



Enhancing mathematics achievement through self-regulated learning and problem-based learning: The mediating role of learning motivation

Addin Zuhrotul 'Aini*

Universitas PGRI MPU Sindok,
INDONESIA

Vera Septi Andrini

Universitas PGRI MPU Sindok,
INDONESIA

Erdyna Dwi Etika

Universitas PGRI MPU Sindok,
INDONESIA

Article Info

Article history:

Received: April 10, 2026

Revised: May 17, 2026

Accepted: June 20, 2026

Keywords:

Learning Motivation;
Mathematics Achievement;
Partial Least Squares
Structural Equation Modeling
(PLS-SEM); Problem-Based
Learning; Self-Regulated
Learning.

Abstract

Background: Improving mathematics achievement remains a major challenge in secondary education, particularly in developing countries where students continue to demonstrate relatively low performance in mathematics. Self-Regulated Learning (SRL) and Problem-Based Learning (PBL) have been widely recognized as effective approaches for enhancing academic performance; however, the psychological mechanism through which these approaches influence mathematics achievement remains insufficiently understood.

Aim: This study examined the direct and indirect effects of SRL and PBL on mathematics achievement through the mediating role of learning motivation.

Method: A quantitative correlational survey design was employed involving 270 Indonesian secondary school students. Data were collected using validated questionnaires measuring SRL, PBL, and learning motivation, alongside a mathematics achievement test. The proposed model was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM).

Results: The findings revealed that the model explained 70.1% of the variance in learning motivation and 69.7% of the variance in mathematics achievement. Learning motivation emerged as the strongest predictor of mathematics achievement, followed by PBL and SRL. Furthermore, learning motivation significantly mediated the relationships between SRL, PBL, and mathematics achievement.

Conclusion: Mathematics achievement can be enhanced through the combined influence of SRL and PBL, with learning motivation serving as a key mechanism that strengthens their impact. These findings highlight the importance of integrating motivational support and student-centered learning strategies in mathematics education.

To cite this article: 'Aini, A. Z., Andrini, V. S. & Etika, E. D. (2026). Enhancing mathematics achievement through self-regulated learning and problem-based learning: The mediating role of learning motivation. *Journal of Advanced Sciences and Mathematics Education*, 6(2), 702-726.

INTRODUCTION

Mathematics has long been recognized as one of the most important disciplines in formal education because it develops logical reasoning, critical thinking, and problem-solving abilities that are essential for academic and professional success. In contemporary society, the importance of mathematics extends beyond classroom learning and increasingly influences decision-making in science, technology, engineering, economics, and various data-driven professions (He et al., 2025). The rapid advancement of digital technologies and artificial intelligence has further increased the demand for individuals who can analyze information, solve complex problems, and make evidence-based decisions (Burlacu et al., 2020; Lee & Yoon, 2021; Letterie, 2021; Munatsi, n.d.). Consequently, mathematics education plays a strategic role in preparing students to meet the challenges of an increasingly competitive and technology-oriented world. Despite its importance, improving mathematics achievement remains a major challenge for many educational systems. Students frequently encounter difficulties in understanding mathematical concepts, applying procedures, and

*Corresponding author:

Addin Zuhrotul 'Aini, Universitas PGRI MPU Sindok, Indonesia
addinzuhrotul@upms.ac.id ✉

solving unfamiliar problems. These challenges often result in low academic performance and limited confidence in learning mathematics. The persistence of these difficulties suggests that mathematics achievement is influenced by a combination of cognitive, behavioral, and environmental factors. Understanding these factors is therefore essential for designing effective educational interventions. As a result, mathematics achievement continues to be a central concern in educational research and practice.

The challenge of improving mathematics achievement is particularly evident in countries where students consistently perform below international expectations. Recent educational reports indicate that a substantial proportion of students continue to struggle with fundamental mathematical competencies, limiting their ability to apply mathematical knowledge in real-world contexts (Kohen & Orenstein, 2021; Manfreda Kolar & Hodnik, 2021; Nilimaa, 2023). Such conditions suggest that improving mathematics achievement requires more than curriculum reform or instructional adjustments alone. Educational researchers increasingly emphasize the importance of psychological and motivational factors that shape students' learning behaviors and academic performance (Korpershoek et al., 2020; Liu et al., 2024; Raza et al., 2020; Yang & Wang, 2022). Among these factors, learning motivation has emerged as one of the most influential predictors of student achievement. Students who are highly motivated tend to demonstrate greater persistence, stronger engagement, and a higher willingness to invest effort in learning activities. Conversely, low levels of motivation often lead to reduced participation, limited perseverance, and weaker academic outcomes. Motivation also influences how students respond to challenges, regulate their learning, and maintain commitment toward academic goals. Therefore, understanding the role of motivation is essential for explaining variations in mathematics achievement among students. This perspective highlights the need to examine mathematics learning not only from an instructional viewpoint but also from a motivational and psychological perspective.

In addition to motivation, contemporary educational research has identified Self-Regulated Learning and Problem-Based Learning as two important factors associated with successful mathematics learning. Self-Regulated Learning emphasizes students' ability to plan, monitor, and evaluate their own learning processes, enabling them to become more independent and strategic learners (Chou & Zou, 2020; Nurjanah et al., 2022). Students with strong self-regulatory skills are generally better able to manage learning difficulties, set academic goals, and sustain effort during challenging tasks. At the same time, Problem-Based Learning promotes active participation through authentic problem-solving experiences that encourage collaboration, inquiry, and critical thinking (Agbi & Yuangsoi, 2022; Marini et al., 2026; Sholihah & Lastariwati, 2020; E. Xu et al., 2023). By engaging students in meaningful learning situations, PBL creates opportunities for deeper conceptual understanding and more effective knowledge construction. Previous findings have consistently demonstrated the positive contribution of both SRL and PBL to various academic outcomes. Moreover, these two approaches share common characteristics that encourage student autonomy, active engagement, and responsibility for learning. The interaction between self-regulation and problem-based instructional experiences may therefore create favorable conditions for academic success. Nevertheless, the mechanisms through which these factors contribute to mathematics achievement remain insufficiently understood. Consequently, further investigation is needed to explain how instructional and self-regulatory processes influence students' academic performance in mathematics.

Although previous studies have identified various determinants of mathematics achievement, including mathematics interest, self-efficacy, mathematics anxiety, gender differences, home learning environments, and student attitudes toward mathematics, these factors have generally been examined independently or within limited theoretical frameworks (Barroso et al., 2021; Daucourt et al., 2021; Mejias et al., 2021; M.-T. Wang et al., 2020; Zhang et al., 2020). Likewise,

extensive research has established Self-Regulated Learning (SRL) as a significant predictor of academic performance and learning motivation across diverse educational contexts (Theobald, 2021; Wolters & Brady, 2021), while Problem-Based Learning (PBL) has been widely recognized as an effective instructional approach for enhancing students' engagement, problem-solving abilities, and learning outcomes. However, existing studies have largely focused on the direct effects of SRL, PBL, or motivation on academic achievement, with limited attention given to how these constructs operate simultaneously within a unified explanatory framework. Furthermore, empirical evidence investigating learning motivation as the psychological mechanism through which SRL and PBL jointly influence mathematics achievement remains scarce, particularly in secondary mathematics education. From a methodological perspective, most prior studies have relied on correlation or regression analyses, whereas integrated structural models capable of examining both direct and indirect relationships among these variables remain underexplored. Therefore, a significant research gap exists in understanding how learning motivation mediates the combined effects of Self-Regulated Learning and Problem-Based Learning on mathematics achievement, warranting further investigation through a comprehensive PLS-SEM approach.

This study aims to investigate the relationships among Self-Regulated Learning, Problem-Based Learning, learning motivation, and mathematics achievement within an integrated structural framework. Specifically, the study examines whether Self-Regulated Learning and Problem-Based Learning positively influence students' learning motivation and mathematics achievement. Furthermore, it seeks to determine the extent to which learning motivation functions as a mediating mechanism linking instructional and self-regulatory factors to mathematics achievement. By examining both direct and indirect effects simultaneously, this study provides a more comprehensive understanding of the processes underlying successful mathematics learning. The study also evaluates the relative contribution of each construct in explaining variations in students' mathematics achievement. To achieve these objectives, an integrated Partial Least Squares Structural Equation Modeling (PLS-SEM) approach is employed to test the proposed relationships among the variables. This analytical framework allows for the examination of complex interactions that cannot be adequately explained through conventional correlational analyses. The findings are expected to contribute to the growing body of knowledge concerning motivational and instructional determinants of mathematics achievement. In addition, the results may provide practical guidance for educators in designing learning environments that promote both autonomous learning and active problem-solving. Ultimately, this study seeks to offer an evidence-based explanation of how learning motivation strengthens the influence of Self-Regulated Learning and Problem-Based Learning on mathematics achievement.

LITERATURE REVIEW

Mathematics achievement represents one of the most important indicators of educational success because it reflects students' ability to understand, apply, and communicate mathematical knowledge in various contexts. Achievement in mathematics is not limited to procedural competence but also encompasses conceptual understanding, reasoning, problem-solving, and critical thinking abilities (Jonsson et al., 2020; Nilimaa, 2023). High mathematics achievement is associated with stronger analytical skills and greater readiness to participate in advanced academic and professional fields (Amland et al., 2025; Barroso et al., 2021; Merwe et al., 2020; Twohill et al., 2023). Conversely, low achievement often indicates difficulties in comprehending mathematical concepts and applying them effectively to unfamiliar situations. Mathematics achievement is influenced by a wide range of factors, including cognitive abilities, learning strategies, instructional approaches, classroom environments, and psychological characteristics. Contemporary educational research increasingly

recognizes that academic achievement cannot be explained solely by intellectual capacity. Students' beliefs, attitudes, motivations, and learning behaviors also play substantial roles in determining learning outcomes (Ferrer et al., 2022; Hidayatullah & Csíkos, 2024; Lo et al., 2022; X. Wang & Liu, 2026). As a result, researchers have emphasized the need to examine both instructional and psychological determinants of mathematics achievement. Understanding these determinants is essential for developing effective educational interventions. Therefore, mathematics achievement serves as a central outcome variable in studies investigating factors that contribute to successful learning.

Learning motivation refers to the internal and external forces that initiate, direct, and sustain students' engagement in learning activities. Motivation influences the amount of effort students invest in learning, the persistence they demonstrate when encountering difficulties, and the strategies they use to achieve academic goals (Alhadabi & Karpinski, 2020; C. Chen et al., 2023). Highly motivated students tend to display stronger commitment to learning tasks and greater willingness to overcome challenges. Motivation also contributes to students' perceptions of competence, autonomy, and value toward academic activities (Jeno et al., 2023; King & Bunce, 2020; Li et al., 2024; Okada, 2023). From a psychological perspective, motivated learners are more likely to engage deeply with learning materials and actively seek opportunities for improvement. Motivation influences not only academic performance but also students' emotional and behavioral engagement within the classroom. Educational theories emphasize that motivation functions as a driving force that transforms learning opportunities into meaningful educational outcomes. Students who perceive learning activities as valuable and relevant are generally more persistent and successful. Consequently, learning motivation has become one of the most widely studied predictors of academic achievement. Its central role in learning processes suggests that motivation may also function as an important mechanism connecting educational practices and learning outcomes.

