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Research Article

Problem-Based Learning Enhances Mathematics Engagement: A Multivariate Examination of Motivation and Interest

Nurina Happy[1,*], Zuhri[2], Hery Saputra[3]
[1] Universitas PGRI Semarang, Jawa Tengah, Indonesia
[2] STIM Sukma Medan, Sumatera Utara, Indonesia
[3] Universitas Jabal Ghafur, Aceh, Indonesia

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ABSTRACT

Purpose of the study: Mathematics learning requires instructional approaches that improve not only cognitive achievement but also affective aspects, particularly students' motivation and interest. This study aimed to examine the effects of PBL on mathematics learning motivation, learning interest, and both variables simultaneously.

Methodology: A quantitative quasi-experimental study employing a nonequivalent control group pretest-posttest design was conducted with 71 tenth-grade students selected through cluster random sampling. The experimental group received PBL, while the control group received conventional instruction. Data were collected using the Mathematics Motivation Questionnaire (16 items) and the Interest in Mathematics Questionnaire (20 items) and analyzed using descriptive statistics and Multivariate Analysis of Variance (MANOVA).

Main Findings: The results showed that PBL significantly improved mathematics learning motivation (Partial Eta Squared = 0.761) and learning interest (Partial Eta Squared = 0.581). MANOVA further confirmed a significant simultaneous effect of PBL on both affective variables (Wilks' Lambda = 0.216, $p < 0.001$). These findings indicate that authentic problem solving, collaboration, and active learning in PBL foster multiple affective outcomes simultaneously.

Novelty/Originality of this study: The novelty of this study lies in the simultaneous examination of mathematics learning motivation and interest using MANOVA while positioning student engagement as the conceptual mechanism underlying PBL effectiveness. The findings provide empirical support for implementing PBL as a student-centered approach to strengthen affective outcomes in mathematics education and offer a foundation for future studies using Structural Equation Modeling (SEM) to examine the underlying mechanisms.

Corresponding Author:
Nurina Happy,
University of PGRI Semarang, Jl. Lontar No.24, Karangtempel, Kec. Semarang Timur, Semarang, Jawa Tengah, 50232, Indonesia
Email: nurinahappy@upgris.ac.id

1. INTRODUCTION

Mathematics plays a fundamental role in developing learners' logical reasoning, analytical thinking, creativity, critical thinking, and problem-solving abilities, all of which are essential competencies for the twentyfirst century. It also serves as a cornerstone for learning in science, technology, engineering, and many other academic disciplines. However, successful mathematics learning is determined not only by students' cognitive abilities but also by the extent to which they actively engage in the learning process. Student engagement is reflected in active participation, psychological investment, sustained attention, perseverance, and the strategic use of learning approaches to accomplish academic goals [1]-[5]. Consequently, fostering high levels of engagement has become a prerequisite for meaningful and sustainable mathematics learning.

A growing body of international evidence based on large-scale samples consistently demonstrates that behavioral, emotional, and cognitive engagement are positively associated with mathematics achievement. Students who are more actively engaged tend to demonstrate greater persistence, complete learning tasks more consistently, and achieve superior academic outcomes [6]-[8]. Likewise, research in educational psychology indicates that active and collaborative instructional practices supported by teachers contribute substantially to strengthening students' motivation and interest in mathematics [9]-[13]. Recent meta-analytic findings further confirm that student-centered instructional approaches are more effective than teacher-centered methods in promoting participation, learner autonomy, reflective thinking, and overall student engagement [14]-[17].

Despite these findings, classroom instruction in many educational settings continues to rely predominantly on teacher-centered practices, limiting students' opportunities to explore ideas, conduct investigations, collaborate with peers, engage in reflective thinking, and participate in meaningful discussions. Such instructional patterns often reduce students' initiative, restrict classroom participation, discourage questioning, and weaken commitment to completing learning tasks. These conditions suggest that current instructional strategies have not yet created learning environments capable of fostering active student engagement. Supporting this argument, a meta-analysis synthesizing evidence from 326 studies reported that student-centered learning consistently outperforms teacher-centered instruction in enhancing participation and learner autonomy [14], implying that one of the principal barriers lies in instructional designs that do not position students as active participants in knowledge construction. Low levels of behavioral and emotional engagement are frequently accompanied by declining motivation, diminishing interest, reduced self-confidence, and weaker perseverance, ultimately constraining academic achievement and the development of higher-order thinking skills in mathematics [18]-[20]. Without appropriate pedagogical interventions, this cycle is likely to persist and further widen disparities in students' learning outcomes.

