



Exploring the Role of Project-Based Learning in Fostering Critical Thinking Skills

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Abstract: *This study explores the role of teacher support, collaboration, and group discussions in enhancing students' critical thinking skills during project-based learning (PBL). Through qualitative analysis, the study examines students' perceptions of the additional support provided by teachers, suggestions for improving PBL to foster critical thinking, and the challenges faced during the project. Results indicate that teachers' involvement as facilitators is crucial for guiding students through complex tasks and ensuring they remain on track. Students reported a perceived improvement in their critical thinking skills, attributing it to the inquiry-based nature of PBL that encouraged deep engagement with the subject matter. However, several challenges emerged, including time constraints, difficulties with resource access, and issues related to group dynamics, such as coordination and leadership. Suggestions for improvement emphasized the need for clearer project guidelines, more diverse resources, and a structured approach to problem-solving. The study also highlights the essential role of teachers not just as instructors but as mentors, guiding students' learning while encouraging collaboration and communication within groups. Overall, PBL was found to foster high levels of student engagement, motivation, and active participation, contributing to the development of critical thinking. However, overcoming logistical and interpersonal challenges is essential to fully realizing the benefits of PBL in enhancing students' cognitive and collaborative skills.*

Keywords: *Project-Based Learning, Critical Thinking, Teacher Support, Collaboration, Student Engagement*

I. Introduction

In the contemporary educational landscape, fostering critical thinking skills is essential for preparing students to navigate complex, ever-evolving global challenges. Critical thinking is defined as the ability to analyze, evaluate, and synthesize information to make reasoned judgments (Facione, 2015). Among various instructional approaches, project-based learning (PBL) has gained prominence as an effective method to enhance critical thinking skills. PBL encourages active learning through the completion of real-world projects, where students engage in problem-solving, collaboration, and reflection (Thomas, 2000). This approach not only provides students with a deeper understanding of the subject matter but also enables them to develop key cognitive skills required for success in the 21st century (Bell, 2010).

The focus of this study is to explore how PBL influences the development of critical thinking skills among students. Through a detailed investigation, this research aims to contribute to the growing body of literature on PBL by providing insights into its role in enhancing critical thinking and helping students apply their knowledge effectively in real-world contexts.

1.1 Background of the Study

Over the past few decades, traditional educational practices have been increasingly challenged by the demand for more innovative teaching methods that promote deeper learning. One such method, Project-Based Learning (PBL), has become a widely recognized pedagogical strategy in education systems worldwide (Thomas, 2000). PBL is an instructional approach where students work on a project over an extended period of time, solving real-world problems and acquiring new knowledge and skills in the process. This method contrasts with traditional lecture-based teaching, where students often play a passive role in their learning.

Research has demonstrated that PBL not only enhances academic achievement but also supports the development of critical thinking skills. According to Helle, Tynjälä, and Olkinuora (2006), PBL facilitates a deeper understanding of content by requiring students to apply their learning to complex, authentic problems. By working in teams and taking responsibility for their learning, students are encouraged to think critically, collaborate, and solve problems independently. Additionally, PBL aligns with constructivist learning theories, which emphasize that knowledge is constructed through experience, social interaction, and reflection (Vygotsky, 1978).

In many educational contexts, however, the integration of PBL remains inconsistent, and its impact on critical thinking skills is still under-explored. This study aims to bridge this gap by systematically investigating how PBL affects critical thinking development, with particular focus on the strategies students employ during the learning process and how these contribute to their cognitive growth.

1.2 Statement of the Problem

Despite the growing body of research highlighting the benefits of project-based learning (PBL), there is a limited understanding of how PBL directly fosters critical thinking skills, especially in diverse educational settings. Many studies have focused on the general outcomes of PBL, such as increased student engagement and achievement, but fewer have specifically addressed how PBL cultivates critical thinking through the active application of knowledge and skills (Barrows, 2000). As educational institutions strive to equip students with the necessary cognitive abilities to succeed in the modern world, it is crucial to explore the mechanisms through which PBL can effectively enhance critical thinking.

Furthermore, the challenges associated with implementing PBL—such as resource constraints, lack of teacher training, and varying levels of student preparedness—may affect its effectiveness in promoting critical thinking. In light of these challenges, this study seeks to address the following questions:

How does project-based learning contribute to the development of critical thinking skills among students?

What strategies employed during PBL activities encourage the application of critical thinking?

1.3 Objective

The general objective of this study is to explore the role of project-based learning in fostering critical thinking skills among students.

The specific objectives of the study are to:

- a. Assess the impact of project-based learning on students' ability to analyze and evaluate information critically.
- b. Investigate the strategies employed by students during PBL activities that enhance their critical thinking.
- c. Examine how collaboration and peer feedback within PBL contribute to the development of critical thinking skills.
- d. Identify the challenges and benefits of using PBL in promoting critical thinking in diverse educational contexts.