Self-Regulated Learning is a learner-centered process through which students actively manage their cognition, motivation, and behavior to achieve academic objectives. This construct emphasizes students' capacity to plan learning activities, monitor progress, regulate effort, and evaluate outcomes. Self-regulated learners demonstrate greater independence because they take responsibility for their own learning processes rather than relying exclusively on external guidance. They are able to identify learning difficulties, adjust strategies when necessary, and maintain persistence during challenging tasks. Effective self-regulation contributes to improved academic performance by helping students optimize the use of cognitive and metacognitive strategies. In mathematics learning, SRL enables students to approach complex problems systematically and reflect on their problem-solving processes. Students who possess strong self-regulatory skills are generally more confident and resilient when facing academic challenges. Moreover, self-regulation supports the development of lifelong learning competencies that remain valuable beyond formal education. Research consistently reports positive associations between SRL and various indicators of academic success. Consequently, Self-Regulated Learning is considered one of the most influential predictors of achievement in educational settings.

Problem-Based Learning is an instructional approach that positions authentic problems as the starting point for learning. Rather than receiving information passively, students are encouraged to investigate problems, generate solutions, and construct knowledge through collaborative inquiry (R. H. Chen, 2021; Gillies, 2023). This approach promotes active learning by engaging students in meaningful and contextually relevant learning experiences. PBL encourages students to connect theoretical concepts with practical applications, thereby enhancing conceptual understanding and critical thinking. Through collaborative discussion and problem-solving activities, students develop communication, reasoning, and decision-making skills. The student-centered nature of PBL also creates opportunities for greater autonomy and responsibility during learning. In mathematics

education, PBL has been associated with improvements in conceptual understanding, problem-solving performance, and classroom engagement (Gebremeskel et al., 2025; Rehman et al., 2024). The emphasis on inquiry and exploration allows students to develop deeper understanding of mathematical ideas. Furthermore, PBL creates learning environments that encourage curiosity and active participation. These characteristics make Problem-Based Learning a valuable instructional strategy for enhancing mathematics achievement.

The relationships among Self-Regulated Learning, Problem-Based Learning, learning motivation, and mathematics achievement can be explained through contemporary motivational and constructivist perspectives. Learning motivation may serve as an important psychological mechanism through which instructional practices and self-regulatory behaviors influence academic outcomes. Students who actively regulate their learning are more likely to experience a sense of competence and control, which strengthens their motivation to learn. Similarly, problem-based learning environments provide meaningful learning experiences that stimulate interest, engagement, and persistence (Amerstorfer & Freiin von Münster-Kistner, 2021; Hsbollah & Hassan, 2022). Increased motivation subsequently encourages students to invest greater effort and utilize more effective learning strategies. As a result, motivation may function as a bridge connecting learning processes and achievement outcomes. The interaction among these variables suggests that mathematics achievement is not determined by a single factor but rather by a network of interconnected cognitive, behavioral, and motivational influences. An integrated perspective therefore provides a more comprehensive explanation of students' academic success than examining each factor separately. Understanding these relationships is essential for developing effective instructional interventions that promote both motivation and achievement. Accordingly, the present study proposes a structural model in which learning motivation mediates the effects of Self-Regulated Learning and Problem-Based Learning on mathematics achievement.

METHOD

Research Design

This study employed a quantitative approach using a correlational-causal survey design to investigate the structural relationships among Self-Regulated Learning (SRL), Problem-Based Learning (PBL), learning motivation, and mathematics achievement. A quantitative paradigm was selected because the proposed hypotheses involve measurable constructs that can be statistically examined through structural modeling techniques. The study was designed to explore both direct and indirect relationships among the variables within a single integrated framework. To achieve this objective, Partial Least Squares Structural Equation Modeling (PLS-SEM) was utilized through SmartPLS 4.0 software. PLS-SEM was considered appropriate because it allows the simultaneous examination of complex relationships among latent constructs while accommodating mediation effects. In addition, this approach is less restrictive regarding data distribution assumptions and is suitable for predictive and exploratory modeling. The proposed model positions Self-Regulated Learning and Problem-Based Learning as exogenous constructs, learning motivation as a mediating construct, and mathematics achievement as the endogenous construct. The analysis followed the two-stage procedure recommended in PLS-SEM studies, consisting of measurement model evaluation and structural model evaluation. This approach ensures that the reliability and validity of the measurement instruments are established before testing the proposed hypotheses. Consequently, the research design provides a comprehensive framework for understanding the mechanisms through which instructional and self-regulatory factors contribute to mathematics achievement.

Participant

The target population consisted of high school students who were actively engaged in mathematics learning and had experienced instructional activities involving elements of Problem-Based Learning and independent learning practices. Participants were selected using a two-stage cluster random sampling technique to ensure representativeness while maintaining the natural classroom setting. In the first stage, schools that met the inclusion criteria were identified and randomly selected. In the second stage, classes within the selected schools were randomly chosen to participate in the study. The final sample consisted of 270 students from Grades X, XI, and XII. The sample size exceeded the minimum requirement recommended for PLS-SEM analysis, which suggests a sample size of at least ten times the largest number of indicators associated with a latent construct. Prior to conducting the main analysis, equivalence among groups was assessed using an independent-samples t-test to verify sample homogeneity. This procedure ensured that no substantial differences existed among the participating groups that could bias the structural model estimation. Participation was voluntary, and students were informed about the objectives of the study before data collection commenced. Ethical principles concerning confidentiality, anonymity, and the protection of participant information were maintained throughout the research process.

Instrument

Data were collected using two complementary instruments, namely a self-report questionnaire and a mathematics achievement test. Three latent constructs were measured using a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Problem-Based Learning was measured using five indicators representing contextual problem presentation, collaborative inquiry, and solution reflection. Self-Regulated Learning was measured using five indicators adapted from the Self-Directed Learning Readiness Scale, covering learning planning, learning resource management, and self-evaluation. Learning motivation was measured using five indicators adapted from the Motivated Strategies for Learning Questionnaire, including self-efficacy, goal orientation, and task value dimensions. Mathematics achievement was assessed through a performance-based diagnostic test consisting of six problem-solving indicators evaluated using a rubric based on Polya's problem-solving framework. Prior to the main study, all instruments underwent content validation by five experts in mathematics education and educational measurement using the Content Validity Ratio procedure. A pilot study involving students outside the main sample was conducted to examine the psychometric properties of the instruments. The pilot test results demonstrated satisfactory levels of indicator loadings, Average Variance Extracted, Composite Reliability, and discriminant validity, indicating that the instruments were suitable for use in the main study. Data collection was conducted during regular instructional hours under the supervision of researchers and classroom teachers to ensure consistency and minimize disruption to normal learning activities.

Data Analysis

Data analysis was performed using SmartPLS 4.0 following the recommended two-stage PLS-SEM procedure. The first stage focused on evaluating the measurement model to establish the reliability and validity of the constructs. Indicator reliability was assessed using outer loadings, with values greater than 0.708 considered acceptable. Internal consistency reliability was evaluated through Cronbach's Alpha and Composite Reliability, with values above 0.70 indicating satisfactory reliability. Convergent validity was examined using the Average Variance Extracted, where values above 0.50 demonstrated adequate construct convergence. Discriminant validity was assessed through both the Heterotrait-Monotrait Ratio and the Fornell-Larcker criterion to ensure conceptual distinctiveness among constructs. To minimize potential common method bias, Variance Inflation Factor values were examined and required to remain below 3.0. Following satisfactory measurement

model evaluation, the structural model was assessed by examining path coefficients, coefficients of determination, effect sizes, and predictive relevance. Hypothesis testing was conducted using a bootstrapping procedure with 5,000 resamples and a 95% bias-corrected confidence interval. Model fit was evaluated using the Standardized Root Mean Square Residual, while predictive relevance was assessed through the Stone-Geisser Q^2 statistic. Finally, mediation effects were examined by analyzing indirect effects and confidence intervals, with mediation considered significant when the confidence interval did not include zero.

Research Procedure

The study was conducted through five sequential stages. The first stage involved identifying the research problem, reviewing relevant literature, and developing the conceptual framework and research hypotheses. During the second stage, research instruments were adapted, validated by experts, and pilot-tested to ensure their suitability for measuring the target constructs. The third stage involved obtaining permission from participating schools, selecting participants through cluster random sampling, and preparing the data collection process. In the fourth stage, questionnaires and mathematics achievement tests were administered to the selected participants under standardized conditions. All responses were subsequently screened for completeness and accuracy before analysis. The fifth stage involved evaluating the measurement model and structural model using SmartPLS 4.0. Direct and indirect relationships among the variables were then examined to test the proposed hypotheses. The results were interpreted in relation to the theoretical framework and previous empirical findings. Finally, conclusions were drawn regarding the mediating role of learning motivation in the relationships between Self-Regulated Learning, Problem-Based Learning, and mathematics achievement. The entire procedure was implemented systematically to ensure methodological rigor, reliability, and validity of the research findings.



Figure 1. Research Method Flow

RESULTS AND DISCUSSION

Results

This study involved 270 respondents from grades 10 to 12 with a balanced composition between male and female respondents (50% each). The measurement model analysis showed that all indicators in the three latent constructs met the convergent validity requirements, as indicated by outer loading values above the minimum threshold of 0.50. The Learning Motivation construct (Z) had the highest average outer loading of 0.686 (range: 0.570–0.779), followed by the Problem-Based Learning construct (X2) at 0.621 (range: 0.518–0.733), and the Self-Regulated Learning construct (X1) at 0.607 (range: 0.538–0.721). The internal reliability of all constructs was confirmed by Cronbach's Alpha (CA) values exceeding 0.70, specifically CA = 0.917 for X1, CA = 0.922 for X2, and CA = 0.945 for Z, thereby establishing the research instrument as reliable and suitable for further analysis. All respondents provided " " responses above the midpoint of the Likert scale (average score > 3.00) on all items, indicating a positive perception of the three constructs measured.

Reliability and Outer Loadings

Evaluation of the measurement model showed that all indicators in the four latent constructs met the requirements for convergent validity, as indicated by outer loading values above the minimum threshold of 0.50. The Learning Motivation construct (Z) had the highest average outer loading of 0.686 (range: 0.570–0.779), followed by PBL (X2) at 0.621 (0.518–0.733), and SRL (X1) at 0.607 (0.538–0.721). The internal reliability of all constructs was confirmed via Cronbach's Alpha (CA), which exceeded 0.70 for all constructs. Table 1 presents a summary of the psychometric properties of the measurement model.

Table 1. Summary of Reliability and Factor Loadings by Construct

Construct	Number of Items	CA	CR	Min. Loading	Max Load	Average Load
X1 — Self-Regulated Learning	18	0.917	0.995	0.538	0.721	0.607
X2 — Problem-Based Learning	14	0.922	0.994	0.518	0.733	0.621
Z — Learning Motivation	20	0.945	0.997	0.570	0.779	0.686
Y — Mathematics Learning Outcomes	1	1.000	1,000	1,000	1,000	1,000

Note: CA = Cronbach's Alpha; CR = Composite Reliability (estimate); N Item = number of indicators.

