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Integration Of The STEM Approach In PJBL Learning To Build Mathematical Critical Thinking Skills

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Abstract: Education must teach 21st-century skills such as critical thinking, collaboration, communication, and creativity. However, conventional approaches are still used in mathematics learning, which do not adequately hone students' critical thinking skills. This research aims to analyze how effective the STEM (Science, Technology, Engineering, and Mathematics) approach combined with the Project Based Learning (PjBL) model is in improving students' mathematical critical thinking skills. The STEM approach has been introduced as a solution, but there has not been much in-depth research on how effective it is. A Systematic Literature Review (SLR) was used for nine articles that met the inclusion criteria. These articles discuss the application of STEM in mathematics learning and its impact on students' critical thinking skills. It shows that the PjBL-STEM approach consistently improves students' ability to think critically. Through learning projects, this model encourages students to think analytically and creatively actively and to link mathematical concepts with real-world situations. The results show that the integration of PjBL with the STEM approach helps build skills such as problem-solving, collaboration, communication, and decision-making in the modern era. Therefore, educators should widely apply this model in the learning process, especially in subjects that require high intelligence such as mathematics.

Keywords: Critical Thinking Mathematics, Project Based Learning, STEM

I. INTRODUCTION

The focus of 21st-century skills is to enhance the capabilities of Indonesian human resources so they can compete in the workforce. 21st-century learning emphasizes four main skills, known as the 4Cs: Critical Thinking, Collaboration, Communication, and Creative Thinking [1].

In detail, critical thinking involves objective and in-depth analysis of a situation or problem, contextualized with facts, evidence, or emerging data [2]. Critical thinking education aims to improve students' cognitive abilities so they can convey information effectively [3]. In decision-making, students with critical thinking skills can analyze problems, evaluate evidence, and construct logical arguments. The STEM approach is one of the learning methods needed to stimulate and develop students' critical thinking skills.

Effective STEM education explores significant 21st-century challenges in contexts such as health, environment, energy, technology, and natural resources [4]. STEM (Science, Technology, Engineering, and Mathematics) is an educational methodology that integrates these four disciplines. However, applying the STEM approach in education faces obstacles in teaching students to improve their critical thinking skills, which are part of the 21st-century skills. This is due to the context offered by the STEM approach [5].

States that STEM-based learning combines knowledge and skills from various disciplines (science, technology, engineering, and mathematics), making learning experiences more meaningful and relevant to daily life [6]. A study by [7], shows that implementing STEM-based learning in mathematics significantly improves students' critical thinking skills compared to conventional mathematics learning.

Despite extensive research on the benefits of STEM in learning, there remains a gap in studies on how effective this method is in enhancing students' critical thinking skills, particularly in mathematics education. Therefore, deeper and more systematic research is needed to identify trends in prior studies, highlight differences, and provide recommendations on how STEM can improve students' critical thinking skills.

This study aims to analyze and examine literature on the effectiveness of the STEM approach in enhancing students' critical thinking skills. By understanding existing research trends, this study is expected to provide deeper insights into implementing the STEM approach in mathematics education and serve as a foundation for developing more creative and efficient teaching methods. It is also hoped that this study will help Indonesian educators and policymakers improve the quality of education.

II. METHOD

Methods should make readers be able to reproduce the experiment. Provide sufficient detail to allow the work to be reproduced. Methods already published should be indicated by a reference: only relevant modifications should be described. Do not repeat the details of established methods.

Systematic Literature Review (SLR) is the systematic approach used in this study to gather, critically examine, synthesize, and compile results from various research studies related to a specific question. The SLR method achieves this by using structured, clear, and repeatable procedures at each step [8]. SLR is useful for identifying, comprehensively assessing, and summarizing findings from all relevant studies discussing STEM-integrated learning and teaching practices in the context of the STEM approach.

The SLR process in this study involves the following steps: formulating research questions, establishing inclusion criteria, searching for studies relevant to the research subject, selecting primary studies, analyzing data from findings, and compiling a results report [9].

Research Questions

The research questions focus on the findings of articles discussing STEM-based Project-Based Learning in improving students' mathematical critical thinking skills and how the STEM approach through the PjBL model can support the development of these skills.