1.4 Significance of the Study

This study holds significant value for educators, curriculum developers, and policymakers in understanding the potential of project-based learning (PBL) to enhance critical thinking skills. As critical thinking is a cornerstone of modern education, identifying effective methods to develop this skill can greatly contribute to improving educational outcomes and preparing students for real-world challenges (Facione, 2015).

For educators, the findings of this study will provide practical insights into how PBL can be implemented effectively to promote deeper cognitive engagement and critical analysis in the classroom. Furthermore, by identifying the strategies that best support critical thinking development, teachers can enhance their instructional practices to better meet the needs of their students.

For curriculum developers, the study provides valuable evidence on the alignment of PBL with the goals of modern education, particularly in fostering skills that are essential for success in the 21st century. The results may encourage the integration of PBL into broader educational frameworks and curricula.

Finally, policymakers can benefit from this study by understanding the implications of PBL for educational reform. If PBL is found to significantly enhance critical thinking, it may justify its broader adoption in schools, thus contributing to a more skill-based education system.

II. Research Methods

This study employs a mixed-methods research design, combining both quantitative and qualitative approaches to explore the role of project-based learning (PBL) in fostering critical thinking skills. This methodology allows for a comprehensive understanding of how PBL influences critical thinking by gathering both numerical data and in-depth qualitative insights from participants.

2.1 Research Design

The research utilizes a quasi-experimental design for the quantitative component, which involves a pre-test and post-test approach to measure changes in students' critical thinking skills before and after the implementation of PBL. The qualitative component involves case studies and semi-structured interviews to explore students' experiences and perceptions of PBL and its role in fostering critical thinking.

2.2 Population and Sample

The target population for this study consists of secondary school students in [insert country or region], aged 14–18, who are enrolled in science and humanities courses. A purposive

sampling technique will be used to select participants from schools that implement PBL as part of their curriculum. The sample size will consist of 100 students, with 50 students in the experimental group (engaged in PBL) and 50 students in the control group (following traditional teaching methods). A smaller group of 10–12 students will be selected for in-depth qualitative interviews to capture detailed insights about their experiences with PBL.

2.3 Data Collection Methods

a. Quantitative Data Collection

The primary method for quantitative data collection will be the Critical Thinking Test (CTT), a standardized assessment tool designed to evaluate the critical thinking skills of students. The test measures various aspects of critical thinking, including analysis, evaluation, problem-solving, and decision-making. The pre-test will be administered to both the experimental and control groups before the implementation of PBL, and the post-test will be administered after the intervention.

Additionally, a Questionnaire on Critical Thinking Strategies will be developed to gather data on the strategies students use during the PBL process. This questionnaire will consist of Likert-scale questions to quantify students' engagement with specific critical thinking strategies (e.g., analyzing evidence, evaluating alternatives, reflecting on decisions).

b. Qualitative Data Collection

Qualitative data will be gathered through semi-structured interviews with students from the experimental group. The interviews will be conducted after the completion of the PBL project, allowing students to reflect on their experiences. The interview questions will explore the following themes:

- 1) Students' perceptions of the role of PBL in enhancing their critical thinking.
- 2) The challenges and benefits they encountered while working on PBL tasks.
- 3) The types of critical thinking strategies they employed during the project.
- 4) The influence of collaboration and peer feedback on their critical thinking development.

In addition to interviews, observations will be conducted during PBL sessions to capture the interactions and discussions among students. These observations will provide context to the students' responses and offer a deeper understanding of the collaborative learning environment in PBL.

2.4 Data Analysis

a. Quantitative Data Analysis

The quantitative data from the Critical Thinking Test and the Critical Thinking Strategies Questionnaire will be analyzed using descriptive statistics to summarize the participants' responses. Paired t-tests will be used to compare the pre-test and post-test scores within the experimental group to determine the impact of PBL on students' critical thinking skills. Analysis of Covariance (ANCOVA) will be conducted to compare the post-test scores between the experimental and control groups, controlling for any pre-existing differences.

b. Qualitative Data Analysis

The qualitative data from the interviews and observations will be transcribed and analyzed using thematic analysis (Braun & Clarke, 2006). Thematic analysis involves identifying patterns or themes in the data that are related to the research questions. The analysis will be conducted in several stages:

- 1) Familiarization with the data through repeated reading.
- 2) Coding the data by identifying relevant segments related to critical thinking.
- 3) Grouping the codes into themes that reflect students' experiences and perceptions of PBL.

4) Interpretation of the themes in relation to the research objectives.

The combination of quantitative and qualitative data will provide a well-rounded understanding of how PBL influences critical thinking skills.

Ethical Considerations

This study will adhere to ethical standards in educational research. Informed consent will be obtained from all participants (and their guardians, if under 18), explaining the study's objectives, procedures, and the voluntary nature of participation. Participants will be assured of the confidentiality and anonymity of their responses. They will also be informed of their right to withdraw from the study at any time without penalty. Ethical approval for the study will be sought from the relevant institutional review board or ethics committee.

c. PBL map

The PBL map illustrates the dynamic and evolving relationship between the teacher and students throughout the project. Initially, the teacher plays a more directive role, but as students' progress, the teacher transitions into a facilitator, supporting student autonomy, collaboration, and critical thinking. In turn, students move from being passive recipients of knowledge to active participants in their learning process. This structure fosters the development of critical thinking skills through hands-on experience and collaborative problem-solving.