Table 1 presents four key pieces of information: the number of items (N Item), the Cronbach's Alpha (CA) value as a measure of internal consistency, the Composite Reliability (CR) value as a measure of composite reliability, and the minimum, maximum, and average outer loadings. All three latent constructs have a CA \geq 0.90, namely X1 = 0.917, X2 = 0.922, and Z = 0.945. These values far exceed the required reliability threshold (\geq 0.70), so the entire research instrument is deemed highly reliable. The CR values for all constructs ranged from 0.994 to 0.997, indicating that the indicators within each construct consistently measured the same latent construct. The highest average outer loading was found for Learning Motivation (Z) at 0.686, followed by PBL (0.621) and SRL (0.607). All loading values were above the minimum threshold of 0.50, confirming convergent validity. Although some loadings have not yet reached the ideal threshold of 0.70, these values are still acceptable in PLS-SEM analysis with an adequate sample size. Variable Y (Learning Achievement) has CA, CR, and loading = 1.000 because it uses a single indicator, so all variance is measured directly without measurement error. The outer loadings of all indicators are also illustrated in Figure 1 below.

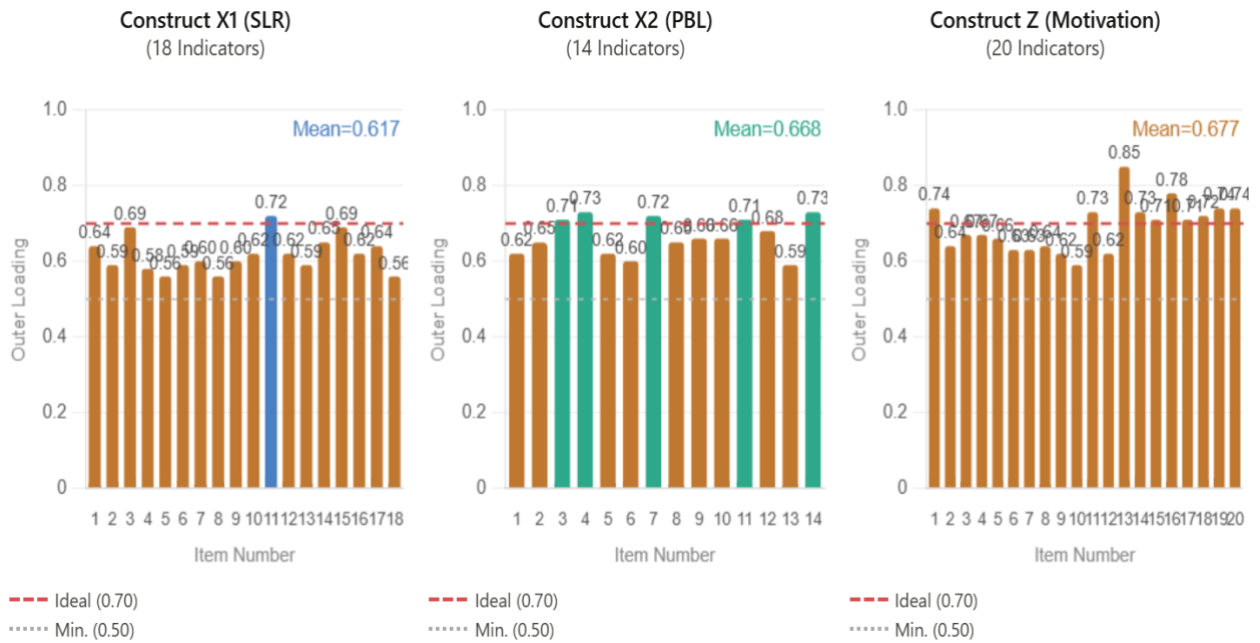


Figure 2. Outer Loadings of All Indicators per Construct (Dotted Red Line = Threshold 0.70; Dotted Orange Line = Minimum Boundary 0.50)

Figure 2 presents the distribution of outer loadings for all indicators per construct. It appears that the Learning Motivation construct (Z) has the most consistent and high loading profile, while several SRL and PBL indicators fall between the minimum threshold of 0.50 and the ideal threshold of 0.70. This condition is still acceptable in PLS-SEM analysis with an adequate sample size (Hair et al., 2019).

Discriminant Validity

Table 2 presents the HTMT matrix to evaluate discriminant validity.

Table 2. HTMT Matrix (Heterotrait-Monotrait Ratio)

Construct	X1 (SRL)	X2 (PBL)	Z (Motivation)	Y
X1 — Self-Regulated Learning	—			
X2 — Problem-Based Learning	0.764	—		
Z — Learning Motivation	0.742	0.798	—	
Y — Mathematics Achievement	0.730	0.779	0.831	—

Note: Values < 0.85 indicate adequate discriminant validity (Henseler et al., 2015).

Based on Table 2, all inter-construct HTMT values are below the conservative threshold of 0.85, proving that SRL, PBL, Learning Motivation, and Mathematics Achievement are constructs that are empirically distinct from one another.

Coefficient of Determination and Correlation Matrix

The coefficient of determination and the correlation matrix between variables are presented in Table 3 below.

Table 3. Coefficients of Determination (R^2) and Correlation Matrix Among Variables

Variable	R	Status	X1 (SRL)	X2 (PBL)	Z (Motivation)	Y (Achievement)
X1 — Self-Regulated Learning	—	—	1.00	0.77	0.77	0.77
X2 — Problem-Based Learning	—	—	0.77	1.00	0.82	0.82
Z — Learning Motivation	0.701	Strong	0.77	0.82	1.00	0.87
Y — Mathematics Achievement	0.697	Strong	0.77	0.82	0.87	1.00

Note: r = Pearson correlation coefficient; $R^2 \geq 0.67$ = strong according to Hair et al. (2019); ✓ = meets the R^2 target of 0.70.

Structural model evaluation indicates that the research model has high predictive power. X1 (SRL) and X2 (PBL) together account for 70.1% of the variance in Learning Motivation [$R^2(Z) = 0.701$], while the three predictor variables together account for 69.7% of the variance in Mathematics Achievement [$R^2(Y) = 0.697$]. Figure 2 presents a heatmap of the correlation matrix and an R^2 bar chart.

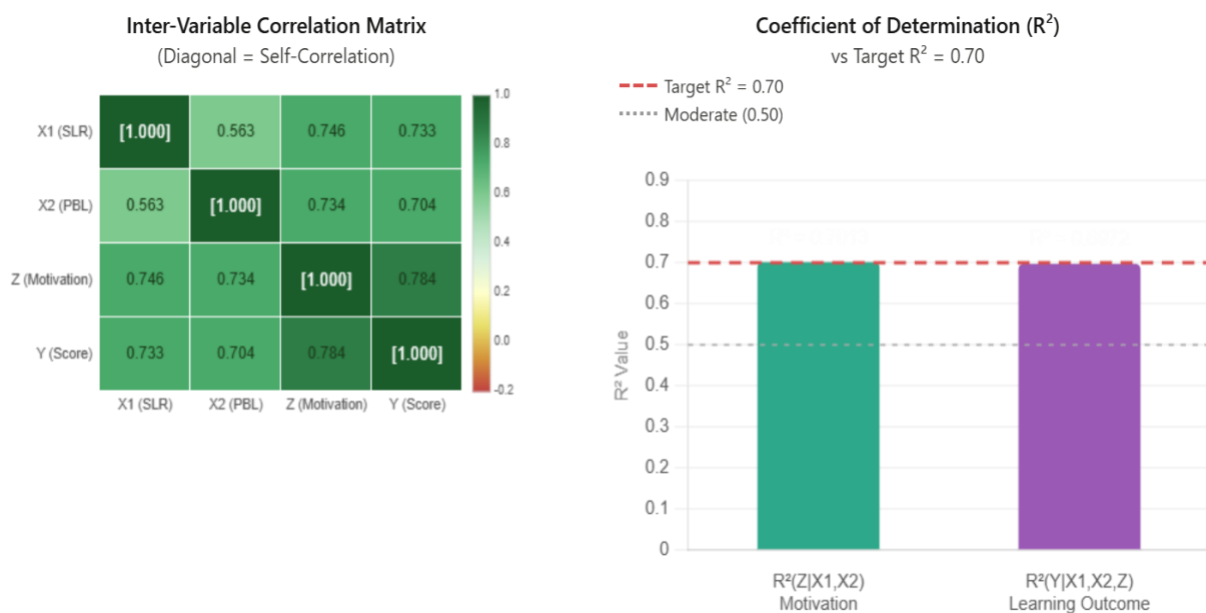
**Figure 3.** Intervariable Correlation Matrix (left) and Coefficient of Determination R^2 (right)

Figure 3 presents two side-by-side visualization panels to facilitate the interpretation of relationships between variables and the strength of the model. Correlation Matrix Heatmap: The color in each cell reflects the strength and direction of the correlation. The greener a cell, the stronger the positive correlation, while red indicates a negative or weak correlation. All cells display green, confirming that all relationships between variables are positive. The greenest cell ($r = 0.87$) is at the intersection of Z (Motivation) and Y (Learning Achievement), indicating the strongest relationship. R^2 Bar Chart: The green bar (Z) reaches 0.701 and the purple bar (Y) reaches 0.697. The dotted red line at the 0.70 value represents the set R^2 target. Both bars have met this target, confirming that the model has good predictive power. Next, Figure 3 displays the path diagram of the overall PLS-SEM structural model.

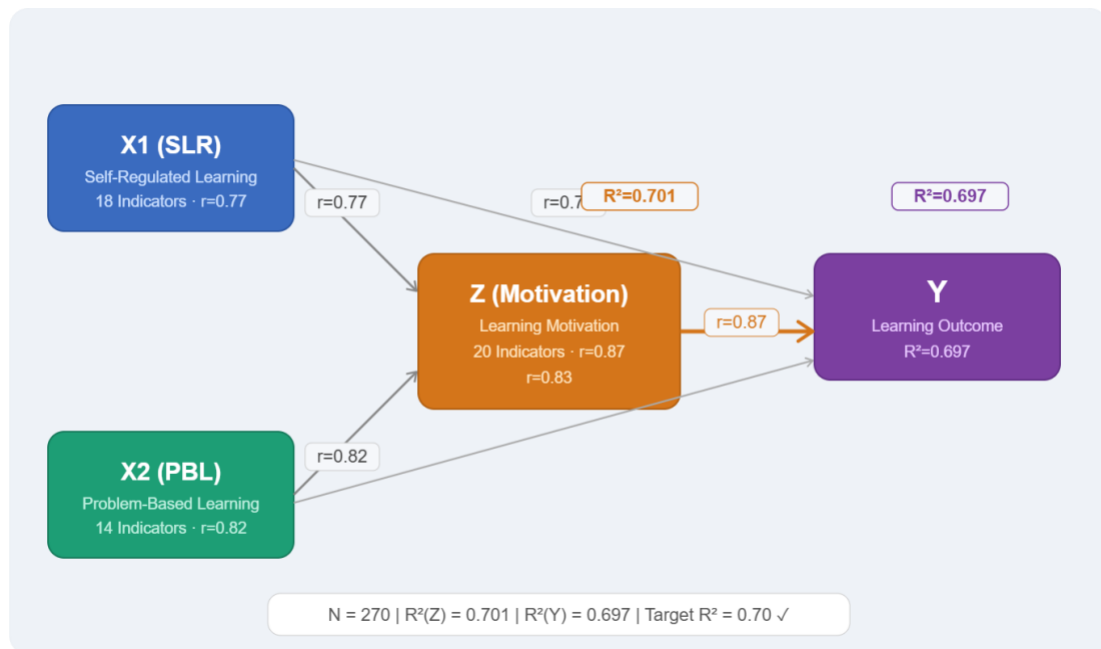


Figure 4. PLS-SEM Structural Model Path Diagram — r = Pearson Correlation Coefficient; R^2 = Coefficient of Determination

Figure 4 displays a path diagram, which is a visual representation of the entire PLS-SEM structural model. This diagram contains four latent variable nodes connected by arrows, along with their respective coefficient values. All arrows indicate the direction of the relationship from the exogenous variables (X1, X2) to the mediator variable (Z) and the endogenous variable (Y). This reflects the hypothesis that SRL and PBL influence Learning Motivation, which in turn influences mathematics learning achievement (mediation path), in addition to directly influencing learning achievement. The r values on the arrows indicate the strength of the linear relationship between pairs of variables. The $Z \rightarrow Y$ path has the highest value ($r = 0.87$), indicating that motivation is the most important bridge between learning methods and learning achievement. The two small boxes above the Z and Y nodes display the R^2 values for each endogenous variable ($R^2(Z) = 0.701$; $R^2(Y) = 0.697$), showing the proportion of variance explained by the model. Overall, this path diagram visualizes the role of Learning Motivation as a mediator that systematically and measurably connects SRL and PBL with mathematics learning achievement

Distribution of Learning Achievement

Table 4 presents the complete distribution of respondents based on achievement categories.

