Problem-Based Learning: A Strategic Intervention in Enhancing Critical and Analytical Thinking Skills of Middle School Students in Mathematics

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ABSTRACT

This study investigates the effectiveness of Problem-Based Learning (PBL) as a strategic intervention to enhance the critical and analytical thinking skills of middle school students in mathematics. Utilizing a quasi-experimental pretest–posttest control group design, 60 seventh-grade students from a public middle school were assigned to either an experimental group receiving eight weeks of PBL instruction or a control group taught through conventional lecture-based methods. Critical and analytical thinking skills were measured using a researcher-developed standardized test, and data were analyzed with paired and independent sample t-tests, alongside effect size calculations. Results indicated that the experimental group demonstrated statistically significant improvements in both critical and analytical thinking, with very large effect sizes, while the control group showed no meaningful gains. Findings underscore the value of PBL in promoting higher-order cognitive skills in middle school mathematics, suggesting its potential as a pedagogical strategy for fostering problem-solving, logical reasoning, and collaborative learning in authentic contexts.

Keywords: Problem-Based Learning, critical thinking, analytical thinking, middle school mathematics, quasi-experimental design, higher-order thinking skills

INTRODUCTION

Critical and analytical thinking skills are fundamental for success in mathematics, especially at the middle school level where students begin to encounter more complex and abstract concepts. These skills enable students to understand problems deeply, evaluate information critically, and apply logical reasoning to arrive at solutions. This study investigates the use of Problem-Based Learning (PBL) as a strategic intervention aimed at enhancing these essential cognitive skills in middle school mathematics students. By focusing on real-world problems, PBL encourages learners to engage actively with content, promoting deeper understanding and improved problem-solving abilities (Hmelo-Silver, 2004).

Several studies have demonstrated the benefits of PBL in various educational contexts, showing its capacity to enhance higher-order thinking and learner engagement. For instance, Hmelo-Silver (2004) highlights that PBL fosters critical thinking and knowledge construction by positioning students as active participants in their learning process. Barrows (1996) emphasizes its role in increasing student motivation and engagement, while Jonassen (2011) underscores that PBL supports the development of analytical skills by situating learning in authentic problem-solving situations. Additionally, Savery (2006) notes that PBL cultivates self-directed learning and improves students' problem-solving strategies. Yeh and Lin (2019), through a meta-analysis, provide strong evidence that PBL significantly improves students' critical thinking abilities across multiple disciplines. Other researchers, such as Strobel and van Barneveld (2009), have compared PBL with traditional teaching and found PBL to be particularly effective in developing problem-solving and reasoning skills. Collectively, these studies suggest that PBL is an effective method for cultivating higher-order thinking skills across diverse educational settings.

However, despite the growing evidence of PBL's effectiveness, limited research has specifically focused on its impact on middle school mathematics students' critical and analytical thinking. Much of the existing literature centers on higher education or fields outside mathematics, creating a gap in understanding how PBL influences younger learners in this subject area. This lack of targeted research limits educators' ability to make evidence-based decisions about implementing PBL in middle school math classrooms.

This study aims to address this gap by evaluating the impact of PBL on the critical and analytical thinking skills of middle school students in mathematics. By implementing an 8-week PBL intervention and comparing it with traditional teaching methods, the study seeks to provide empirical evidence on the effectiveness of PBL as a pedagogical strategy in this specific educational setting. The findings are expected to inform teaching practices and curriculum development aimed at improving mathematical thinking skills among middle school learners.

Research Objective

The primary objective of this study is to evaluate the impact of Problem-Based Learning on the development of critical and analytical thinking skills in middle school students within the mathematics curriculum for the School Year 2024-2025.

METHODS

Design. This study utilized a quasi-experimental design, specifically a pretest–posttest control group design. A quasi-experimental design is defined as an empirical interventional study that resembles an experimental design but lacks random assignment of participants to groups (Cook & Campbell, 1979; Shadish, Cook, & Campbell, 2002). Unlike true experiments, quasi-experiments often use existing groups or non-randomized samples, making them more practical in natural educational settings where randomization may not be feasible (Creswell & Creswell, 2018).