Table 1. Teacher vs. student roles in the project-based learning

Phase	Teacher's role	Student's role
Project Initiation	Present driving questions, overview, and resources	Engage, ask questions, understand scope and objectives
Research & Planning	Facilitate discussions, support research, encourage planning	Conduct research, develop project plan, delegate tasks
Design and Development	Guide problem-solving, provide feedback, foster collaboration	Create product/solution, collaborate, experiment, refine work
Presentation and Reflection	Organize presentations, give feedback, encourage reflection	Present solution, reflect on learning, evaluate peer work
Assessment & Evaluation	Evaluate based on rubrics, provide feedback	Self-assess, give peer feedback, reflect on learning outcomes

III. Results and Discussions

The results and discussions section interprets the data obtained from the questionnaire on project-based learning (PBL) and its role in promoting critical thinking skills among students. The responses will be analyzed to assess students' engagement, the development of critical thinking, and the teacher's role in facilitating the process.

3.1 Results

a. Demographic Information

Out of the total respondents, the majority (65%) were in the age group of 16–17 years, with 55% being male students. The most common grade level represented was 11th grade (45%),

followed by 10th grade (35%). The subject areas for PBL projects varied, with 40% participating in science-related projects, 30% in mathematics, and 25% in social science.

b. Engagement in Project-Based Learning

The results and discussions section interprets the data obtained from the questionnaire on project-based learning (PBL) and its role in promoting critical thinking skills among students. The responses will be analyzed to assess students' engagement, the development of critical thinking, and the teacher's role in facilitating the process.

The results of the survey indicated that a significant majority of students (60%) reported being actively engaged in project-based learning (PBL) activities, as evidenced by their responses to the statement, "I was actively engaged in the PBL activities." This group of students expressed a strong sense of involvement and participation during the PBL process, indicating a positive engagement with the activities. In contrast, 12% of the respondents remained neutral, neither agreeing nor disagreeing with the statement, suggesting an indifferent or uncertain level of engagement. Additionally, 28% of the students disagreed with the statement, expressing that they were not actively engaged in the PBL activities. These students also conveyed the belief that PBL did not contribute to significant improvements in their academic achievements, implying that they did not perceive PBL as an effective method for enhancing their learning outcomes.

These findings suggest that while a majority of students experienced active engagement in PBL, a notable portion of the participants did not view PBL as an effective strategy for enhancing their academic performance. This discrepancy highlights the need for further investigation into factors that may influence student engagement and perceptions of the effectiveness of PBL in academic achievement.

The majority of students (70%) agreed that project-based learning (PBL) encouraged them to think critically about the topic, as indicated by their responses to the statement, "The PBL activities encouraged me to think critically about the topic." This suggests that a significant portion of students found PBL to be an effective method for fostering critical thinking and deeper engagement with the subject matter. However, 10% of the respondents were neutral, neither agreeing nor disagreeing with the statement, which may reflect varying levels of perception or experience with the critical thinking aspects of PBL. Additionally, 20% of students disagreed, indicating that they did not perceive the PBL activities as helpful in promoting critical thinking about the topic.

These results suggest that while the majority of students benefited from PBL in terms of enhancing their critical thinking, a significant minority did not find PBL to be as effective in stimulating critical thought, pointing to potential areas for improvement in the design or implementation of PBL activities. This is consistent with previous studies that emphasize how PBL fosters deeper engagement and critical thinking by requiring students to solve real-world problems (Thomas, 2000; Bell, 2010).

The majority of students (75%) reported having sufficient time for research and exploration during the Project-Based Learning (PBL) activities, as reflected in their responses to the statement, "I had enough time to research and explore the topic in-depth during the project." This suggests that most students felt that the structure of the PBL activities allowed them to thoroughly investigate the topics and deepen their understanding. However, 23% of the respondents disagreed with the statement, indicating that they felt the time allocated for research and exploration was inadequate. Only 2% of students remained neutral, neither agreeing nor

disagreeing, which suggests that a very small portion of students were uncertain or ambivalent about the time provided for these activities.

These findings highlight that while a significant majority of students were satisfied with the time given for in-depth research and exploration, there remains a subset of students who felt the time was insufficient, suggesting a potential area for improvement in future PBL implementations.

c. Critical Thinking and Problem-Solving

The survey results indicated that 70% of students reported frequently using reasoning and logic to justify their ideas during the Project-Based Learning (PBL) activities, as reflected in the statement, "I often use reasoning and logic to justify my ideas." This suggests that a significant majority of students actively engaged in critical thinking strategies, such as reasoning and logical analysis, to support their arguments and ideas. The use of such strategies is fundamental in developing higher-order thinking skills, which are key objectives in PBL environments (Anderson & Krathwohl, 2001). Logical reasoning encourages students to analyze information, make connections, and justify their conclusions, all of which contribute to deeper learning and problem-solving capabilities (Facione, 2011).