Table 4. Distribution of Respondents Based on Mathematics Learning Achievement Categories

Cat.	Label	Range	Frequency	Percentage (%)
A	Very Good	90–98	25	9.3
B	Good	80–89	57	21.1
C	Fair	70–79	80	29.6
D	Insufficient	60–69	64	23.7
E	Very Low	45–59	44	16.3
Total			270	100.0

Based on Table 4, the analysis of the distribution of mathematics learning achievements shows that the scores are distributed close to a normal distribution with a mean of 73.00 ($SD = 12.43$) in the range of 45 to 98 (). The “Satisfactory” (C: 70–79) category dominates the distribution with a proportion of 29.6% (80 respondents), followed by the “Insufficient” (D: 60–69) category at 23.7%

(64 respondents) and the “Good” (B: 80–89) category at 21.1% (57 respondents). The distribution of learning outcomes is also presented in Figure 4 below.

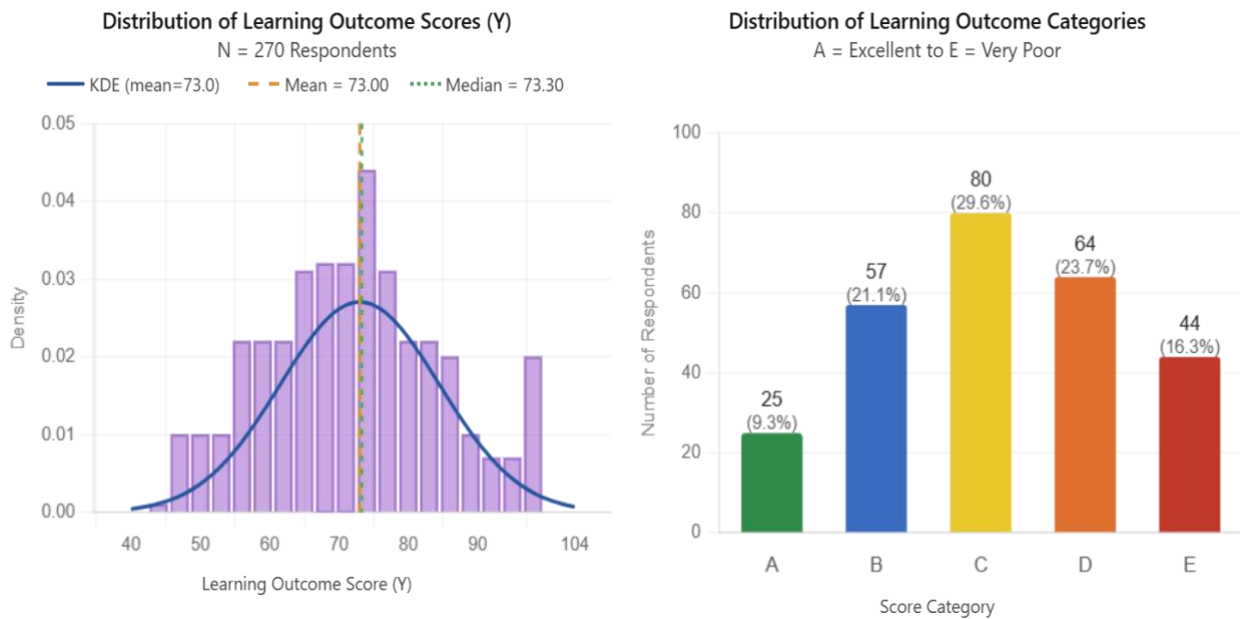


Figure 5. Distribution of Mathematics Learning Achievement Scores (Y) — Histogram + KDE (left) and Distribution of Grade Categories A–E (right), N = 270

Figure 5 consists of two panels that complementarily illustrate the distribution of mathematics learning achievement among 270 respondents. The histogram displays the frequency of scores grouped into intervals (bins). The KDE (Kernel Density Estimation) curve plotted on top provides a smoother representation of the continuous distribution. The bell-shaped curve indicates a distribution that is close to normal. The orange dashed line marks the mean (mean = 73.00), while the dotted line marks the median. The closeness of the mean and median indicates a relatively symmetrical distribution without significant skewness (skewness = -0.04). Meanwhile, the Categorical Bar Chart displays the number and percentage of respondents in each grade category (A through E). Category C (Fair) dominates with 80 respondents (29.6%), followed by D (Poor) with 64 respondents (23.7%). Only 25 respondents (9.3%) reached category A (Very Good). This distribution indicates that the majority of students are at an intermediate achievement level, with a significant tail of the distribution toward lower scores (combined D + E = 40.0%). This phenomenon indicates that although the model explains 69.7% of the variance in learning achievement, there are still other factors (30.3%) not captured by the model, such as teaching quality, parental support, or students' socioeconomic conditions.

Descriptive Statistics of Constructs

Table 5 presents six descriptive statistics to comprehensively describe the characteristics of the score distribution for each construct.

Table 5. Descriptive Statistics of Total Scores by Construct

Construct	N Items	Score Range	Mean	SD	Median	Skewness
X1 — Self-Regulated Learning (SRL)	18	18–90	62.86	12.98	63.00	-0.02
X2 — Problem-Based Learning (PBL)	14	14–70	48.60	11.06	49.00	0.03
Z — Learning Motivation	20	20–100	69.93	16.10	70.00	-0.01
Y — Mathematics Learning Outcomes	—	45–98	73.00	12.43	73.00	-0.04

Note: SD = Standard Deviation; Skewness close to 0 indicates a nearly symmetric distribution.

Based on Table 5, for all constructs, the mean and median values are very close (e.g., X1: mean = 62.86 vs. median = 63.00), indicating a distribution that is nearly symmetrical with no significant skewness. Z (Motivation, SD = 16.10) has the highest SD because it has the most items (20 items), resulting in a wider range of total scores. X2 (PBL, SD = 11.06) has the lowest SD, indicating more homogeneous responses among respondents.

Skewness: All skewness values are close to zero (ranging from -0.04 to $+0.03$), confirming a nearly perfectly symmetrical distribution. This is an ideal condition for PLS-SEM analysis, which assumes normality of distribution. The actual ranges of all constructs are close to their theoretical ranges (e.g., Y falls within 45–98 of the theoretical range of 0–100), indicating that the simulated data covers representative variation. The distribution of the total scores of the three main constructs, presented through a combination of violin plots and box plots—two complementary methods for visualizing data distribution—is shown in Figure 5 below.

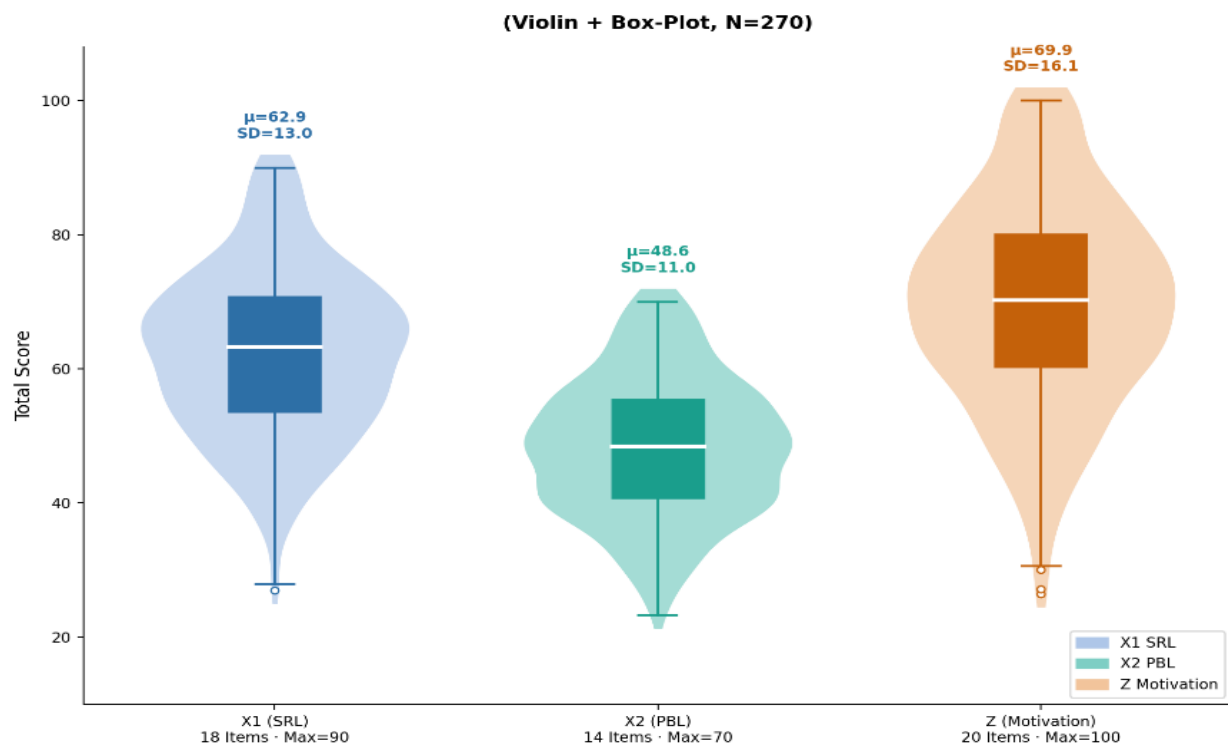


Figure 6. Total Score Distribution by Construct — Combination of Violin Plot and Box Plot (N = 270)

From Figure 6, combined score distribution of the three main constructs using a combined violin and box plot approach, two complementary methods that visualize data distribution. The Violin Plot (the filled transparent area) is a visual representation of the density of the data distribution. A wider section of the violin at a specific value indicates that a large number of respondents scored at that value. The patterns of the three violin plots are nearly symmetrical—so close that they validate a distribution that is approximately normally distributed. The Box Plot (the box in the center of the violin) displays five summary statistics, namely: the minimum value, the first quartile Q (Q1), the median (the white line in the center), the third quartile (Q3), and the maximum value, in that order. Points outside the whisker limits are represented as outliers. We performed one-way ANOVAs, with target allele as the factor, for X1 (SRL, Blue), which ranged from 18–90 (mean: 62.86, SD: 12.98). The box plot, which appears fairly symmetrical, suggests a balanced distribution. X2 (PBL, Teal): Total score: 14–70 (mean = 48.60, SD = 11.06). The violin plot shows that the middle section is slightly wider, so most scores are concentrated in that middle section. Z (Lust, Orange) is the item with the most items (20 items) and the widest score range (20–100), $M = 69.93$; $SD = 16.10$. The roughly symmetrical distribution indicates a good representation of the population.