In the context of this study, the design enabled the comparison of two intact seventh-grade classes: one receiving Problem-Based Learning (PBL) and the other taught through conventional lecture-based methods. By administering both pretests and posttests, the design allowed for the measurement of learning gains while controlling for baseline differences in students' critical and analytical thinking skills.

Setting. The study was carried out in a public middle school during the School Year 2024–2025, using two intact seventh-grade mathematics classes as the research sites. Each classroom accommodated about 30 students and was equipped with a whiteboard, projector, and standard instructional materials. To align with the instructional approaches, the control group's classroom maintained a traditional row arrangement to support lecture-based teaching, while the experimental group's classroom was organized into clusters of four to five desks to facilitate collaboration, discussion, and problem-solving activities. This intentional modification of the learning environment was designed to complement the pedagogical strategies, creating a structured yet supportive space for student engagement.

Participants. The participants of this study were 60 seventh-grade students enrolled in mathematics at a public middle school during the School Year 2024–2025. Students were between 12 and 13 years old and represented diverse socioeconomic backgrounds. To ensure comparability, both the experimental and control groups were taught by the same mathematics teacher.

Inclusion criteria required that participants be officially enrolled in the selected seventh-grade mathematics classes, attend school regularly, and obtain parental consent and personal assent to participate in the study. Students also needed to complete both the pretest and posttest to be included in the analysis. Exclusion criteria applied to students with extended absences during the intervention period, those receiving individualized education programs (IEPs) with accommodations beyond the scope of the study, and students who did not secure full consent or complete the required assessments.

Sampling Design. A purposive sampling method was employed. Two intact seventh-grade classes of approximately equal size were assigned to either the experimental group ($n = 30$), which received PBL instruction, or the control group ($n = 30$), which received conventional lecture-based instruction. The groups were matched in terms of prior mathematics achievement based on school records.

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Instrument. Critical and analytical thinking skills were measured using a researcher-developed standardized test consisting of 30 multiple-choice and word problem items aligned with middle school mathematics competencies. The instrument was reviewed by three mathematics education experts for content validity and pilot-tested with a separate group of students (n = 20). Reliability analysis yielded a Cronbach's alpha of 0.82, indicating acceptable internal consistency.

Data Collection. Pretests were administered to both groups prior to the start of the intervention to establish baseline equivalence. The experimental group then participated in eight weeks of Problem-Based Learning (PBL) sessions, while the control group received conventional lecture-based instruction covering the same mathematics topics. Each class session lasted 45 minutes and followed the school's regular daily schedule. During the PBL sessions, students engaged in collaborative inquiry, hypothesis generation, exploration of solutions, and presentation of findings, while the control group focused on teacher-led explanations and individual practice. Posttests were administered to both groups immediately after the intervention. In addition to the quantitative assessments, qualitative data were gathered through structured classroom observations focusing on student engagement, participation, and collaborative problem-solving behaviors.

Data Analysis. Quantitative data were analyzed using paired sample t-tests to determine within-group improvements between pretest and posttest scores, and independent samples t-tests to compare differences between the experimental and control groups. Effect sizes (Cohen's d) were calculated to determine the magnitude of observed differences.

Ethical Considerations. Prior to data collection, approval was obtained from the school administration. Informed consent was secured from students' parents or guardians, and student assent was obtained. Participants were assured of confidentiality, and all data were anonymized. Students were informed that participation in the study would not affect their grades or academic standing.

RESULTS

Table 1. Independent-Sample t-test Results for Critical and Analytical Thinking Skills of Experimental and Control Groups (n = 30 per group)

Measure	Group	Mean ($\bar{x}$)	SD	t (58)	p-value	Effect size (d)	Interpretation
Critical Thinking (Pretest)	Experimental	62.3	8.5	0.33	0.74		No significant difference
	Control	61.7	9.0				
Analytical Thinking (Pretest)	Experimental	60.8	9.2	-0.13	0.90		No significant difference
	Control	61.1	8.8				
Critical Thinking (Posttest)	Experimental	77.3	7.5	7.60	<0.001	1.96	Significant, large effect
	Control	62.1	8.0				
Analytical Thinking (Posttest)	Experimental	79.1	7.2	9.14	<0.001	2.36	Significant, very large effect
	Control	61.0	8.1				

Comparison of Critical Thinking Skills Prior to Intervention

An independent-sample t-test was conducted to compare the critical thinking skills of the experimental (PBL) group and the control group before the intervention. The mean pretest score for the experimental group was 62.3 (SD = 8.5), while the control group had a mean score of 61.7 (SD = 9.0). The t-test indicated no statistically significant difference between the two groups prior to the intervention, $t(58) = 0.33$, $p = 0.74$, suggesting that the groups were equivalent in critical thinking skills at baseline.

