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A Comparative Study of PJBL-STEM Learning Models: Analyzing Similarities and Differences Between Two Research Articles

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Abstract
A Comparative Study of PJBL-STEM Learning Models: Analyzing Similarities and Differences Between Two Research Articles. *This study aimed to compare two research studies that focused on the implementation of Project-Based Learning (PjBL) integrated with STEM in enhancing students' critical thinking, conceptual understanding, and creativity. The research employed a qualitative methodology, specifically content analysis, with data gathered through a literature review. Articles were selected based on specific criteria, including the accreditation ranking of the publishing journal, relevance to the topic, and citation impact. Data was collected using Google Scholar and Publish or Perish with keywords such as "Project-Based Learning" and "STEM.". The findings reveal key similarities between the studies, notably the success of PjBL-STEM in improving students' scientific skills. However, the studies differ in their research objectives, target subjects, methodologies, and data collection instruments, highlighting varied focuses and anticipated outcomes. For instance, one study may prioritize critical thinking while another emphasizes conceptual understanding. The study concludes that integrating PjBL with STEM significantly enhances students' critical thinking, conceptual grasp, and creative problem-solving abilities. These findings demonstrate that PjBL-STEM is an effective and comprehensive educational strategy, preparing students to meet real-world challenges by developing essential scientific and creative skills.*

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INTRODUCTION

Amidst the rapid pace of globalization and technological advancement, education in Natural Sciences (IPA) must undergo significant transformation to remain pertinent and effective. The 21st century necessitates that students not only grasp fundamental scientific concepts but also apply them within complex real-world contexts. Educational reforms are considered crucial for enhancing the quality of education in Indonesia (Ariyatun & Octavianelis, 2020). A notable example of this reform is the transition from pedagogical methods that predominantly emphasize lower-order cognitive skills to those that foster higher-order thinking (Herlita et al., 2023). Current pedagogical practices are often criticized for inadequately providing students with opportunities to address real-life problems, which impedes the development of their creativity. Furthermore, students frequently lack opportunities to construct a more profound and meaningful understanding of scientific concepts. Consequently, there is a need for instructional strategies that emphasize student-centered activities to enhance creativity and conceptual comprehension in science education

(Yulaikah et al., 2022). In addition to critical thinking, conceptual understanding and creativity are essential for optimal learning outcomes (Prajoko et al., 2023).

One innovative pedagogical approach that addresses these challenges is Project-Based Learning (PjBL) integrated with STEM (Science, Technology, Engineering, and Mathematics). Implementing STEM through PjBL encourages students to engage in specific activities that facilitate the development of projects during the learning process (Diana et al., 2021). The effectiveness of the PjBL model in STEM education is underpinned by the congruence of its procedural steps, which include (1) Observation and enrichment, (2) Testing, (3) Association, (4) Simplification, and (5) Reconstruction (Diana et al., 2021). The low sense of responsibility among students is often attributed to their mindset and awareness. Enhancing students' critical thinking skills and fostering a responsible scientific attitude towards effective learning can be achieved through the STEM approach (Nisah et al., 2024). Additionally, PjBL-STEM instruction promotes active student engagement, which leads to more meaningful learning experiences. This approach has the potential to stimulate creativity and deepen students' conceptual understanding of science (Diana et al., 2021).

The urgency of the research lies in the existing gap in pedagogical practices, where students are often not sufficiently challenged to apply scientific concepts in real-world problem-solving situations, hindering their creative and critical thinking abilities. Given the increasing demand for students who can think critically, solve problems, and innovate in today's fast-changing world, it becomes essential to explore new instructional strategies that can address these deficiencies.

The novelty of this research lies in its comparative analysis of the effectiveness of PjBL integrated with STEM in enhancing three key educational outcomes: critical thinking, conceptual understanding, and creativity. While previous studies have focused on the separate impact of PjBL or STEM approaches, the combination of both in fostering these competencies has not been extensively explored. This research, therefore, fills an important gap in the literature by offering insights into how this integrated approach can improve multiple dimensions of student learning simultaneously.