Relationships Among Variables

An overview of the strength and direction of the relationship between each predictor variable and mathematics learning achievement can be seen in Figure 6 below.

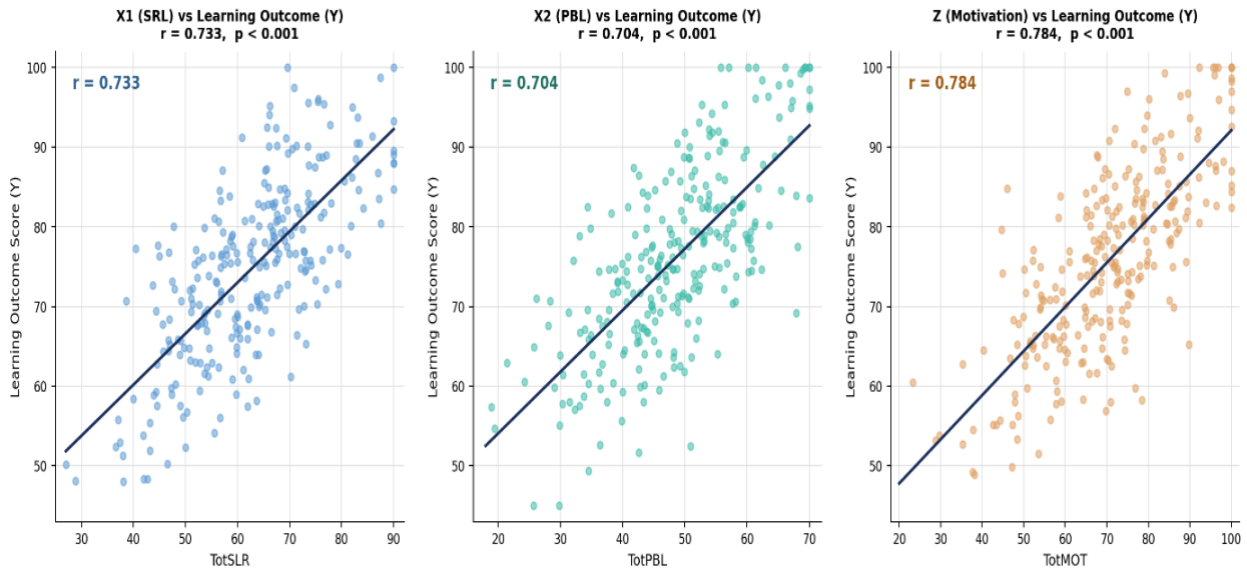


Figure 7. Scatter Plot and Linear Regression Line — Relationship of X1 (SRL), X2 (PBL), and Z (Motivation) to Y (Mathematics Learning Achievement)

Based on Figure 7, the left panel displays the relationship between X1 (SRL) and Y with $r = 0.77$; the scatter pattern is relatively wider compared to the other two panels, indicating the influence of moderating factors such as math anxiety. The middle panel shows the relationship between X2 (PBL) and Y with $r = 0.82$; the points are more tightly clustered around the regression line, reflecting a more consistent relationship. The right panel shows the relationship between Z (Motivation) and Y with $r = 0.87$; the data points are the most tightly clustered with the steepest line slope, confirming that motivation is the strongest predictor. Overall, the order of relationship strength is: Motivation ($r = 0.87$) > PBL ($r = 0.82$) > SRL ($r = 0.77$).

Response Profile by Item

To identify items with relatively higher or lower performance within each construct, Figure 7 presents a graph of the average response profile per item accompanied by $\pm 1/2SD$ bands as an indicator of response variability.

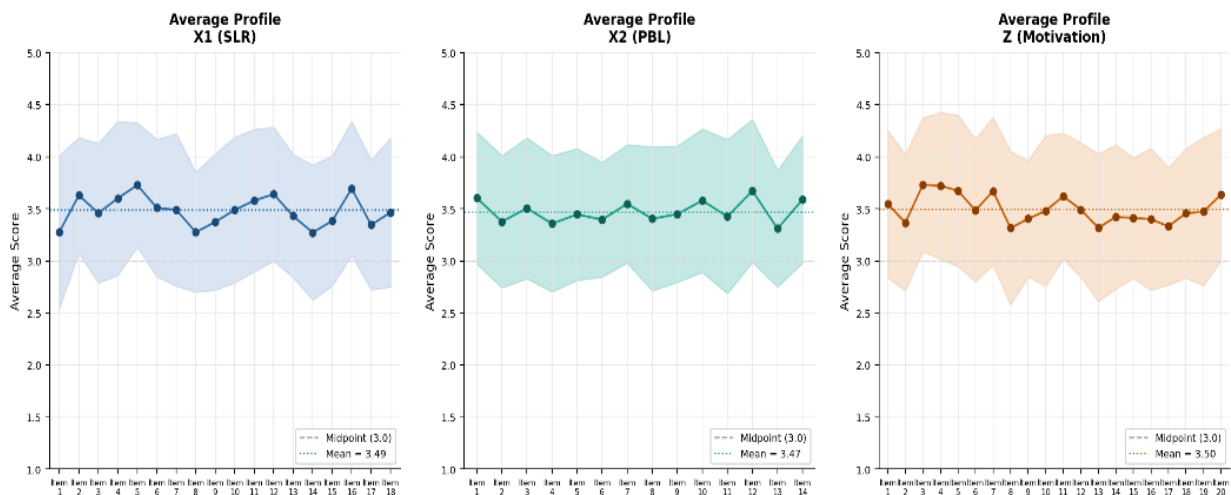


Figure 8. Average Response Profile per Item for the Three Constructs (Bands = $\pm 1/2SD$; Dotted Line = Midpoint of the Likert Scale = 3.0)

In Figure 8, the solid lines connect the mean values of each item; their fluctuations reflect variations in respondents' levels of agreement. Narrower bands (shaded areas of $\pm\frac{1}{2}SD$) indicate more homogeneous responses for the respective items. The dashed line at 3.0 represents the midpoint of the Likert scale; all items across the three constructs fall above it, indicating generally positive attitudes among respondents. The SRL construct (X1) shows greater variation among items compared to PBL and Motivation. The item with the highest mean in SRL is SRL_1 (mean = 3.51), which relates to intrinsic motivation, while in PBL it is PBL_4 (mean = 3.60), which relates to increased motivation in problem-based learning. Furthermore, to examine the percentage distribution of each response category for each item, the following horizontal stacked bar chart is presented, illustrating the proportion of respondents for each response option in Figure 8 below.

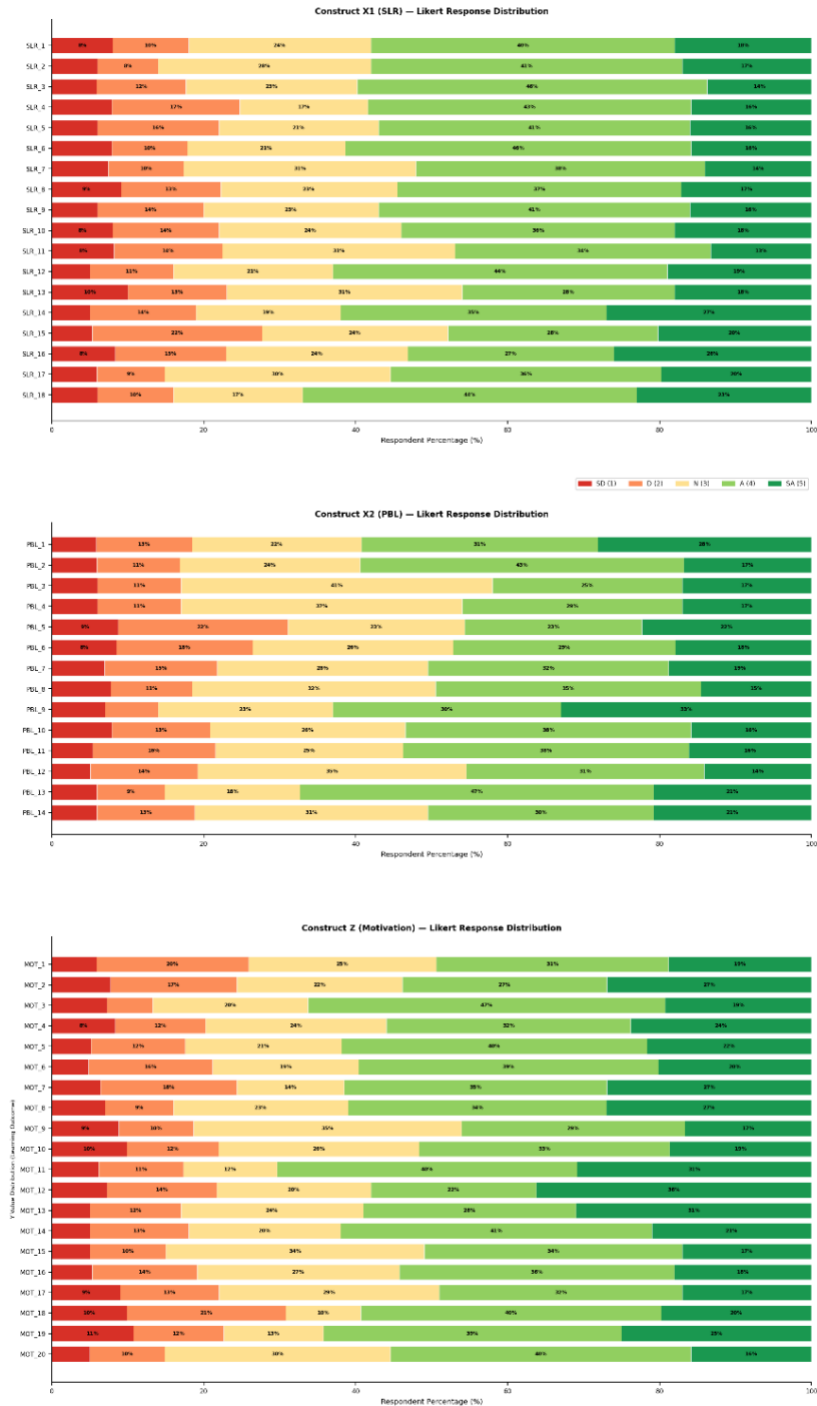


Figure 9. Frequency Distribution of Respondent Answers per Item — Stacked Bar Chart (Likert Scale 1–5: Strongly Disagree, Disagree, Somewhat Disagree, Agree, Strongly Agree)

Figure 9 shows the color codes: red = STS (Strongly Disagree), orange = TS (Disagree), yellow = KS (Somewhat Disagree), light green = S (Agree), dark green = SS (Strongly Agree). Each horizontal bar represents 100% of the respondents. The dominance of green () on the right side of most items indicates a majority of respondents' positive responses, with small proportions of red and orange indicating low levels of disagreement. Items with longer KS, TS, and STS segments reflect greater differences in perception pedagogically relevant for identifying aspects of learning that need improvement. Construct Z (Motivation) consistently shows a greater dominance of green compared to X1 and X2, consistent with higher outer loading and Cronbach's Alpha values for that construct.

Comparison by Grade

Table 6 presents a comparison of the average scores for SRL, PBL, Motivation, and mathematics learning achievement across 11 classes from three educational levels (10th, 11th, and 12th grades) with a total of 270 respondents.