Comparison of Analytical Thinking Skills Prior to Intervention

An independent-sample t-test was conducted to compare the analytical thinking skills of the experimental (PBL) group and the control group before the intervention. The mean pretest score for the experimental group was 60.8 (SD = 9.2), while the control group had a mean of 61.1 (SD = 8.8). The t-test indicated no statistically significant difference between the two groups prior to the intervention, t(58) = -0.13, p = 0.90, suggesting that the groups were equivalent in analytical thinking skills at baseline.

Comparison of Critical Thinking Skills After the Intervention

An independent-sample t-test was conducted to compare the posttest scores of critical thinking skills between the experimental (PBL) group and the control group. The experimental group obtained a higher mean score ($\bar{x}$ = 77.3, SD = 7.5) compared to the control group ($\bar{x}$ = 62.1, SD = 8.0). The results revealed a statistically significant difference between the two groups, t(58) = 7.60, p < 0.001, favoring the experimental group. The effect size was large (d = 1.96), indicating that PBL had a substantial impact on enhancing students' critical thinking skills in mathematics compared to conventional instruction.

Comparison of Analytical Thinking Skills After the Intervention

An independent-sample t-test was conducted to compare the posttest scores of analytical thinking skills between the experimental (PBL) group and the control group. The experimental group achieved a substantially higher mean score ($\bar{x}$ = 79.1, SD = 7.2) than the control group ($\bar{x}$ = 61.0, SD = 8.1). The difference was statistically significant, t(58) = 9.14, p < 0.001, with a very large effect size (d = 2.36). This result demonstrates that PBL had a powerful impact on enhancing students' analytical thinking skills, greatly surpassing the outcomes of conventional lecture-based instruction.

Table 2. Pretest–Posttest Comparison within Groups

Skill	Group	Pretest Mean (SD)	Posttest Mean (SD)	t (29)	p-value	Effect Size (d)	Interpretation
Critical Thinking	Control	61.7 (9.0)	62.1 (8.0)	0.87	0.39	0.16	Not Significant
	Experimental	62.3 (8.5)	77.3 (7.5)	10.95	<0.001	2.00	Significant
Analytical Thinking	Control	61.1 (8.8)	61.0 (8.1)	-0.23	0.82	-0.04	Not Significant
	Experimental	60.8 (9.2)	79.1 (7.2)	12.53	<0.001	2.29	Significant

Pretest–Posttest Comparison of Critical Thinking Skills in the Control Group

A paired-sample t-test was conducted to evaluate whether the control group showed improvements in critical skills after eight weeks of conventional instruction. The results indicated no significant difference between pretest scores ($\bar{x}$ = 61.7, SD = 9.0) and posttest scores ($\bar{x}$ = 62.1, SD = 8.0), t(29) = 0.87, p = 0.39. The effect size was small (d = 0.16), suggesting that conventional lecture-based instruction did not lead to meaningful gains in students' critical thinking skills during the intervention period.

Pretest–Posttest Comparison of Analytical Thinking Skills in the Control Group

A paired-sample t-test revealed no significant change in the control group's analytical thinking scores between pretest ($\bar{x}$ = 61.1, SD = 8.8) and posttest ($\bar{x}$ = 61.0, SD = 8.1), t(29) = -0.23, p = 0.82. The effect size was negligible (d = -0.04), indicating that conventional lecture-based instruction did not improve analytical thinking skills.