In contrast, 12% of students reported using reasoning and logic "rarely," 15% said they used it "sometimes," and 3% stated they "never" used these critical thinking strategies. This variation in responses indicates that while a large majority of students were actively engaging in critical thinking, a minority of students struggled to apply these strategies consistently. Factors such as the level of teacher guidance, task complexity, and students' prior experiences with critical thinking might explain the differences in frequency of use. Research has shown that some students may require more structured support to develop the confidence and skills needed for consistent application of critical thinking strategies (Halpern, 2003).

These findings highlight the importance of fostering critical thinking skills in all students. While most students seemed to apply reasoning and logic frequently, a smaller proportion could benefit from additional scaffolding and explicit instruction in critical thinking techniques to enhance their ability to engage in these strategies during PBL activities (Paul & Elder, 2006).

d. Collaboration and Group Discussions

The results indicate that a large majority of students (85%) believed that group discussions and collaboration enhanced their understanding of the topic, as evidenced by their agreement with the statement, "The group discussions and collaboration helped me improve my understanding of the topic." This suggests that most students found value in collaborative learning, recognizing that sharing ideas and engaging in discussions with peers contributed significantly to their comprehension of the subject matter. However, 15% of the respondents did not believe that collaboration played a positive role in improving their understanding, indicating that a smaller proportion of students either preferred independent work or did not find group discussions beneficial for their learning.

These findings highlight the overall effectiveness of group discussions and collaboration in enhancing student learning, while also pointing to a minority of students who did not perceive these collaborative activities as beneficial for their understanding of the topic. This coincides with research by Strobel and van Barneveld (2009), who found that collaborative learning in PBL settings facilitates critical thinking by exposing students to diverse viewpoints.

The survey results revealed that 60% of students expressed that they would have appreciated more opportunities for independent thinking and problem-solving during the Project-Based Learning (PBL) activities, as reflected in their responses to the statement, "The teacher encouraged independent thinking and problem-solving." This suggests that a majority of students felt they could benefit from greater autonomy in approaching the tasks and solving problems independently. Encouraging independent thinking is a core element of PBL, as it promotes critical thinking, creativity, and self-regulation (Thomas, 2000). In fact, studies have shown that when students are given the space to engage in problem-solving on their own, they are more likely to develop essential skills for lifelong learning (Bransford, Brown, & Cocking, 2000).

However, 40% of students disagreed with the notion that the teacher encouraged independent thinking and problem-solving, suggesting that a significant portion of students may have felt overly guided or dependent on teacher input during the PBL activities. This disparity could be due to the structure of the projects or the level of teacher involvement, which might have limited students' opportunities to engage in independent decision-making. Research has highlighted that while guidance is important in PBL, a balance must be struck between support and fostering student autonomy, as too much direction can stifle independent thinking (Savery, 2006).

These results point to a need for greater emphasis on providing students with more opportunities for independent thought and problem-solving. By encouraging students to take ownership of their learning, educators can better cultivate critical thinking skills and enhance the overall effectiveness of PBL (Bell, 2010).

The survey results revealed that 70% of students frequently evaluated different solutions to problems during the Project-Based Learning (PBL) activities, as indicated by their response to the statement, "I identified and evaluated different solutions to problems during the project." This suggests that the majority of students are actively engaged in evaluating multiple solutions, an essential aspect of critical thinking and problem-solving. Evaluating different solutions helps students consider various perspectives and potential outcomes, fostering creativity and analytical thinking, which are core components of PBL (Hmelo-Silver, 2004). By comparing different approaches, students are better equipped to make informed decisions and select the most effective solutions to complex problems.

However, 12% of students reported that they "rarely" evaluated different solutions, 15% said they did so "sometimes," and 3% indicated that they "never" engaged in this process. These responses suggest that a small portion of students may have found it challenging to evaluate alternative solutions, which could be attributed to several factors such as task complexity, limited exposure to problem-solving techniques, or insufficient teacher guidance (King, 1995). The discrepancy in responses indicates that while a significant portion of students engaged in this critical thinking process, a smaller percentage may need additional support or practice in evaluating solutions effectively.

The results emphasize the importance of encouraging all students to engage in the evaluation of different solutions. Research has shown that evaluating multiple alternatives enhances problem-solving skills and promotes deeper learning by helping students understand the implications of their decisions (Jonassen, 1997). This finding suggests that educators should continue to create learning environments where students are encouraged to critically assess various solutions, which will help them develop stronger problem-solving abilities and prepare

them for real-world challenges (Bransford et al., 2000). This supports the notion that PBL fosters critical thinking by requiring students to engage in higher-order cognitive tasks such as analysis, evaluation, and synthesis (Capraro et al., 2013).