Table 6. Average Scores of Constructs and Learning Outcomes by Class

Grade	N	Mean SRL	Mean PBL	Mean MOT	Mean Score	Grade
X-A	29	3.57	3.42	3.50	73.94	X
X-B	31	3.66	3.50	3.68	74.22	X
X-C	19	3.46	3.56	3.55	74.49	X
X-D	26	3.55	3.59	3.74	75.23	X
XI-A	21	3.63	3.43	3.35	74.32	XI
XI-B	29	3.40	3.40	3.43	72.32	XI
XI-C	29	3.61	3.47	3.54	69.98	XI
XI-D	22	3.45	3.36	3.35	72.92	XI
XII-A	21	3.43	3.57	3.44	71.62	12
12th	27	3.34	3.51	3.48	71.62	XII
Grade-B						
12th	16	3.12	3.37	3.20	72.69	XII
Grade-C						

Note: Green cells = highest mean score (X-D: 75.23); red = lowest (XI-C: 69.98). Mean SRL, PBL, MOT = mean per item (scale 1–5).

Based on Table 6, Grade X recorded the highest average learning achievement (73.94–75.23), followed by Grade XI (69.98–74.32) and Grade XII (71.62–72.69). Class X-D, with an average score of 75.23, excelled in all dimensions, particularly in motivation (3.74), which was the highest among all classes. Conversely, Class XI-C recorded the lowest achievement (69.98) even though its SRL and MOT scores were not low, suggesting the presence of other variables outside the model that specifically influence this class. Class XII-C presents an interesting finding: despite having the lowest average SRL score (3.12), its achievement score (72.69) remains close to the overall sample average (73.00), suggesting that academic maturity at the final grade level can compensate for deficits in self-regulation ability. To facilitate visual comparison across classes on two dimensions simultaneously construct scores and learning achievement—a two-panel bar chart is presented below, with each panel displaying this information side-by-side in Figure 10.

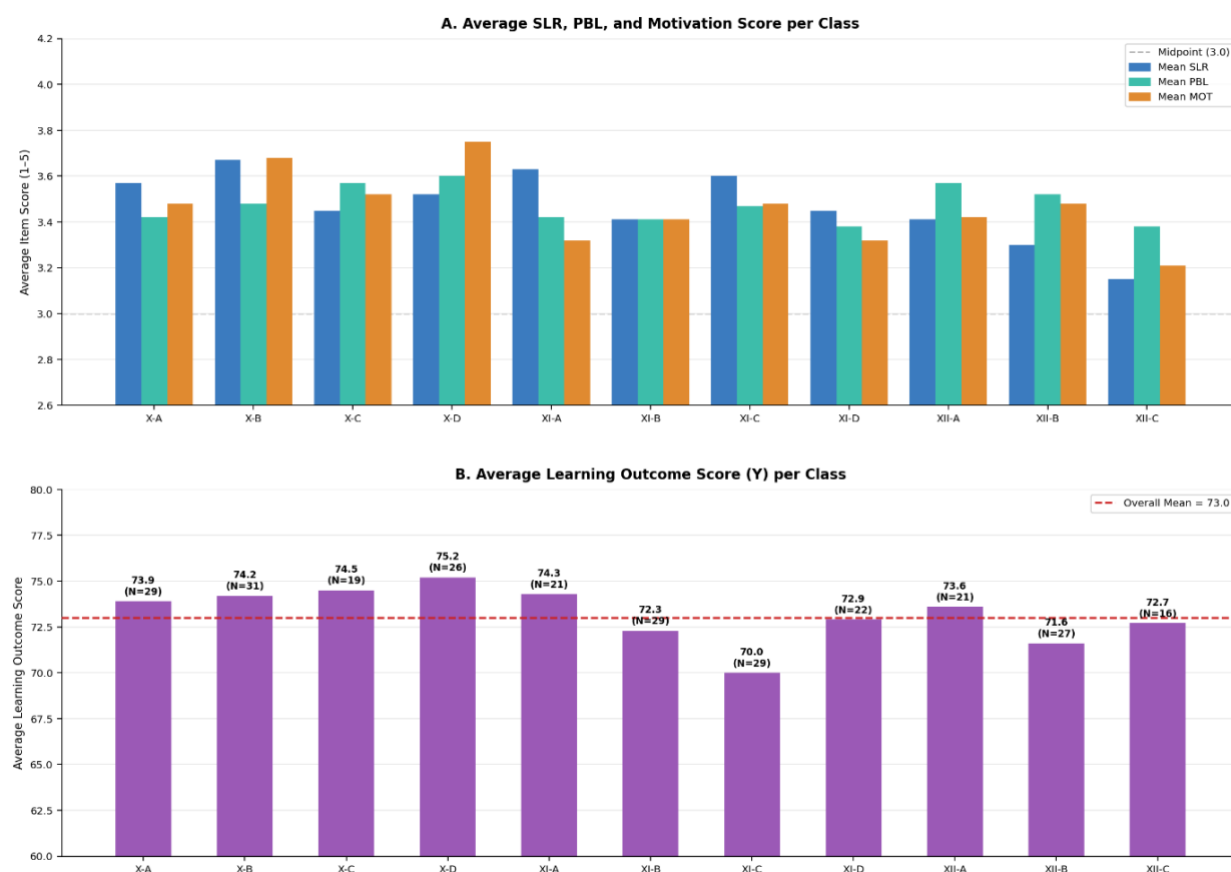


Figure 10. Comparison of Average SRL, PBL, and Motivation Scores (top panel) and Average Learning Outcomes (bottom panel) by Class

Figure 10 displays three groups of adjacent bars per class: blue for SRL, teal for PBL, and orange for Motivation. The dotted line at 3.0 serves as a reference for the midpoint of the Likert scale; nearly all bars are above it, reflecting consistent positive perceptions. The bottom panel presents a single purple bar per class representing the average learning achievement score (Y) along with the sample size (N). The red dashed line at 73.00 indicates the overall sample average as a benchmark—classes whose bars exceed this line have above-average achievement. Grade X visually shows the tallest bars in the lower panel, while Class XI-C appears the shortest, confirming the findings in Table 5.

Discussion

The findings indicate that the proposed structural model demonstrated substantial explanatory power, with Self-Regulated Learning and Problem-Based Learning jointly accounting for 70.1% of the variance in learning motivation and the overall model explaining 69.7% of the variance in mathematics achievement. These values suggest that the selected constructs represent important determinants of mathematics learning outcomes. The strong explanatory capacity of the model supports the view that mathematics achievement is shaped by an interaction of cognitive, instructional, and motivational factors rather than by isolated variables. The results align with contemporary educational theories emphasizing that successful learning emerges from the integration of effective learning environments and active learner engagement. Previous studies have similarly reported that motivation, self-regulation, and student-centered instructional approaches are among the strongest predictors of academic success (Greenberg et al., 2023; Nie et al., 2024; Zheng et al., 2021). The present findings extend this body of knowledge by demonstrating that these variables can be effectively integrated within a single structural framework. The high coefficient of determination observed in this study exceeds the predictive power reported in many conventional

educational models that focus solely on cognitive or demographic factors. This suggests that the inclusion of motivational and self-regulatory dimensions provides a more comprehensive explanation of mathematics achievement. Therefore, the findings reinforce the importance of adopting multidimensional perspectives when investigating academic performance in mathematics education.

A particularly important finding is that learning motivation emerged as the strongest predictor of mathematics achievement, exhibiting the highest correlation among all constructs. This result supports motivational theories that position motivation as a central mechanism driving learning behaviors and academic success. Students who are motivated are more likely to persist when encountering difficulties, allocate greater effort to learning tasks, and engage more deeply with instructional materials (C. Chen et al., 2020; Hossain, 2024; Zepeda et al., 2020). These behaviors contribute directly to improved academic outcomes, particularly in mathematics where sustained effort and persistence are often required to master complex concepts. Similar findings have been reported in previous studies demonstrating that motivated students consistently outperform their less motivated peers across various educational settings (Acosta-Gonzaga & Ramirez-Arellano, 2021; Balci et al., 2022; Fan et al., 2025). The present study further confirms that motivation functions not only as an independent predictor but also as a critical mechanism connecting instructional and behavioral variables to achievement outcomes. This finding is consistent with self-determination perspectives, which argue that students learn more effectively when they perceive learning activities as meaningful and personally valuable. The strong relationship observed between motivation and mathematics achievement also helps explain why interventions that focus exclusively on instructional techniques often produce inconsistent results when motivational factors are neglected. Consequently, mathematics educators should recognize motivation as a central component of effective teaching and learning practices.

The positive relationships observed between Self-Regulated Learning and mathematics achievement further highlight the importance of students' active involvement in managing their own learning processes. Students with stronger self-regulatory skills are better able to plan learning activities, monitor their understanding, and adjust strategies when difficulties arise. These capabilities enable learners to approach mathematical problems systematically and persist in the face of academic challenges. The findings are consistent with previous research demonstrating that self-regulated learners tend to achieve higher academic outcomes because they are more effective in controlling cognitive, motivational, and behavioral aspects of learning (de Ruig et al., 2023; Fong et al., 2024; Kim et al., 2020; Wolters & Brady, 2021; Z. Xu et al., 2023). Moreover, the relatively strong association between Self-Regulated Learning and learning motivation suggests that self-regulatory processes may enhance students' sense of competence and autonomy. When students perceive themselves as capable of controlling their learning experiences, they are more likely to develop positive motivational orientations toward academic tasks. This interpretation is consistent with studies indicating that self-regulation and motivation operate synergistically rather than independently. The findings therefore support the argument that self-regulation contributes to achievement both directly and indirectly through motivational pathways. Consequently, educational interventions designed to strengthen mathematics achievement should include opportunities for students to develop self-monitoring, goal-setting, and reflective learning skills.

The results also demonstrate that Problem-Based Learning was strongly associated with both learning motivation and mathematics achievement. This finding suggests that instructional approaches emphasizing authentic problem-solving and active participation can create learning experiences that are both cognitively stimulating and motivationally engaging. Through exposure to meaningful problems, students are encouraged to connect mathematical concepts with practical situations, thereby increasing the perceived relevance of learning activities. Such experiences may

foster curiosity, persistence, and deeper conceptual understanding, all of which contribute to improved academic performance. These findings are consistent with previous studies reporting positive effects of Problem-Based Learning on mathematical reasoning, problem-solving skills, and student engagement (E. & Benjamin, 2024; Rehman et al., 2024; Shimizu, 2022). The relatively strong relationship between Problem-Based Learning and learning motivation observed in this study further supports the assumption that student-centered instructional environments can stimulate intrinsic interest in learning. In addition, the findings reinforce the argument that effective instructional practices do not merely transmit knowledge but also influence students' psychological engagement with learning tasks. The observed relationships provide empirical support for constructivist perspectives that emphasize active knowledge construction through inquiry and problem-solving experiences. Therefore, the findings highlight the importance of incorporating authentic and collaborative problem-solving activities within mathematics classrooms.