These challenges highlight the need for instructional approaches capable of creating more participatory, collaborative, and student-centered learning environments to strengthen engagement in mathematics classrooms. One instructional model that aligns well with these objectives is Problem-Based Learning (PBL), which positions students at the center of learning through authentic problem-solving, collaborative discussion, inquiry, and reflective investigation. Numerous studies have demonstrated that PBL effectively enhances student engagement, critical thinking, problem-solving skills, and mathematical competence, making it one of the most promising pedagogical approaches for mathematics education [21]-[25].

Although the effectiveness of Problem-Based Learning in improving cognitive outcomes and several affective dimensions has been widely documented, previous studies have predominantly examined learning motivation and learning interest as separate constructs rather than investigating them simultaneously. Consequently, the application of multivariate statistical techniques, particularly Multivariate Analysis of Variance (MANOVA), remains relatively limited in evaluating the concurrent effects of PBL on multiple affective outcomes. Moreover, existing research has primarily focused on determining whether PBL is effective, while paying comparatively less attention to explaining how student-centered learning environments established through PBL cultivate complementary affective characteristics, particularly motivation and interest, within the broader theoretical framework of student engagement.

The novelty of this study lies in both its methodological and conceptual contributions. Methodologically, this study simultaneously examines the effects of PBL on two essential affective constructs learning motivation and learning interest using MANOVA, thereby providing a more comprehensive understanding than conventional univariate analyses. Conceptually, student engagement is employed as the theoretical foundation to explain the mechanisms through which the defining characteristics of PBL, including authentic problem solving, collaboration, inquiry, and reflective learning, facilitate the development of students' motivation and learning interest. Importantly, student engagement functions as the underlying theoretical lens rather than as a directly measured research variable [26]-[29].

Based on these considerations, this study seeks to address three research questions: (RQ1) Does Problem-Based Learning significantly influence students' mathematics learning motivation? (RQ2) Does Problem-Based Learning significantly influence students' mathematics learning interest? and (RQ3) Does Problem-Based Learning simultaneously influence students' mathematics learning motivation and learning interest? The findings are expected to provide empirical evidence regarding the effectiveness of PBL in enhancing affective dimensions of mathematics learning, particularly learning motivation and learning interest. Furthermore, this study is anticipated to enrich the existing literature on the implementation of Problem-Based Learning in mathematics education while offering evidence-based recommendations for educators in selecting instructional approaches that foster active, meaningful, and student-centered learning experiences, ultimately contributing to improved quality of mathematics instruction.

2. RESEARCH METHOD

This study employed a quantitative approach using a quasi-experimental none equivalent control group pretest–posttest design. The research was conducted at senior hight school at Semarang during the second semester of the 2025/2026 academic year. The study population comprised all tenth-grade students, while the sample was selected through cluster random sampling. Class X IPA 2 (35 students) was assigned as the experimental group and received instruction using the Problem-Based Learning (PBL) model, whereas Class X IPA 3 (36 students) served as the control group and received conventional teacher-centered instruction. Both groups completed a pretest before the intervention and a posttest after the intervention to measure students' mathematics learning motivation and interest.

Table 1. Nonequivalent Control Group Pretest–Posttest Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	X_1	O_2
Control	O_3	X_2	O_4

Data were collected using two self-report questionnaires employing a five-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree). Mathematics learning motivation was measured using the Mathematics Motivation Questionnaire (MMQ) developed by Meng et al, [30] consisting of 16 items. This instrument has been validated to assess mathematics learning motivation among secondary school students across multiple motivational dimensions. Mathematics learning interest was assessed using the Interest in Mathematics Questionnaire developed by Fiorella et al, [31], consisting of 20 items designed to measure students' interest in mathematics across various aspects of classroom learning.

Prior to the main study, both instruments were pilot-tested on students with characteristics comparable to those of the research participants. Item validity was evaluated using the Pearson Product–Moment correlation, while internal consistency reliability was assessed using Cronbach's Alpha. Following the recommendation of Zakiah et al [33], instruments were considered acceptable when all items met the validity criteria and the Cronbach's Alpha coefficient was at least 0.70. The mathematics motivation questionnaire demonstrated excellent internal consistency with a Cronbach's Alpha of 0.91, whereas the mathematics learning interest questionnaire yielded a Cronbach's Alpha of 0.89, indicating that both instruments were highly reliable.