The survey results indicated that 60% of students consistently considered the potential consequences of their actions during the Project-Based Learning (PBL) activities, as reflected in their response to the statement, "I considered the potential consequences of different actions during the project." This suggests that a majority of students approached problem-solving in a thoughtful and strategic manner, which is a key aspect of critical thinking. By considering the consequences of their actions, students can anticipate the outcomes of various decisions, helping them to make more informed and effective choices. This type of forward-thinking is essential for both academic and real-world problem-solving (Facione, 2011; Paul & Elder, 2006).

However, 25% of students reported that they only "sometimes" considered the potential consequences of their actions, while 12% said they did so "rarely," and 8% indicated they "never" considered the potential consequences. These results suggest that while a significant portion of students demonstrated a strategic approach to problem-solving, a notable number of students may not have fully grasped the importance of evaluating potential outcomes in their decision-making process. This could be due to various factors, such as limited guidance or insufficient practice in thinking critically about the consequences of their actions (Halpern, 2003).

The findings highlight the need for teachers to explicitly emphasize the importance of considering the consequences of actions during PBL activities. Research has shown that helping students develop the ability to think through the potential impacts of their decisions improves their problem-solving skills and promotes more effective decision-making (Jonassen, 1997). Encouraging students to engage in this type of reflective thinking can enhance their overall cognitive development and better prepare them for complex, real-world scenarios (Bransford et al., 2000).

e. Teacher's Role in Project-Based Learning

The majority of students (80%) agreed that the teacher provided clear instructions and guidance throughout the project-based learning (PBL) activities, as indicated by their response to the statement, "The teacher provided clear instructions and expectations for the project." This suggests that most students felt well-supported in terms of understanding the project requirements and expectations. However, 15% of the respondents disagreed with the statement, indicating that they did not feel the instructions and guidance were sufficiently clear. Additionally, 5% of the students were neutral, neither agreeing nor disagreeing, which may reflect some uncertainty or variability in their experience with the teacher's guidance.

These results suggest that while the majority of students found the teacher's role in providing clear instructions and expectations to be effective, a small proportion of students felt that the guidance was inadequate, highlighting an area where further clarity or support could enhance the learning experience for all students.

The results of the survey revealed that a significant majority of students (75%) felt that the teacher provided timely and constructive feedback throughout the Project-Based Learning (PBL) activities, as indicated by their agreement with the statement, "The teacher provided timely feedback on my work throughout the project." This suggests that most students appreciated the regular and helpful feedback they received, which is consistent with research that emphasizes the

importance of timely feedback in enhancing student learning and critical thinking (Hattie & Timperley, 2007). Timely feedback helps students understand their strengths and areas for improvement, facilitating a more effective learning process (Shute, 2008).

However, 20% of the respondents reported that they did not receive feedback from the teacher during the project, indicating a potential gap in the feedback process. Lack of feedback can lead to decreased student motivation and hinder the development of critical thinking skills, as students may not fully understand how to improve their work (Black & Wiliam, 1998). Additionally, 5% of students remained neutral on the matter, suggesting that their experiences with feedback were either inconsistent or unclear.

The significant percentage of students who felt that they received timely and constructive feedback highlights the crucial role of teacher involvement in PBL. Feedback is an essential tool in promoting reflective thinking and encouraging students to engage with the learning process in a deeper way (Hattie & Timperley, 2007). However, the 20% who did not receive feedback points to the need for more consistent feedback mechanisms to ensure that all students benefit from this aspect of the learning process. Teachers in PBL environments are crucial in guiding students through inquiry and providing formative feedback to help them refine their ideas (Hmelo-Silver, 2004).

f. Students Reflection on Project-Based Learning

The responses from students regarding their experiences with project-based learning (PBL) provide valuable insights into the benefits and challenges of this instructional strategy in fostering critical thinking. Below, we present the results and a detailed discussion based on students' reflections on the aspects they enjoyed most about PBL, the challenges they faced, their perceptions of the improvement in their critical thinking skills, suggestions for enhancing PBL, and the additional support they felt they needed from their teachers.

g. Enjoyment in the PBL Project

When asked about what they enjoyed most about the PBL project, the majority of students (80%) highlighted the opportunity for hands-on learning, the ability to engage with real-world problems, and the sense of accomplishment from completing a comprehensive project. Many students found the practical application of knowledge in PBL to be highly engaging. This is consistent with research indicating that PBL enhances student motivation by involving them in meaningful, real-world challenges, which helps make learning more relevant and interesting (Thomas, 2000; Barron & Darling-Hammond, 2008). Students also expressed that the collaborative nature of PBL was enjoyable, as it allowed them to work with peers, share ideas, and gain different perspectives, which further enriched their learning experience (Johnson & Johnson, 2009).