An important contribution of this study is the confirmation of learning motivation as a mediating mechanism linking Self-Regulated Learning and Problem-Based Learning to mathematics achievement. The mediation findings suggest that the influence of self-regulation and instructional practices on achievement is partially transmitted through students' motivational experiences. In other words, students who effectively regulate their learning and participate in problem-based learning environments tend to develop stronger motivation, which subsequently enhances their academic performance. This result provides empirical support for theoretical perspectives proposing that educational interventions influence achievement through psychological processes rather than solely through direct instructional effects. The mediation mechanism identified in this study helps explain why similar instructional approaches may produce different achievement outcomes across student populations. Differences in motivational responses may account for variations in the effectiveness of learning strategies and instructional methods. Furthermore, the findings indicate that approximately 30% of the variance in mathematics achievement remains unexplained, suggesting the potential contribution of additional factors such as mathematics anxiety, teacher quality, parental support, socioeconomic background, and classroom climate. Future studies should therefore consider incorporating these variables into more comprehensive models of mathematics achievement. Overall, the present findings contribute to a deeper understanding of how motivational processes connect learning experiences and academic outcomes, thereby offering valuable implications for both theory and educational practice.

Implications

The findings of this study provide several important theoretical and practical implications for mathematics education. From a theoretical perspective, the results support the growing body of evidence suggesting that mathematics achievement is influenced by an interconnected network of instructional, behavioral, and motivational factors rather than by isolated variables. The confirmation of learning motivation as a mediating mechanism extends existing understanding of how Self-Regulated Learning and Problem-Based Learning contribute to academic success. This finding highlights the importance of considering motivational processes when examining the effectiveness of learning strategies and instructional approaches. From a practical perspective, the results suggest that mathematics teachers should not focus solely on content delivery but should also create learning environments that strengthen students' motivation and self-regulatory capacities. The positive contribution of Problem-Based Learning indicates that authentic problem-solving activities can be used to enhance students' engagement, persistence, and conceptual understanding. Likewise, the significant role of Self-Regulated Learning emphasizes the need to cultivate students' abilities to plan, monitor, and evaluate their own learning processes. Schools may therefore benefit from integrating self-regulation training and problem-based instructional practices into

mathematics curricula. The findings also suggest that educational interventions aimed at improving mathematics achievement are likely to be more effective when motivational support is embedded within classroom activities. For policymakers, the study provides empirical evidence supporting the implementation of learner-centered pedagogies that encourage autonomy, active participation, and meaningful learning experiences. Furthermore, the strong explanatory power of the proposed model indicates that combining instructional and psychological factors may provide a more comprehensive framework for improving mathematics learning outcomes. Ultimately, the study underscores the importance of developing educational practices that simultaneously foster motivation, self-regulation, and problem-solving competencies to achieve sustainable improvements in mathematics achievement.

Limitations and Suggestions for Future Research

This study has several limitations that should be considered when interpreting its findings. First, the research employed a cross-sectional survey design, which limits the ability to establish causal relationships among Self-Regulated Learning, Problem-Based Learning, learning motivation, and mathematics achievement over time. Second, the data were collected from a specific group of secondary school students, which may restrict the generalizability of the findings to other educational levels, geographical regions, or cultural contexts. Third, the psychological constructs were measured using self-report questionnaires, making the responses susceptible to social desirability bias and individual perception differences. Fourth, although the proposed model explained a substantial proportion of variance in mathematics achievement, approximately 30.3% of the variance remained unexplained, indicating the presence of additional influential factors not included in the current model. Variables such as mathematics anxiety, academic self-efficacy, teacher instructional quality, parental involvement, socioeconomic status, classroom climate, and peer support may also contribute significantly to students' learning outcomes. Furthermore, the study focused exclusively on learning motivation as a mediating variable, while other psychological mechanisms may simultaneously influence the relationships among the constructs. Future research is therefore encouraged to employ longitudinal or experimental designs to provide stronger evidence regarding causal relationships. Researchers may also expand the model by incorporating additional cognitive, affective, and contextual variables to improve explanatory power. Comparative studies across different educational levels, school types, and cultural settings would provide valuable insights into the stability of the proposed relationships. The use of mixed-methods approaches combining quantitative and qualitative data may further enrich understanding of students' learning experiences and motivational processes. Finally, future studies should investigate multiple mediation and moderation models to develop a more comprehensive explanation of how instructional practices and self-regulatory behaviors influence mathematics achievement.

CONCLUSION

This study investigated the relationships among Self-Regulated Learning, Problem-Based Learning, learning motivation, and mathematics achievement within an integrated structural model. The findings demonstrated that the proposed model possessed substantial explanatory power, indicating that the selected constructs collectively contribute significantly to students' mathematics achievement. Learning motivation emerged as the strongest predictor of mathematics achievement and played a central role in explaining how learning processes influence academic outcomes. The results further revealed that both Self-Regulated Learning and Problem-Based Learning were positively associated with learning motivation, suggesting that instructional and behavioral factors jointly support students' engagement in mathematics learning. In addition, the findings confirmed

that learning motivation serves as an important mediating mechanism linking Self-Regulated Learning and Problem-Based Learning to mathematics achievement. These results indicate that improvements in mathematics achievement are not solely dependent on instructional approaches or self-regulatory abilities, but also on students' motivational responses to learning experiences. The study therefore supports the view that effective mathematics learning requires the integration of cognitive, motivational, and instructional dimensions. The strong predictive relationships identified in the model highlight the importance of fostering autonomous learning behaviors and meaningful problem-solving experiences in mathematics classrooms. Furthermore, the findings provide empirical evidence that learner-centered approaches can strengthen students' motivation and subsequently enhance academic performance. From a theoretical perspective, the study contributes to a more comprehensive understanding of the mechanisms through which learning processes affect mathematics achievement. From a practical perspective, the results emphasize the need for educational strategies that simultaneously promote self-regulation, active problem solving, and sustained learning motivation. Overall, this study demonstrates that learning motivation functions as a critical bridge connecting Self-Regulated Learning and Problem-Based Learning with mathematics achievement, thereby offering a holistic framework for improving mathematics education outcomes.

AUTHOR CONTRIBUTIONS STATEMENT

Addin Zuhrotul 'Aini conceived the study, developed the research framework, conducted data analysis, interpreted the results, and prepared the original manuscript draft. Vera Septi Andrini contributed to the research design, methodological validation, supervision of the research process, and critical revision of the manuscript. Erdyna Dwi Etika contributed to data collection, data validation, visualization, and manuscript revision. All authors discussed the results, reviewed and approved the final manuscript, and agreed to be accountable for the integrity and accuracy of the work.

REFERENCES

- Acosta-Gonzaga, E., & Ramirez-Arellano, A. (2021). The influence of motivation, emotions, cognition, and metacognition on students' learning performance: A comparative study in higher education in blended and traditional contexts. *SAGE Open*, 11(2), 21582440211027561. <https://doi.org/10.1177/21582440211027561>
- Agbi, A., & Yuangsoi, P. (2022). Enhancement of critical thinking skills in students using mobile-blended learning with a collaborative inquiry-based approach. *Humanities, Arts and Social Sciences Studies*, 9–20. <https://doi.org/10.14456/hasss.2022.2>
- Alhadabi, A., & Karpinski, A. C. (2020). Grit, self-efficacy, achievement orientation goals, and academic performance in university students. *International Journal of Adolescence and Youth*, 25(1), 519–535. <https://doi.org/10.1080/02673843.2019.1679202>
- Amerstorfer, C. M., & Frein von Münster-Kistner, C. (2021). Student perceptions of academic engagement and student-teacher relationships in problem-based learning. *Frontiers in Psychology*, 12. <https://doi.org/10.3389/fpsyg.2021.713057>
- Amland, T., Grande, G., Scherer, R., Lervåg, A., & Melby-Lervåg, M. (2025). Cognitive factors underlying mathematical skills: A systematic review and meta-analysis. *Psychological Bulletin*, 151(1), 88–129. <https://doi.org/10.1037/bul0000457>
- Balci, S., Secaur, J. M., & Morris, B. J. (2022). Comparing the effectiveness of badges and leaderboards on academic performance and motivation of students in fully versus partially gamified online physics classes. *Education and Information Technologies*, 27(6), 8669–8704. <https://doi.org/10.1007/s10639-022-10983-z>

- Barroso, C., Ganley, C. M., McGraw, A. L., Geer, E. A., Hart, S. A., & Daucourt, M. C. (2021). A meta-analysis of the relation between math anxiety and math achievement. *Psychological Bulletin*, 147(2), 134–168. <https://doi.org/10.1037/bul0000307>
- Burlacu, A., Iftene, A., Busoiu, E., Cogean, D., & Covic, A. (2020). Challenging the supremacy of evidence-based medicine through artificial intelligence: The time has come for a change of paradigms. *Nephrology Dialysis Transplantation*, 35(2), 191–194. <https://doi.org/10.1093/ndt/gfz203>
- Chen, C., Bian, F., & Zhu, Y. (2023). The relationship between social support and academic engagement among university students: The chain mediating effects of life satisfaction and academic motivation. *BMC Public Health*, 23(1), 2368. <https://doi.org/10.1186/s12889-023-17301-3>
- Chen, C., Sonnert, G., Sadler, P. M., Sasselov, D., & Fredericks, C. (2020). The impact of student misconceptions on student persistence in a MOOC. *Journal of Research in Science Teaching*, 57(6), 879–910. <https://doi.org/10.1002/tea.21616>
- Chen, R. H. (2021). Fostering students' workplace communicative competence and collaborative mindset through an inquiry-based learning design. *Education Sciences*, 11(1). <https://doi.org/10.3390/educsci11010017>
- Chou, C.-Y., & Zou, N.-B. (2020). An analysis of internal and external feedback in self-regulated learning activities mediated by self-regulated learning tools and open learner models. *International Journal of Educational Technology in Higher Education*, 17(1), 55. <https://doi.org/10.1186/s41239-020-00233-y>
- Daucourt, M. C., Napoli, A. R., Quinn, J. M., Wood, S. G., & Hart, S. A. (2021). The home math environment and math achievement: A meta-analysis. *Psychological Bulletin*, 147(6), 565–596. <https://doi.org/10.1037/bul0000330>
- de Ruig, N. J., de Jong, P. F., & Zee, M. (2023). Stimulating elementary school students' self-regulated learning through high-quality interactions and relationships: A narrative review. *Educational Psychology Review*, 35(3), 71. <https://doi.org/10.1007/s10648-023-09795-5>
- E., S., & Benjamin, A. E. W. (2024). Studying the student's perceptions of engagement and problem-solving skills for academic achievement in chemistry at the higher secondary level. *Education and Information Technologies*, 29(7), 8347–8368. <https://doi.org/10.1007/s10639-023-12165-x>
- Fan, Y., Tang, L., Le, H., Shen, K., Tan, S., Zhao, Y., Shen, Y., Li, X., & Gašević, D. (2025). Beware of metacognitive laziness: Effects of generative artificial intelligence on learning motivation, processes, and performance. *British Journal of Educational Technology*, 56(2), 489–530. <https://doi.org/10.1111/bjet.13544>
- Ferrer, J., Ringer, A., Saville, K., A Parris, M., & Kashi, K. (2022). Students' motivation and engagement in higher education: The importance of attitude to online learning. *Higher Education*, 83(2), 317–338. <https://doi.org/10.1007/s10734-020-00657-5>
- Fong, C. J., Altan, S., Gonzales, C., Kirmizi, M., Adelugba, S. F., & Kim, Y. (2024). Stay motivated and carry on: A meta-analytic investigation of motivational regulation strategies and academic achievement, motivation, and self-regulation correlates. *Journal of Educational Psychology*, 116(6), 997–1018. <https://doi.org/10.1037/edu0000886>
- Gebremeskel, A. A., Ayele, M. A., & Wondimuneh, T. E. (2025). Student engagement, conceptual-understanding, and problem-solving ability in learning plane geometry through an integrated instructional approach. *Eurasia Journal of Mathematics, Science and Technology Education*, 21(5), em2634. <https://doi.org/10.29333/ejmste/16391>
- Gillies, R. M. (2023). Using cooperative learning to enhance students' learning and engagement during inquiry-based science. *Education Sciences*, 13(12). <https://doi.org/10.3390/educsci13121242>
- Greenberg, A., Olvet, D. M., Brenner, J., Zheng, B., Chess, A., Schlegel, E. F. M., & Ginzburg, S. B. (2023). Strategies to support self-regulated learning in integrated, student-centered curricula. *Medical Teacher*, 45(12), 1387–1394. <https://doi.org/10.1080/0142159X.2023.2218538>
- He, A., Yuan, W., Lee, L. S., & Tian, T. (2025). AI-driven predictive models for optimizing mathematics education technology: Enhancing decision-making through educational data mining and meta-