The collected data were analyzed using IBM SPSS Statistics through descriptive and inferential statistical procedures. Descriptive statistics were employed to summarize the characteristics of the data, including minimum and maximum scores, means, standard deviations, and changes between pretest and posttest scores for each group. Before hypothesis testing, the assumptions required for Multivariate Analysis of Variance (MANOVA) were examined. These included the Shapiro–Wilk test for normality, Levene's Test for homogeneity of variances, Box's M Test for homogeneity of covariance matrices, and the correlation analysis between the dependent variables to ensure compliance with multivariate assumptions [34], [35].

The research hypotheses were tested using Multivariate Analysis of Variance (MANOVA) because the study involved one independent variable (learning model) and two correlated dependent variables, namely mathematics learning motivation and mathematics learning interest. Multivariate significance was evaluated using Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root at a significance level of 0.05. When the multivariate test indicated statistically significant differences, the analysis was followed by Tests of Between-Subjects Effects to determine the influence of the PBL model on each dependent variable individually. The magnitude of the treatment effect was interpreted using Partial Eta Squared (η^2p) (Tabachnick Barbara G.and Fidell, 2025)

The hypotheses of the study were formulated as follows: H_0: There is no simultaneous difference in mathematics learning motivation and mathematics learning interest between students who are taught using the Problem-Based Learning model and those who receive conventional instruction. H_1: There is a simultaneous difference in mathematics learning motivation and mathematics learning interest between students who are taught using the Problem-Based Learning model and those who receive conventional instruction.

3. RESULTS AND DISCUSSION

This section presents the findings according to the three research questions: (RQ1) Does Problem-Based Learning (PBL) influence students' mathematics learning motivation? (RQ2) Does PBL influence students' interest in learning mathematics? and (RQ3) Does PBL simultaneously affect students' mathematics learning motivation and interest? Does Problem-Based Learning Influence Mathematics Learning Motivation?

To provide an initial overview of the changes in students' mathematics learning motivation and interest across the experimental and control groups, descriptive statistics are presented in Table 2.

Table 2. Descriptive Statistics of Mathematics Learning Motivation and Interest

Variable	Group	N	Mean	SD
Motivation (Pretest)	Experimental	35	36.40	6.34
	Control	36	36.40	9.44
Motivation (Posttest)	Experimental	35	80.00	6.09
	Control	36	52.40	9.44
Interest (Pretest)	Experimental	35	7.30	3.92
	Control	36	7.20	4.24
Interest (Posttest)	Experimental	35	14.10	4.14
	Control	36	7.35	4.50

As shown in Table 2, both groups demonstrated identical average motivation scores during the pretest ($M = 36.40$), indicating comparable baseline conditions before the intervention. Following the implementation of Problem-Based Learning, the experimental group's mean motivation score increased substantially to 80.00, whereas the control group reached only 52.40. These descriptive findings suggest that students who participated in PBL demonstrated considerably greater improvement in learning motivation than those receiving conventional instruction. To determine whether these differences were statistically significant, a Tests of Between-Subjects Effects analysis was conducted. The results are presented in Table 3.

Table 3. Tests of Between-Subjects Effects

Dependent Variable	F	Sig.	Partial Eta Squared
Motivation	120.773	0.000	0.761
Interest	120.000	0.000	0.581

The analysis revealed that the learning model had a statistically significant effect on mathematics learning motivation ($F = 120.773$, $p < .001$) with a Partial Eta Squared of 0.761, indicating a very large effect size. Accordingly, RQ1 is supported, demonstrating that Problem-Based Learning significantly enhances students' mathematics learning motivation. As presented in Table 1, the experimental and control groups showed nearly identical levels of learning interest before the intervention, with mean scores of 7.30 and 7.20, respectively. After the instructional treatment, the experimental group's average interest score increased markedly to 14.10, while the control group's score showed only a marginal increase to 7.35. These descriptive results indicate that students exposed to Problem-Based Learning experienced substantially greater growth in mathematics learning interest than those taught through conventional methods. The Tests of Between-Subjects Effects reported in Table 4 further confirmed that the learning model significantly affected students' interest in mathematics ($p < .001$). The obtained Partial Eta Squared value of 0.581 indicates a large practical effect. Therefore, RQ2 is supported, confirming that Problem-Based Learning significantly improves students' interest in learning mathematics.

Does problem-based learning simultaneously influence mathematics learning motivation and interest?. before performing the multivariate analysis of variance (MANOVA), the assumption of homogeneity of variance was examined using levene's test. the results are summarized in table 4.

Table 4. Results of Levene's Test for Homogeneity of Variance

Dependent Variable	F	Sig.
Motivation	3.325	0.076
Interest	0.066	0.799

The significance values for motivation (0.076) and learning interest (0.799) exceeded the threshold of 0.05, indicating that the assumption of equal variances across groups was satisfied. A multivariate analysis was subsequently performed to examine the simultaneous effect of the learning model on students' motivation and interest in mathematics. The multivariate test results are presented in Table 5.

