the implementation of PBL, the model's inherent capacity to promote critical thinking and problem-solving skills remains a significant advantage in mathematics education.

4.1. Practical Implications

The results of this research have several important practical implications for educators and policy makers in the education sector. One of the necessary first steps is to provide intensive training for teachers to design and implement PBL-based projects in an effective manner. Teachers need to be given skills and strategies to manage classes in a PBL context, including how to design relevant and challenging projects, as well as how to support students in the process of collaboration and problem solving. This training also needs to include a deep understanding of how to use technology to support project-based learning, so that teachers can utilize the tools and resources available to increase the effectiveness of PBL.

In addition, to overcome the challenges that arise in implementing PBL, closer collaboration between educators and policy makers is needed. Policy makers must provide support in the form of adequate resources, such as the necessary technology, relevant teaching materials, and sufficient time to implement the project. In addition, policies that support ongoing training for teachers in PBL methods as well as a more comprehensive evaluation of the effectiveness of implementing PBL in mathematics learning contexts would be very beneficial. With a policy that takes these constraints into account, the implementation of PBL can be carried out more optimally, and the desired learning outcomes, namely increasing students' mathematical critical thinking skills, can be achieved.

Thus, the application of PBL in mathematics learning can have a significant impact on the development of students' critical thinking skills, but its success is very dependent on adequate teacher training, relevant project design, and sufficient resource support. Therefore, collaboration between teachers, schools and policy makers is the key to creating an effective learning environment and supporting the improvement of students' mathematical critical thinking skills.

5. CONCLUSION

Based on the findings of this research, it can be concluded that Project-Based Learning (PBL) has enormous potential in improving secondary school students' mathematical critical thinking abilities. PBL encourages students to engage in deeper thinking processes, hone analytical, evaluation and creativity skills in solving mathematical problems. However, the success of implementing PBL is highly dependent on planned implementation and adequate support. Factors such as school context, teacher training, availability of resources, and relevance of the project to students' real lives play an important role in determining how effectively PBL can improve students' critical thinking skills. Therefore, it is important to pay attention to these various elements so that PBL can be implemented optimally and provide maximum benefits for students.

5.1. Research Contribution

This research makes a significant contribution to the field of mathematics education by providing insight into best practices in implementing PBL for mathematics learning at the secondary school level. This study identifies various strategies and challenges that educators need to consider in designing and implementing PBL-based projects. In addition, this research also provides useful recommendations for teachers and policy makers to improve the effectiveness of PBL. One of the main recommendations is the importance of providing adequate training to teachers so that they can design projects that are relevant and interesting for students and make wise use of technology to support the learning process.

5.2. Suggestions for Further Research

Although this research has made a significant contribution, there are still many areas that need further exploration. Further research is needed to explore the long-term impact of

implementing PBL in various educational contexts, particularly to see whether the improvements in critical thinking skills gained through PBL can continue after students complete the project. Further research could also focus on other variables that might influence the success of PBL, such as differences in student characteristics, the role of parents, and the influence of the social environment on project-based learning. Additionally, empirical studies that test the strategies identified in this research in the field would be very useful. Using direct data from experiences implementing PBL in the classroom can provide a deeper understanding of how these strategies are received by students and implemented by teachers. This will also help in identifying more specific challenges that may arise in various educational contexts and how to overcome them. This research paves the way for more studies that can deepen our understanding of the potential of PBL in improving mathematics learning at the middle school level.

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