Inclusion Criteria

The inclusion criteria for this study are as follows: articles discussing the application of the STEM approach in mathematics learning; articles assessing the influence or effectiveness of STEM on critical thinking skills; primary studies in the form of experimental or quasi-experimental research; articles containing information on integrating STEM with project-based learning models; and articles from indexed national journals, proceedings, and research journals. Initial studies analyzed span from 2020 to 2025. The eligibility of a study for further analysis is determined using these criteria.

Study Search

This study collects information using Google Scholar and the Publish or Perish application as primary search tools. Additionally, articles found are traced to their original sources. Keywords used in the search include "STEM," "critical thinking," "mathematical critical thinking," "project-based learning," and "project-based education."

Study Selection and Evaluation

Articles are selected and evaluated to ensure relevance to the research focus. Only articles aligned with the topic and meeting the inclusion criteria are chosen for analysis. From the search results, 100 studies were found related to the research theme, but only 9 articles met all inclusion criteria and were thoroughly evaluated.

Data Analysis and Research Reporting

Selected articles are analyzed, and findings are compiled into a report to provide a comprehensive and balanced understanding of the subject.

III. RESULT AND DISCUSSION

Findings on The PjBL-STEM Approach in Improving Students' Mathematical Critical Thinking Skills

The findings from the 9 selected articles meeting the inclusion criteria, related to the STEM-based Project-Based Learning model, are summarized in Table 1.

Table 1. Research Findings on The STEM-Based PjBL Model

No	Author (Year)	Article Title	Results
1	[10]	"Pengaruh Model Project Based Learning (PjBL) dengan Pendekatan STEM Terhadap Penguasaan Konsep dan Keterampilan Berpikir Kritis Siswa"	The integration of project-based learning (PjBL) with the STEM approach yields positive effects on students' critical thinking skills. The diverse activities incorporated within the STEM framework effectively contribute to the enhancement of students' critical thinking abilities.
2	[11]	"Analisis Mengukur Kemampuan Berpikir Kritis Melalui Pembelajaran Menggunakan Metode STEAM-PjBL"	The implementation of the STEAM-PjBL methodology demonstrates a direct impact on learning outcomes, particularly in enhancing the learning experience. Significant differences in academic achievement are observed following the adoption of this approach.
3	[12]	"Pedesaan Pengembangan Model Project Based Learning Terintegrasi STEM untuk Meningkatkan Kemampuan Berpikir Kritis Matematis Siswa SMP"	The implementation of STEM-based project learning models in mathematics education has been shown to effectively enhance junior high school students' mathematical critical thinking skills.
4	[13]	"Model Project Based Learning Terintegrasi STEAM Terhadap Kecerdasan Emosional dan Kemampuan Berpikir Kritis Siswa Berbasis Soal Numerasi"	Students engaged in the PjBL-STEAM instructional model acquire practical competencies aligned with real-world demands, including self-management, problem-solving, initiative, communication, and collaboration skills. Furthermore, these students demonstrate superior critical thinking capabilities compared to their peers exposed to conventional learning methodologies.
5	[14]	"Implementasi Pendekatan STEM untuk Meningkatkan Kemampuan Berpikir Kritis,	Students exposed to STEM-based instructional methods demonstrate significantly enhanced