The benefits of this research include providing empirical evidence that can guide educators and policymakers in adopting more effective teaching strategies. By demonstrating the advantages of the PjBL-STEM model, this study can contribute to the development of instructional practices that not only foster higher-order thinking skills but also encourage student engagement and creativity in science education, ultimately leading to improved learning outcomes. The primary objective is to demonstrate how active learning methodologies can enhance student engagement and improve learning outcomes more effectively than traditional based instruction. This involves investigating the comparative benefits of active learning, which emphasizes student participation, critical thinking, and collaboration, in contrast to passive information delivery typical of conventional teaching approaches (Sulaiman, 2024).

Empirical studies have indicated that the STEM approach, when combined with the PjBL model, can improve students' creative thinking abilities, conceptual understanding, and overall creativity in science education. This motivates the present analysis, which aims to elucidate and compare the findings of two distinct studies regarding the effectiveness of the PjBL model integrated with STEM on critical thinking, conceptual understanding, and student creativity.

METHODS

This study is qualitative research that employs content analysis methodology and collects data through a literature review. Each stage in this methodology is explained in detail below :

1. Literature Review: The researcher conducted the literature review using search engines Google Scholar and Publish or Perish software. Keywords used included project-based learning (PjBL) and STEM (Nurhidayah et al., 2021), focusing on articles relevant to the integration of PjBL and STEM in science education. This stage began with searching for articles based on the keywords, followed by filtering the articles according to relevance and quality criteria.
2. Selection of Method: The selection of content analysis methodology for this study is based on the qualitative nature of the research, which aims to delve deeper into the characteristics and effectiveness of the PjBL-STEM learning model. This method was chosen because it allows the researcher to comprehensively analyze the content of various articles, identifying similarities and differences among the studies being compared.
3. Research Flow: The research process commenced with a literature search, which was followed by filtering articles using specific criteria such as topic relevance, journal quality, and the article's contribution to the PjBL-STEM field. After filtering, the articles that met the criteria were further processed using Publish or Perish to analyze the quality and citations of the selected articles. This process continued with the selection of two primary articles for comparative analysis.
4. Criteria for Article Selection: From the search results, several articles relevant to the PjBL-STEM topic were obtained. The researcher employed criteria such as citation count, journal quality (e.g., journal ranking and accreditation), and the relevance of the articles to this research focus. After the initial analysis, two primary articles were selected for in-depth comparative analysis. Only two articles were compared because the focus of this study is to conduct a thorough analysis of research specifically highlighting the impact of PjBL-STEM on critical thinking, conceptual understanding, and student creativity.
5. Article Analysis: Comparative analysis was conducted to determine the similarities and differences between the two selected articles. The researcher evaluated the data and findings reported in each article, focusing on how the PjBL-STEM model was implemented and its outcomes on students' scientific skills. Analysis was carried out qualitatively by identifying key themes and aligning them with the indicators of this research.
6. Instruments and Indicators: This study utilized instruments in the form of content analysis of the selected articles. The main indicators used are critical thinking skills, conceptual understanding, and student creativity. Each indicator was measured based on the outcomes reported in the analyzed articles. For example, critical thinking skills were evaluated based on how students solved scientific problems, while creativity was assessed through students' ability to design STEM-based projects.

The primary goal of this study is to evaluate and compare the characteristics and effectiveness of the project-based learning (PjBL) model integrated with STEM in enhancing science skills, particularly critical thinking, conceptual understanding, and student creativity.