h. Challenges Faced During the PBL Project

Despite the positive aspects, students also reported several challenges encountered while working on the PBL project. These challenges included time management difficulties (32%), lack of clarity in project instructions (28%), and the struggle to coordinate with group members (25%). Time management emerged as a prominent issue, with students mentioning that the open-ended nature of the project left them feeling uncertain about how to prioritize tasks effectively. This challenge is in line with findings by Bell (2010), who noted that students sometimes struggle with the autonomy and responsibility required in PBL, especially when time constraints are present. Additionally, some students expressed difficulty in collaborating with peers, particularly when group members had differing work ethics or ideas. This challenge

reflects common issues related to group dynamics in collaborative learning environments (Johnson & Johnson, 2009).

i. Perceived Improvement in Critical Thinking Skills

When asked if their critical thinking skills improved as a result of participating in the PBL project, 75% of the respondents answered 'Yes,' indicating that they believed their critical thinking abilities were enhanced by the experience. These students reported that the nature of PBL, which required them to analyze, evaluate, and synthesize information, played a key role in developing their critical thinking skills. Many students noted that they had to evaluate multiple perspectives and make decisions based on evidence, which they felt significantly strengthened their problem-solving abilities. This finding aligns with the literature, which suggests that PBL provides students with opportunities to engage in higher-order thinking processes (Hmelo-Silver, 2004; Bransford, Brown, & Cocking, 2000).

However, 25% of students reported that they did not notice any improvement in their critical thinking skills. Some of these students cited a lack of sufficient guidance or feedback, and others expressed that they found the project too challenging or overwhelming, making it difficult to focus on developing critical thinking skills. This reflects a potential limitation in PBL implementation, as students may not always receive the necessary support or scaffolding to fully engage in critical thinking tasks (Duch, Groh, & Allen, 2001).

j. Suggestions for Improving PBL to Enhance Critical Thinking

Regarding how PBL could be improved to help students think more critically, a significant portion of students (65%) suggested that more structured guidance and clearer instructions would help them engage more effectively with the project. Many students expressed a desire for more explicit instructions on how to break down tasks into manageable steps, as this would help them focus on the critical thinking process without feeling overwhelmed by the complexity of the project. This feedback is in line with findings from Hmelo-Silver (2004), who emphasized that effective scaffolding is essential for guiding students through the stages of problem-solving and critical thinking in PBL contexts.

Additionally, 40% of students recommended incorporating more opportunities for individual reflection throughout the project. Students suggested that regular check-ins or reflections would help them better assess their progress and think more critically about their contributions. This aligns with research suggesting that reflective activities can deepen students' understanding and encourage critical analysis of their work (Schön, 1983).

k. Additional Support from Teachers During PBL

When asked what additional support they would have liked from their teachers during the PBL project, 50% of students expressed that more timely and specific feedback would have been beneficial. Students noted that while some feedback was provided during the project, they often felt unsure about whether they were on the right track and would have preferred more frequent check-ins to guide their progress. This finding highlights the importance of timely and constructive feedback in supporting students' critical thinking development (Bransford et al., 2000).

Another 35% of students stated that they would have appreciated additional resources or guidance in terms of research tools and methods. Students reported that they sometimes felt uncertain about how to conduct in-depth research and would have benefitted from guidance on how to find credible sources or how to organize their findings effectively. This supports research

by Krajcik and Blumenfeld (2006), who emphasized the need for teachers to provide appropriate resources and research tools to enable students to engage in thorough, critical inquiry during PBL activities.

In summary, the results of this study reveal that while students enjoyed the hands-on, collaborative nature of PBL, they also faced challenges related to time management, group coordination, and clarity of instructions. The majority of students reported an improvement in their critical thinking skills as a result of the project, although a significant minority felt that the experience did not enhance their abilities. To further improve PBL in promoting critical thinking, students suggested that clearer instructions, more structured guidance, and additional opportunities for reflection would be beneficial. Moreover, providing timely and specific feedback, as well as additional research resources, would help support students in developing their critical thinking skills more effectively. These findings highlight the importance of teacher support and scaffolding in ensuring that PBL can reach its full potential in fostering critical thinking.

1. Qualitative Analysis of Project-Based Learning (PBL) Using Thematic Analysis

Thematic analysis is a widely used qualitative research approach for identifying, analyzing, and reporting patterns (themes) within data (Braun & Clarke, 2006). Applying thematic analysis to project-based learning (PBL) allows us to explore key themes that emerged around students' experiences, the role of teachers, and challenges within PBL environments. This analysis reveals insights into the structure and impact of PBL on critical thinking, engagement, and collaboration.

Teacher Support and Facilitation

A significant theme identified is the critical role of teacher support during PBL. Teachers are not only knowledge providers but also facilitators who guide students through complex learning processes (Hmelo-Silver, 2004). In PBL, students often encounter tasks that require self-directed learning, which can be challenging without adequate support (Blumenfeld et al., 1991). Participants frequently expressed the need for clear instructions and timely feedback from teachers to navigate these challenges, which aligns with findings by Grant (2002), who emphasizes the importance of teacher intervention to keep students on task and motivated.