		Berpikir Kreatif dan Self Efficacy"	critical thinking competencies compared to those receiving conventional pedagogical approaches.
6	[15]	"Efektivitas Model Pembelajaran Project Based Learning Terintegrasi STEM Terhadap Keterampilan Berpikir Kritis Siswa SMP"	Students participating in the PjBL-STEM model demonstrate significantly superior critical thinking skills compared to their counterparts in non-PjBL instructional approaches. Quantitative analysis reveals that the PjBL-STEM model accounts for 75.5% of the variance in students' critical thinking skill development. These findings conclusively demonstrate that the integrated PjBL-STEM pedagogical strategy constitutes an effective intervention for enhancing students' critical thinking competencies.
7	[16]	"Peningkatan Kemampuan Berpikir Kritis Siswa dalam Pembelajaran Project Based Learning Pendekatan STEM Materi SPLDV Kelas VIII"	The significant improvement in students' average scores from 37.9 to 92.8 provides empirical evidence that the PjBL-STEM instructional model is highly effective in enhancing students' critical thinking abilities.
8	[17]	Pengaruh Pendekatan STEM Berbasis Project Based Learning Terhadap Kemampuan Berpikir Kreatif dan Berpikir Kritis Pada Mata Pelajaran Matematika Siswa SMP Labschool Cibubur (Quasi Eksperimen)	The assessment results demonstrate that students engaged in project-based STEM approaches exhibit significantly superior performance in both creative thinking and mathematical critical thinking skills compared to their peers in conventional learning environments. This enhanced performance can be attributed to the dual nature of the STEM methodology, which not only fosters an engaging learning experience but also presents intellectually challenging opportunities for students to develop innovative and analytical approaches to mathematical problem-solving.
9	[18]	Implementasi STEM Berbasis Project Based Learning dalam Pembelajaran Bentuk-Bentuk Bangun Datar Segitiga dan Segiempat	The implementation of project-based STEM methodology in teaching triangle and quadrilateral concepts has demonstrated significant improvements in student engagement, classroom dynamism, creativity, and critical thinking skills. Our research findings indicate successful execution of the STEM project-based approach, with all students actively participating in the learning process. Quantitative analysis reveals that 84% of participants achieved clear conceptual understanding, while the remaining 16% required additional reinforcement in differentiating between triangular and quadrilateral geometric properties.

Source: Result of data processing, 2025

Table 1, shows that the STEM-based PjBL method enhances students' critical thinking skills. Generally, this approach integrates science, technology, engineering, and mathematics, encouraging students to apply these ideas in relevant, contextual projects.

Implementing STEM with Project Based Learning to Improve Students' Mathematical Critical Thinking Skills

STEM is an educational methodology combining four main fields: mathematics, technology, science, and engineering. This approach connects school-learned knowledge with real-life situations, bridging theoretical mathematical concepts with applications in information technology and everyday problems [19, 20, 21]. The STEM approach enhances students' mathematical critical thinking skills to collaborate, communicate, adapt, and solve problems critically, logically, and systematically [22].

In mathematics education, the STEM approach can be applied in various ways, such as using each STEM element separately, incorporating it into other subjects, or integrating two or more STEM elements [23]. Based on the synthesis of primary studies, improving mathematical critical thinking skills can be achieved through STEM-based teaching materials.

Overall, this study aligns with prior research showing that STEM PjBL enhances critical thinking skills. Previous studies, such as [10], also emphasize the importance of integrating STEM into education, highlighting students' active exploration and direct application of scientific concepts.

However, minor differences exist in the focus of subjects studied and contexts used. For example, [18] focus on teaching basic mathematics with a project-based approach, while [15] examines higher-level applications with statistically measurable results.

To effectively implement STEM PjBL in enhancing critical thinking, educators can take steps such as designing real-life projects (e.g., engineering problems or scientific experiments) to demonstrate STEM applications, encouraging multidisciplinary teamwork, fostering critical and creative thinking in project planning and evaluation, and providing constructive feedback for continuous improvement. With these steps, STEM PjBL is expected to significantly improve students' critical thinking skills.

IV. CONCLUSION

Based on the analysis of nine research articles, it is concluded that project-based learning (PjBL) combined with the STEM approach improves students' critical thinking skills. This method engages students in project-based learning activities integrating science, technology, engineering, and mathematics, encouraging creative, analytical, and solution-oriented thinking to solve problems.

Overall, the PjBL-STEM model offers many benefits. It helps students become more engaged in learning and builds higher-order thinking skills, particularly critical thinking. This model also significantly improves learning outcomes compared to conventional methods and develops modern skills like collaboration, communication, problem-solving, and decision-making.

The analysis suggests that teachers should begin implementing the PjBL model combined with the STEM approach in their lessons, especially in subjects requiring critical thinking, such as mathematics. To make learning more contextual and meaningful, teachers should design projects relevant to students' lives. To deepen understanding and gather empirical evidence supporting STEM-PjBL's effectiveness, further research is recommended on its application across various educational levels and subjects.

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