RESULTS AND DISCUSSION

Project-Based Learning (PjBL) is a student-centered instructional approach aimed at fostering active engagement among students in their educational journey. This method encourages learners to assume full responsibility for their learning, thereby enhancing their critical thinking and problem-solving skills as they confront real-world challenges. The primary objectives of this research are to evaluate the effectiveness of PjBL in improving student understanding and engagement, as well as to assess its impact on developing essential skills for future success. Our hypothesis posits that students participating in PjBL will demonstrate greater mastery of the subject matter and exhibit improved critical skills compared to those engaged in traditional learning methods (Nurhidayah et al., 2021). Nurhidayah et al. (2021) further elaborate on the principles and benefits of project-based learning, highlighting its relevance in contemporary education.

The importance of integrating STEM through project-based learning to enhance student engagement and foster creative problem-solving skills. They argue that embedding STEM in curricula better equips students with critical thinking and collaborative abilities, preparing them for future challenges (Mu'minah & Suryaningsih, 2020). Here is the syntax of PjBL (Project-Based Learning):

Table 1. Syntax of Project-Based Learning Model

No	Syntax	Activity
1.	Reflection	Students are guided to understand the context of the material and relate their existing knowledge to what needs to be learned further. They are then presented with relevant problems to analyze.
2.	Research	Students collect various relevant sources of information to address the problem. Each group is encouraged to discuss collaboratively.
3.	Discovery	Each group designs experiments aimed at testing the hypotheses they have formulated.
4.	Application	Each group conducts trials on their designed experiments to evaluate their hypotheses.
5.	Communication	Each group prepares a report of their findings and collectively concludes their results.

The Project-Based Learning (PjBL) model enables students to solve problems through project work. STEM integration (Science, Technology, Engineering, and Mathematics) combines various disciplines into a comprehensive subject aimed at building knowledge, improving competencies, and applying concepts to students' daily lives (WINARNI et al., 2022). STEM incorporates four components with an emphasis on solving real-world problems (Erduran, 2020). This approach not only includes discussions about knowledge but also about technology, engineering, and mathematics. STEM education aims to prepare students to develop community competencies and apply their knowledge to real-world problems. STEM education also emphasizes four key skills: creativity, critical thinking, collaboration, and communication (WINARNI et al., 2022). Consequently, combining PjBL with STEM results in a highly effective learning strategy. In practice, PjBL-STEM integrated projects require students to apply scientific, technological, engineering, and mathematical concepts. For example, students may be tasked with designing and building a technology prototype that requires a deep understanding of scientific principles and technical skills, thereby improving their critical thinking, creativity, and conceptual comprehension.

Despite the many benefits gained from the application of the PjBL-STEM model, this research also has some limitations. First, the scope of the research, which is limited to two studies, may affect the generalization of the results. Further research with more diverse populations and in different educational contexts is needed to gain a more comprehensive understanding.

The research results show that the PjBL-STEM model not only enhances students' understanding of scientific concepts but also significantly impacts the development of critical thinking skills. Students engaged in project-based learning focusing on science, technology, engineering, and mathematics tend to exhibit better analytical abilities, more effective problem-solving skills, and increased creativity. By combining theory and practice through relevant and challenging projects, the PjBL-STEM model encourages students to think beyond traditional boundaries, integrate knowledge from various disciplines, and produce innovative solutions. As a result, students not only learn more effectively but also become more engaged and motivated, indicating that this model is a superior educational strategy for addressing the challenges of modern education.

The studies conducted by (Herlita et al., 2023) and (Prajoko et al., 2023) exhibit several significant similarities, particularly in their use of the Project-Based Learning (PjBL) model integrated with STEM. Both studies aim to evaluate the effectiveness of integrating PjBL and STEM in enhancing educational quality. Both (Herlita et al., 2023) and (Prajoko et al., 2023) recognize the importance of combining interdisciplinary approaches to facilitate deeper and more meaningful learning for students. They find that the use of PjBL-STEM can enhance critical thinking skills and problem-solving abilities. Additionally, both studies indicate that this method can increase student engagement and motivation, as project-based learning allows students to directly participate in practical and real-world relevant learning processes. Integration of PBL with STEM is recognized in both studies as an effective strategy for addressing educational challenges in the evolving technological and informational era.