- analysis. *Smart Learning Environments*, 12(1), 64. <https://doi.org/10.1186/s40561-025-00415-z>
- Henseler, J., Ringle, C. M., & Sarstedt, M. (2015). A new criterion for assessing discriminant validity in variance-based structural equation modeling. *Journal of the Academy of Marketing Science*, 43(1), 115–135. <https://doi.org/10.1007/s11747-014-0403-8>
- Hidayatullah, A., & Csíkos, C. (2024). The role of students' beliefs, parents' educational level, and the mediating role of attitude and motivation in students' mathematics achievement. *The Asia-Pacific Education Researcher*, 33(2), 253–262. <https://doi.org/10.1007/s40299-023-00724-2>
- Hossain, K. I. (2024). Literature-based language learning: Challenges, and opportunities for English learners. *Ampersand*, 13, 100201. <https://doi.org/10.1016/j.amper.2024.100201>
- Hsbollah, H. M., & Hassan, H. (2022). Creating meaningful learning experiences with active, fun, and technology elements in the problem-based learning approach and its implications. *Malaysian Journal of Learning and Instruction*, 19(1), 147–181. <https://doi.org/10.32890/mjli2022.19.1.6>
- Jeno, L. M., Nylehn, J., Hole, T. N., Raaheim, A., Velle, G., & Vandvik, V. (2023). Motivational determinants of students' academic functioning: The role of autonomy-support, autonomous motivation, and perceived competence. *Scandinavian Journal of Educational Research*, 67(2), 194–211. <https://doi.org/10.1080/00313831.2021.1990125>
- Jonsson, B., Granberg, C., & Lithner, J. (2020). Gaining mathematical understanding: The effects of creative mathematical reasoning and cognitive proficiency. *Frontiers in Psychology*, 11. <https://doi.org/10.3389/fpsyg.2020.574366>
- Kim, Y., Brady, A. C., & Wolters, C. A. (2020). College students' regulation of cognition, motivation, behavior, and context: Distinct or overlapping processes? *Learning and Individual Differences*, 80, 101872. <https://doi.org/10.1016/j.lindif.2020.101872>
- King, N., & Bunce, L. (2020). Academics' perceptions of students' motivation for learning and their own motivation for teaching in a marketized higher education context. *British Journal of Educational Psychology*, 90(3), 790–808. <https://doi.org/10.1111/bjep.12332>
- Kohen, Z., & Orenstein, D. (2021). Mathematical modeling of tech-related real-world problems for secondary school-level mathematics. *Educational Studies in Mathematics*, 107(1), 71–91. <https://doi.org/10.1007/s10649-020-10020-1>
- Korpershoek, H., Canrinus, E. T., Fokkens-Bruinsma, M., & de Boer, H. (2020). The relationships between school belonging and students' motivational, social-emotional, behavioural, and academic outcomes in secondary education: A meta-analytic review. *Research Papers in Education*, 35(6), 641–680. <https://doi.org/10.1080/02671522.2019.1615116>
- Lee, D., & Yoon, S. N. (2021). Application of artificial intelligence-based technologies in the healthcare industry: Opportunities and challenges. *International Journal of Environmental Research and Public Health*, 18(1). <https://doi.org/10.3390/ijerph18010271>
- Letterie, G. (2021). Three ways of knowing: The integration of clinical expertise, evidence-based medicine, and artificial intelligence in assisted reproductive technologies. *Journal of Assisted Reproduction and Genetics*, 38(7), 1617–1625. <https://doi.org/10.1007/s10815-021-02159-4>
- Li, L., Hew, K. F., & Du, J. (2024). Gamification enhances student intrinsic motivation, perceptions of autonomy and relatedness, but minimal impact on competency: A meta-analysis and systematic review. *Educational Technology Research and Development*, 72(2), 765–796. <https://doi.org/10.1007/s11423-023-10337-7>
- Liu, Y., Ma, S., & Chen, Y. (2024). The impacts of learning motivation, emotional engagement and psychological capital on academic performance in a blended learning university course. *Frontiers in Psychology*, 15. <https://doi.org/10.3389/fpsyg.2024.1357936>
- Lo, K. W. K., Ngai, G., Chan, S. C. F., & Kwan, K. (2022). How students' motivation and learning experience affect their service-learning outcomes: A structural equation modeling analysis. *Frontiers in Psychology*, 13. <https://doi.org/10.3389/fpsyg.2022.825902>
- Manfreda Kolar, V., & Hodnik, T. (2021). Mathematical literacy from the perspective of solving contextual problems. *European Journal of Educational Research*, 10(1), 467–483. <https://doi.org/10.12973/eu-jer.10.1.467>
- Marini, A., Muawanah, U., & Marfu, A. (2026). Enhancing critical thinking through problem-based learning: The role of student engagement and technology for education sustainability in Indonesia. *Sustainable Futures*, 11, 101846. <https://doi.org/10.1016/j.sftr.2026.101846>

- Mejias, P. P., McAllister, D. E., Diaz, K. G., & Ravest, J. (2021). A longitudinal study of the gender gap in mathematics achievement: Evidence from Chile. *Educational Studies in Mathematics*, 107(3), 583–605. <https://doi.org/10.1007/s10649-021-10052-1>
- van der Merwe, R. L., Groenewald, M. E., Venter, C., Scrimnger-Christian, C., & Bolofo, M. (2020). Relating student perceptions of readiness to student success: A case study of a mathematics module. *Heliyon*, 6(11). <https://doi.org/10.1016/j.heliyon.2020.e05204>
- Munatsi, R. (n.d.). Using artificial intelligence to enhance evidence informed-decision-making. *South African Journal of Information Management*, 27(1), 2004. <https://doi.org/10.4102/sajim.v27i1.2004>
- Nie, Y., Sun, B., & Xiong, F. (2024). Motivation and self-regulated learning profiles: A person-centered perspective of English learning and achievement in an Asia context. *System*, 125, 103448. <https://doi.org/10.1016/j.system.2024.103448>
- Nilimaa, J. (2023). New examination approach for real-world creativity and problem-solving skills in mathematics. *Trends in Higher Education*, 2(3), 477–495. <https://doi.org/10.3390/higheredu2030028>
- Nurjanah, R. L., Mujiyanto, J., Pratama, H., & Rukmini, D. (2022). Students' perceptions on learning independence: How self-regulated learning strategy helps? *Language Value*, 15(2), 29–53. <https://doi.org/10.6035/languagev.6930>
- Okada, R. (2023). Effects of perceived autonomy support on academic achievement and motivation among higher education students: A meta-analysis. *Japanese Psychological Research*, 65(3), 230–242. <https://doi.org/10.1111/jpr.12380>
- Raza, S. A., Qazi, W., & Yousufi, S. Q. (2020). The influence of psychological, motivational, and behavioral factors on university students' achievements: The mediating effect of academic adjustment. *Journal of Applied Research in Higher Education*, 13(3), 849–870. <https://doi.org/10.1108/JARHE-03-2020-0065>
- Rehman, N., Huang, X., Mahmood, A., AlGerafi, M. A. M., & Javed, S. (2024). Project-based learning as a catalyst for 21st-century skills and student engagement in the math classroom. *Heliyon*, 10(23). <https://doi.org/10.1016/j.heliyon.2024.e39988>
- Shimizu, Y. (2022). Relation between mathematical proof problem solving, math anxiety, self-efficacy, learning engagement, and backward reasoning. *Journal of Education and Learning*, 11(6), 62–75. <https://doi.org/10.5539/jel.v11n6p62>
- Sholihah, T. M., & Lastariwati, B. (2020). Problem based learning to increase competence of critical thinking and problem solving. *Journal of Education and Learning (EduLearn)*, 14(1), 148–154. <https://doi.org/10.11591/edulearn.v14i1.13772>
- Theobald, M. (2021). Self-regulated learning training programs enhance university students' academic performance, self-regulated learning strategies, and motivation: A meta-analysis. *Contemporary Educational Psychology*, 66, 101976. <https://doi.org/10.1016/j.cedpsych.2021.101976>
- Twohill, A., NicMhuirí, S., Harbison, L., & Karakolidis, A. (2023). Primary preservice teachers' mathematics teaching efficacy beliefs: The role played by mathematics attainment, educational level, preparedness to teach, and gender. *International Journal of Science and Mathematics Education*, 21(2), 601–622. <https://doi.org/10.1007/s10763-022-10259-5>
- Wang, M.-T., Guo, J., & Degol, J. L. (2020). The role of sociocultural factors in student achievement motivation: A cross-cultural review. *Adolescent Research Review*, 5(4), 435–450. <https://doi.org/10.1007/s40894-019-00124-y>
- Wang, X., & Liu, H. (2026). Exploring the moderating roles of emotions, attitudes, environment, and teachers in the impact of motivation on learning behaviours in students' English learning. *Psychological Reports*, 129(1), 492–518. <https://doi.org/10.1177/00332941241231714>
- Wolters, C. A., & Brady, A. C. (2021). College students' time management: A self-regulated learning perspective. *Educational Psychology Review*, 33(4), 1319–1351. <https://doi.org/10.1007/s10648-020-09519-z>
- Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications*, 10(1), 16. <https://doi.org/10.1057/s41599-023-01508-1>

- Xu, Z., Zhao, Y., Zhang, B., Liew, J., & Kogut, A. (2023). A meta-analysis of the efficacy of self-regulated learning interventions on academic achievement in online and blended environments in K-12 and higher education. *Behaviour & Information Technology*, 42(16), 2911-2931. <https://doi.org/10.1080/0144929X.2022.2151935>
- Yang, S., & Wang, W. (2022). The role of academic resilience, motivational intensity and their relationship in EFL learners' academic achievement. *Frontiers in Psychology*, 12. <https://doi.org/10.3389/fpsyg.2021.823537>
- Zepeda, C. D., Martin, R. S., & Butler, A. C. (2020). Motivational strategies to engage learners in desirable difficulties. *Journal of Applied Research in Memory and Cognition*, 9(4), 468-474. <https://doi.org/10.1016/j.jarmac.2020.08.007>
- Zhang, J.-H., Zou, L., Miao, J., Zhang, Y.-X., Hwang, G.-J., & Zhu, Y. (2020). An individualized intervention approach to improving university students' learning performance and interactive behaviors in a blended learning environment. *Interactive Learning Environments*, 28(2), 231-245. <https://doi.org/10.1080/10494820.2019.1636078>
- Zheng, B., Chang, C., Lin, C.-H., & Zhang, Y. (2021). Self-efficacy, academic motivation, and self-regulation: How do they predict academic achievement for medical students? *Medical Science Educator*, 31(1), 125-130. <https://doi.org/10.1007/s40670-020-01143-4>