Table 5. Multivariate Test Results (MANOVA)

Multivariate Statistic	Value	F	Sig.
Pillai's Trace	0.784	67.101	0.000
Wilks' Lambda	0.216	67.101	0.000
Hotelling's Trace	3.627	67.101	0.000
Roy's Largest Root	3.627	67.101	0.000

As reported in Table 5, all multivariate statistics yielded significance values below 0.001, indicating a statistically significant multivariate effect of the instructional model. Specifically, Wilks' Lambda = 0.216 ($F = 67.101$, $p < .001$) demonstrates that the learning model significantly influenced the combined outcomes of students' mathematics learning motivation and interest. Therefore, the null hypothesis (H_0) was rejected, and the alternative hypothesis (H_1) was accepted. Follow-up analyses using the Tests of Between-Subjects Effects (Table 4) indicated that the instructional model significantly affected both dependent variables. For learning motivation, the analysis yielded $F = 120.773$, $p < .001$, with a Partial Eta Squared of 0.761, indicating a very large effect. Likewise, mathematics learning interest showed a statistically significant effect ($p < .001$) with a Partial Eta Squared of 0.581, representing a large effect size. These findings demonstrate that Problem-Based Learning exerts a substantial positive influence on both students' mathematics learning motivation and interest, which is consistent with previous studies conducted by Mitrayana and Juandi (2023) and Siagian et al. (2023). Thus, RQ3 is supported, confirming that Problem-Based Learning simultaneously and significantly improves students' mathematics learning motivation and interest.

The findings of this study demonstrate that Problem-Based Learning (PBL) significantly enhances students’ mathematics learning motivation, with a very large effect size (Partial Eta Squared = 0.761). This result indicates that students' active engagement in problem-solving activities, investigation, discussion, and collaborative learning effectively strengthens their motivation to learn mathematics compared with conventional instructional approaches. In other words, the greater students' active participation throughout the learning process, the higher their motivation to engage in mathematics learning. These findings are consistent with previous experimental studies reporting that PBL consistently improves students’ learning motivation by promoting student-centered and problem-oriented learning environments [36]-[41]. Similar conclusions have also been reported in several meta-analyses, which indicate that PBL produces greater improvements in students' motivation, engagement, and learning outcomes than conventional instructional methods because it creates learning experiences that are more active, collaborative, and meaningful [42], [43].

These findings can be interpreted through the lens of Self-Determination Theory (SDT), which posits that learning motivation develops when educational environments satisfy three fundamental psychological needs: autonomy, competence, and relatedness [44]-[46]. The instructional procedures embedded in PBL provide students with opportunities to determine appropriate problem-solving strategies, develop competence through inquiry and investigation, and strengthen social relationships through collaborative group discussions. Consequently, these learning experiences fulfill the three basic psychological needs proposed [47], [48]. Therefore, the improvement in students' learning motivation observed in this study can be regarded as a logical consequence of meaningful, student-centered learning experiences fostered through Problem-Based Learning.

The present study also revealed that Problem-Based Learning significantly improves students’ interest in mathematics learning, with a large effect size (Partial Eta Squared = 0.581). This finding suggests that learning activities initiated through authentic and contextual problems successfully stimulate students’ curiosity, capture their attention, and encourage them to peSrceive mathematics as a subject that is relevant to everyday life. This result is consistent with previous experimental studies demonstrating that PBL enhances students’ learning interest through exploration, collaborative learning, and contextual problem-solving activities [49]-[54]. Nevertheless, to the best of the authors’ knowledge, no published meta-analysis has specifically synthesized empirical evidence regarding the effectiveness of Problem-Based Learning in improving students’ interest in mathematics learning.

The findings may be explained using the Four-Phase Model of Interest Development, which proposes that interest evolves progressively from situational interest to well-developed individual interest through meaningful and sustained learning experiences [55]-[58]. By connecting mathematical concepts with authentic real-world problems, PBL provides relevant and meaningful learning experiences that sustain students' engagement throughout the instructional process. As a result, students become increasingly interested in mathematics because they recognize its practical relevance and usefulness beyond the classroom. The MANOVA results revealed that Problem-Based Learning (PBL) had a statistically significant simultaneous effect on students' mathematics learning motivation and interest (Wilks’ Lambda = 0.216; $p < 0.001$). This finding indicates that PBL enhances not only individual affective outcomes but also promotes the concurrent development of motivation and interest, two interrelated psychological constructs that are essential for successful mathematics learning. Empirically, the results suggest that student-centered learning environments foster learning experiences capable of facilitating multiple affective dimensions simultaneously.