However, (Herlita et al., 2023) and (Prajoko et al., 2023) also present notable differences despite employing the same project-based learning (PjBL) model integrated with STEM. Firstly, the research objectives differ. Herlita et al. focus on evaluating the effectiveness of PjBL-STEM in enhancing students' science problem-solving skills at the secondary school level, aiming to assess how this approach can develop students' analytical abilities. In contrast, (Prajoko et al., 2023) aim to evaluate the impact of PjBL-STEM on scientific concept mastery and creativity enhancement among high school students, with particular attention to the development of creative thinking and understanding of science concepts.

Secondly, the research methods employed vary. (Herlita et al., 2023) use a quasi-experimental method with a pretest-posttest control group design to measure changes in critical thinking. This method allows for comparison between an experimental group using PBL-STEM and a control group not using the method. On the other hand, (Prajoko et al., 2023) use a quasi-experimental design with a post-test-only classroom action research approach, involving cycles of planning, action, observation, and reflection. This approach is more dynamic and adaptive, allowing researchers to continuously improve the learning process based on results from each action cycle.

The subject populations also differ between the studies. (Herlita et al., 2023) involve eighth-grade junior high school students, specifically class VIII E as the experimental group and class VIII F as the control group, focusing on critical thinking enhancement. Meanwhile, Prajoko et al. involve eleventh-grade senior high school students, specifically class MIPA 1 as the experimental group and MIPA 2 as the control group, each consisting of 36 students, with a focus on creativity development and concept mastery.

The data collection instruments used in the studies also differ. (Herlita et al., 2023) employ validated tests and non-test instruments to measure students' critical thinking related to the applied learning model, providing quantitative data on the effectiveness of PjBL-STEM in enhancing critical thinking. In contrast, (Prajoko et al., 2023) use tests, questionnaires, and observations. Tests assess students' understanding of concepts, while questionnaires gauge student creativity regarding the PjBL-STEM learning process. This approach provides more detailed quantitative data on students' interaction with projects and the development of creative skills. Thus, the research objectives, subjects, methods, and data collection instruments highlight variations in focus and expected outcomes between the two studies.

CONCLUSION

This study confirms the effectiveness of integrating the Project-Based Learning (PjBL) model with STEM education in enhancing students' critical thinking, creativity, problem-solving skills, and engagement. The research highlights the value of interdisciplinary learning, where students apply theoretical knowledge to real-world challenges, fostering deeper understanding and motivation. Both (Herlita et al., 2023) and (Prajoko et al., 2023) reinforce these findings, showing that PjBL-STEM benefits students across different educational levels. The novelty of this study lies in demonstrating how PjBL-STEM can bridge the gap between theory and practice, contributing to the growing discourse on innovative teaching strategies. However, the study's limitations, including a narrow research scope and a focus on quantitative data, suggest the need for broader, more diverse studies. Future research should explore the long-term impact of PjBL-STEM across various contexts and incorporate qualitative methods for deeper insights into student learning experiences.

In conclusion, this research advances our understanding of how PjBL-STEM can effectively prepare students for the modern workforce, emphasizing its potential as a transformative educational approach. While the results are promising, further inquiry is essential to maximize its applicability and impact across diverse learning environments.

SUGGESTION

Future studies should examine the long-term effects of PjBL-STEM on student skills, including critical thinking and creativity. Expanding the research to include diverse educational settings and larger sample sizes would offer broader insights into its applicability.

Additionally, incorporating qualitative approaches, like student and teacher feedback, would provide a deeper understanding of the learning process. Exploring the integration of emerging technologies, such as AI and virtual labs, could also enhance the effectiveness of PjBL-STEM.

In summary, future research should aim to refine and expand the model's application across various contexts for more comprehensive results.

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