Pretest–Posttest Comparison of Critical Thinking Skills in the Experimental Group

A paired-sample t-test was conducted to examine the effect of Problem-Based Learning on the experimental group's critical thinking skills. Results revealed a statistically significant increase from pretest ($\bar{x}$ = 62.3, SD = 8.5) to posttest ($\bar{x}$ = 77.3, SD = 7.5), t(29) = 10.95, p < 0.001. The effect size was very large (d = 2.00), indicating that PBL had a substantial impact on improving students' critical thinking skills in mathematics.

Pretest–Posttest Comparison of Analytical Thinking Skills in the Experimental Group

A paired-sample t-test indicated a statistically significant increase in analytical thinking scores for the experimental group from pretest ($\bar{x}$ = 60.8, SD = 9.2) to posttest ($\bar{x}$ = 79.1, SD = 7.2), t(29) = 12.53, p < 0.001.

The effect size was extremely large (d = 2.29), confirming that Problem-Based Learning had a powerful positive effect on analytical thinking skills.

DISCUSSION

The findings of this study provide strong evidence that Problem-Based Learning (PBL) significantly enhances both critical thinking and analytical thinking skills compared to conventional lecture-based instruction. The baseline comparison revealed no significant differences between the experimental and control groups in their pretest scores, confirming that both groups were comparable prior to the intervention. This equivalence strengthened the validity of the observed post-intervention differences, as improvements can be attributed to the instructional approach rather than pre-existing disparities.

Posttest comparisons revealed that students exposed to PBL achieved substantially higher levels of critical and analytical thinking than those taught through traditional methods. The experimental group's mean scores in both domains increased significantly, with very large effect sizes, underscoring the powerful influence of PBL on higher-order cognitive skills. In contrast, the control group showed no meaningful gains, highlighting the limited effectiveness of lecture-based instruction in fostering critical and analytical reasoning. These findings are consistent with Hmelo-Silver (2004), who noted that PBL helps students develop flexible knowledge and problem-solving strategies through active engagement in authentic tasks. Similarly, Loyens, Kirschner, and Paas (2011) emphasized that PBL promotes deeper understanding by requiring learners to construct knowledge collaboratively and critically evaluate different perspectives.

The within-group analyses further corroborated these outcomes. While the control group demonstrated negligible progress from pretest to posttest, the experimental group exhibited statistically significant improvements with very large effect sizes in both critical and analytical thinking skills. This aligns with Tarmizi and Bayat (2012), who reported that PBL fosters critical mathematical reasoning through structured inquiry processes, and with Bezanilla et al. (2019), who found that explicit use of PBL tasks leads to measurable improvements in students' critical thinking development.

The results highlight the pedagogical value of adopting PBL in mathematics instruction. By situating learning within authentic, problem-centered contexts, PBL enables students to actively construct knowledge, evaluate multiple perspectives, and apply logical reasoning in collaborative environments. This process contrasts with the passive reception of information typical of conventional instruction, thereby accounting for the stark differences observed between the two groups. Research by Dolmans et al. (2016) further supports this, showing that the collaborative and self-directed nature of PBL nurtures both analytical and critical thinking skills essential for lifelong learning.

Overall, the findings support the assertion that PBL is a highly effective instructional strategy for cultivating higher-order thinking skills. Implementing PBL may thus serve as a viable pathway for schools to better prepare students for the demands of 21st-century learning, where critical and analytical thinking are vital competencies. As noted by Kek and Huijser (2011), PBL not only enhances academic outcomes but also equips students with the cognitive flexibility required for problem-solving in real-world contexts.

CONCLUSION

In conclusion, this study demonstrates that Problem-Based Learning (PBL) is a highly effective instructional strategy for enhancing the critical and analytical thinking skills of middle school mathematics students, directly addressing the study's primary objective. By engaging learners in authentic, problem-centered tasks, PBL enables students to actively construct knowledge, apply logical reasoning, and collaborate effectively, resulting in substantial improvements in higher-order cognitive skills compared to conventional lecture-based instruction. Its implementation bridges the gap between traditional teaching methods and the development of essential 21st-century competencies, equipping students with the cognitive tools needed for both academic success and real-world problem-solving. Future research should examine the long-term effects of PBL across diverse student populations, investigate its influence on additional cognitive and affective outcomes, and explore strategies for sustainable integration into standard curricula to maximize its transformative potential in mathematics education.

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