To the best of the authors’ knowledge, relatively few studies have examined the simultaneous effects of PBL on mathematics learning motivation and interest using a multivariate approach such as MANOVA. Most previous studies have investigated either motivation or learning interest as a single dependent variable. Therefore, the present study extends the existing body of empirical evidence by demonstrating that these two affective constructs develop concurrently through the implementation of PBL. This finding is also supported by previous experimental studies, as well as systematic reviews and meta-analyses, which consistently report that

PBL improves the quality of mathematics instruction, student engagement, learning motivation, critical thinking skills, and academic achievement more effectively than conventional instructional approaches [26], [27]

These findings can be interpreted from a constructivist perspective, which views learning as an active process in which learners construct knowledge through social interaction, reflection, inquiry, and problem-solving. Throughout the PBL process, students actively engage in identifying problems, exploring relevant information, discussing alternative solutions, and presenting their findings. Such integrated learning activities simultaneously promote cognitive, affective, and social engagement, thereby fostering both learning motivation and interest within a unified learning experience. This interpretation is further supported by the concept of student engagement, which posits that active and collaborative learning environments provide the underlying mechanism through which multiple affective outcomes develop concurrently.

The novelty of this study lies in the application of MANOVA to investigate the simultaneous effects of PBL on two affective variables, thereby providing a more comprehensive understanding than previous studies that primarily relied on univariate analyses. Furthermore, this study introduces student engagement as a conceptual framework to explain the mechanism through which PBL enhances students' motivation and learning interest without directly measuring engagement as a research variable. Consequently, this study broadens the theoretical perspective on the effectiveness of PBL in mathematics education. The findings of this study provide further evidence that Problem-Based Learning is an effective instructional approach for simultaneously enhancing students' motivation and interest in mathematics learning. From a theoretical perspective, these findings reinforce the student engagement framework by demonstrating that student-centered learning environments can foster the concurrent development of multiple affective outcomes. From a practical perspective, the results offer empirical support for mathematics teachers to adopt PBL as an instructional strategy that promotes active participation, collaboration, and meaningful learning experiences. The principal contribution of this study lies in its use of MANOVA to examine the simultaneous influence of PBL on two affective learning outcomes, while also employing student engagement as a theoretical lens to explain the underlying mechanism of PBL. Compared with previous studies that generally examined a single affective variable, this approach provides a more comprehensive empirical understanding of the affective benefits associated with PBL implementation in mathematics classrooms.

Despite these contributions, this study has several limitations. First, the research was conducted in only two classes within a single school, which may limit the generalizability of the findings to broader educational contexts. Second, although student engagement was used as the theoretical basis for interpreting the findings, it was not measured empirically. Consequently, the mechanism linking PBL with students' motivation and learning interest remains conceptual rather than empirically validated. Accordingly, future studies are encouraged to involve more diverse samples across different educational levels and school settings to enhance the external validity of the findings. Furthermore, future research should empirically examine student engagement as either a mediating or moderating variable by employing Structural Equation Modeling (SEM), thereby providing a more comprehensive explanation of the mechanisms through which PBL influences students' affective outcomes in mathematics learning.

4. CONCLUSION

This study demonstrates that Problem-Based Learning (PBL) has significant positive effects on students' mathematics learning motivation, learning interest, and both affective outcomes simultaneously. The MANOVA results indicate that PBL is more effective than conventional instruction in promoting students' affective development by engaging them in problem-solving, collaborative learning, and active participation throughout the learning process. These findings strengthen existing empirical evidence that PBL not only improves individual affective outcomes but also facilitates the concurrent development of motivation and learning interest. Future research is recommended to include larger and more diverse samples and to investigate the role of student engagement as a mediating or moderating variable using Structural Equation Modeling (SEM). Such investigations would provide a deeper understanding of the mechanisms through which Problem-Based Learning enhances students' affective outcomes in mathematics education.

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AUTHOR CONTRIBUTIONS

Nurina Happy: Conceptualization, methodology, investigation, formal analysis, data curation, writing original draft. Zuhri: Validation, supervision, writing review and editing. Hery Saputra: Data curation, visualization, validation, writing review and editing. All authors have read and approved the final version of the manuscript.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

INFORMED CONSENT STATEMENT

Prior to participation, each subject was provided with a detailed explanation of the study's objectives, procedures, potential risks, and benefits. All participants voluntarily agreed to participate and signed a written informed consent form. All images in this article have been authorized and are the property of the authors.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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