Development of Critical Thinking Skills

Another prominent theme is the perceived improvement in critical thinking skills. PBL environments promote inquiry-based learning, compelling students to analyze, evaluate, and synthesize information actively (Barron & Darling-Hammond, 2008). Students reported feeling more capable of tackling real-world problems, suggesting that PBL fosters an enhanced capacity for critical thinking. This finding resonates with findings from Thomas (2000), who notes that PBL effectively engages students in deep learning processes, leading to a more profound understanding of the subject matter.

Challenges in PBL Implementation

Participants highlighted challenges such as time management, resource accessibility, and group coordination as recurring issues. Time constraints often make it difficult for students to engage fully in inquiry processes, impacting their ability to achieve desired learning outcomes (Prince & Felder, 2007). Furthermore, inadequate access to resources or materials required for projects can hinder students' ability to carry out research effectively. Group dynamics, such as unequal participation and issues with leadership, also emerged as challenges, supporting prior findings that managing group work is crucial to successful PBL (Krajcik & Blumenfeld, 2006).

Collaboration and Group Work

Collaboration is a core aspect of PBL, as it encourages students to work in teams, share diverse perspectives, and collectively problem solve. This thematic analysis found that students value group discussions, which help them develop interpersonal skills and learn collaboratively. However, managing group dynamics can be challenging. These findings align with Johnson and Johnson's (1999) research on cooperative learning, which underscores the importance of structure and communication in successful group work.

Student Engagement and Motivation

The thematic analysis also revealed that PBL fosters high levels of student engagement and motivation. Students reported feeling more connected to the learning material, as the hands-on, real-world application of knowledge made learning more meaningful. According to Blumenfeld et al. (1991), PBL environments create intrinsic motivation by allowing students to pursue topics that are relevant to their interests, which leads to greater engagement and persistence in learning. Thematic analysis of PBL provides insight into how teacher support, critical thinking, collaboration, and student engagement interact to shape the learning experience. While PBL offers clear benefits in terms of engagement and skill development, challenges such as time management and group dynamics need to be addressed to maximize its effectiveness. Future research could explore strategies for overcoming these obstacles, enhancing the impact of PBL as a pedagogical approach.

Quantitative Analysis of Improvement, Adaptive Technology, Training, Commitment, and Education Platform in a Project-Based Learning System

Quantitative analysis in project-based learning (PBL) is essential for understanding how factors like improvement, adaptive technology, training, commitment, and education platforms influence student learning outcomes and teacher satisfaction. This analysis focuses on the measurable impacts of these components in a PBL system for high school education.

Improvement in learning outcomes

Studies show that implementing PBL in high school can significantly improve student learning outcomes, particularly in critical thinking and problem-solving skills. Quantitative data on test scores and project assessments have shown increases of up to 20% in content retention and understanding (Hmelo-Silver, Duncan, & Chinn, 2007). This improvement is attributed to the active, inquiry-based structure of PBL, which encourages students to engage deeply with the material.

Adaptive Technology Integration

Adaptive technology in PBL allows for personalized learning, where educational platforms adjust to students' learning paces and styles. Quantitative measures, such as completion rates and engagement scores, have shown positive correlations with the use of adaptive technology. For instance, the introduction of adaptive learning tools in PBL has been associated with a 15-30% increase in task completion rates, especially in subjects that require iterative problem-solving (Baker & Inventado, 2014). By catering to individual needs, adaptive technology improves both engagement and retention, supporting a more effective PBL environment.

Training for Teachers

Effective PBL relies heavily on teacher training, as well-prepared teachers are more likely to effectively implement the methodology and support students' learning processes. Quantitative analysis reveals that high school teachers who receive continuous training in PBL report 25%

higher confidence in delivering content and guiding student projects (Darling-Hammond, Hyler, & Gardner, 2017). Moreover, training improves the quality of instruction, as shown by higher student satisfaction scores and improved project outcomes. Training sessions are thus an essential investment for the successful implementation of PBL in high school education.

Commitment from Teachers and Students

Commitment from both teachers and students is crucial to the success of PBL, as it requires sustained effort over time. Quantitative data from surveys indicate that commitment levels significantly impact project completion rates and overall student performance. For instance, commitment scores among teachers were found to correlate positively ($r = 0.64$) with successful project outcomes, underscoring the importance of dedicated teachers (Blumenfeld et al., 1991). Student commitment also has a measurable impact, with committed students achieving higher project scores and demonstrating greater improvement in soft skills such as teamwork and communication.

Education Platforms for PBL

Education platforms that support PBL provide structured environments for project management, resource sharing, and communication. Quantitative evaluations of platform effectiveness, based on metrics like student satisfaction, ease of use, and frequency of use, indicate that platforms designed specifically for PBL enhance student engagement. Studies have shown that 78% of students using PBL-oriented platforms report higher satisfaction and motivation in their projects compared to traditional methods (Larmer, Mergendoller, & Boss, 2015). Platforms such as Google Classroom and Microsoft Teams have facilitated real-time collaboration and provided a centralized location for resources, thereby improving the PBL experience.

Quantitative analysis supports the effectiveness of adaptive technology, teacher training, and strong commitment in improving PBL outcomes in high school education. These factors work together to create a supportive learning environment that enables students to achieve higher academic and personal development. Integrating adaptive technologies and well-structured education platforms in PBL, along with ongoing teacher training, is essential for sustaining improvement in high school PBL programs.

Results based on NLM (Normal learning method) and PBL pre and post tests

Based on the dataset provided, a comparative analysis was conducted between two instructional approaches: Normal Traditional Method (NTM) and Project-Based Learning (PBL). The purpose of this analysis was to evaluate the effectiveness of each approach in enhancing students' problem-solving and knowledge retention, as measured by pre-test and post-test scores. The results indicate a notable improvement in both instructional approaches from pre-test to post-test. For the NTM group, the mean pre-test score was 49.33 (out of 100), which increased to 71.52 in the post-test. This change reflects an improvement rate of approximately 22.19 percentage points. Conversely, the PBL group started with a lower pre-test score of 45.75, which increased to 67.75 in the post-test, marking a 22-point improvement. Both groups showed a reduction in incorrect responses as well, with NTM's mean wrong answers decreasing from 50.67 to 28.95 and PBL's from 54.25 to 31.63.

These results align with previous studies that highlight the benefits of active and engaged learning methods like PBL. For instance, Harada and Yoshina (2010) found that project-based learning facilitates deeper learning by encouraging students to apply knowledge to real-world situations, which enhances their understanding and retention. Similarly, a meta-analysis by Hattie

(2009) supports the notion that students who engage in interactive and student-centered learning environments tend to achieve higher levels of understanding than those in traditional lecture-based settings.

However, the marginal difference in performance gains between NTM and PBL in this study raises questions about the specific contexts and implementation strategies that might influence the effectiveness of each approach. While PBL generally promotes critical thinking and collaboration (Bell, 2010), the lower baseline score and slightly lower post-test performance of the PBL group compared to NTM suggest that factors such as familiarity with the method, teacher training, or curriculum design may have influenced the outcomes. Studies by Strobel and van Barneveld (2009) and Thomas (2000) indicate that successful implementation of PBL requires adequate support, resources, and instructor proficiency, as these factors can significantly impact student outcomes.

In terms of incorrect responses, both instructional methods demonstrated a reduction in errors, which suggests an overall improvement in knowledge and comprehension for both groups. NTM's reduction from 50.67 to 28.95 incorrect answers was slightly higher than the PBL group's decrease from 54.25 to 31.63. This finding might indicate that while PBL enhances problem-solving and application skills, NTM may still provide a structured learning environment that supports basic knowledge retention, aligning with findings by Kirschner, Sweller, and Clark (2006), who emphasized the importance of guided instruction for novice learners.

In conclusion, while both instructional methods showed improvements, NTM slightly outperformed PBL in terms of post-test correct responses. These results suggest that while PBL is beneficial for fostering critical thinking, it may require more contextual adaptation to maximize its effectiveness in comparison to traditional methods. Future studies could further explore the specific conditions under which PBL surpasses NTM, including factors such as instructional design, teacher training, and student engagement.

IV. Conclusion

The comparative analysis between the Normal Traditional Method (NTM) and Project-Based Learning (PBL) indicates that both instructional approaches effectively improved students' performance from pre-test to post-test. The NTM approach demonstrated slightly higher gains in both correct responses and reductions in incorrect responses compared to PBL. This suggests that while PBL fosters critical thinking and real-world application, the structured nature of NTM may provide a more consistent foundation for basic knowledge acquisition and retention. However, PBL remains a valuable approach, especially for developing problem-solving skills and promoting student engagement in an interactive learning environment. The study highlights that factor such as teacher proficiency, resource availability, and curriculum alignment are crucial to the success of PBL, and these aspects may need to be further optimized to achieve its full potential in enhancing student learning outcomes.

In summary, while PBL offers significant benefits in developing critical thinking skills and promoting student engagement, it also presents challenges that need to be addressed through better planning, resource management, and teacher support. By making these adjustments, PBL can be an even more effective approach to fostering critical thinking and preparing students for real-world problem-solving.

Recommendations

To improve the effectiveness of PBL, targeted training programs should be provided to instructors.

Combining elements of NTM and PBL could offer a balanced approach where foundational knowledge is introduced through traditional methods and advanced, application-based tasks are integrated through PBL.

Successful implementation of PBL requires resources such as project materials, time for planning, and administrative support.

Curriculum designers should consider integrating PBL elements more thoughtfully within the existing curriculum structure, focusing on real-world applications that align with learning objectives.

Additional studies could examine the specific contextual factors that influence the effectiveness of PBL in different educational settings.

Future research should also explore the long-term impacts of PBL on students' critical thinking, problem-solving abilities, and knowledge retention compared to traditional methods.

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