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THE EFFECT OF STEM-BASED LEARNING ON PRIMARY SCHOOL STUDENTS' PROBLEM-SOLVING SKILLS: THE MEDIATING ROLE OF NUMERACY SKILLS

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ABSTRACT

Strengthening mathematical problem-solving skills is a key demand of 21st-century learning, particularly at the primary school level. This study aims to examine the effect of Science, Technology, Engineering, and Mathematics (STEM)-based learning on students' problem-solving skills, with numeracy positioned as a mediating variable. An explanatory quantitative approach with an ex post facto, posttest-only design was employed. The participants comprised 138 fifth-grade students from two public primary schools in Yogyakarta City that had implemented STEM-based instruction on the topics of area and perimeter of plane figures. Data were collected using a questionnaire measuring students' perceptions of STEM learning and a descriptive test assessing numeracy and problem-solving skills. Data analysis was conducted using Structural Equation Modelling-Partial Least Squares (SEM-PLS). The results indicate that STEM-based learning has a positive and significant effect on numeracy and problem-solving skills. Furthermore, numeracy exerts a significant influence on problem-solving skills and functions as a mediating variable that strengthens the effect of STEM learning. These findings suggest that the effectiveness of STEM learning extends beyond cross-disciplinary integration and is strongly determined by its capacity to foster numeracy as a fundamental component of mathematical thinking. This study concludes that numeracy plays a critical mediating role in optimising STEM-based learning to enhance primary school students' problem-solving skills, aligning with the national emphasis on numeracy development within the Merdeka Curriculum.

KEYWORDS: STEM-Based Learning; Numeracy; Problem-Solving Skills; Primary School Students; Mathematics Learning.

1. INTRODUCTION

Mathematics is a fundamental discipline that plays a strategic role in shaping human cognitive abilities in modern life. In the context of education, mathematics is not only positioned as a core subject but also serves as a primary vehicle for developing logical, analytical, critical, and systematic thinking skills from an early age (Arisoy & Aybek, 2021; Wang et al., 2025; Q. Wang & Abdullah, 2024; Cresswell & Speelman, 2020). Mathematics learning in primary school plays a key role in establishing a cognitive foundation that will shape the quality of students' learning at subsequent levels of education.

At the primary school level, mathematics learning should ideally no longer be oriented solely towards procedural mastery and the memorisation of algorithms, but rather directed towards developing students' ability to understand concepts, connect mathematics with real-life situations, and solve contextual problems reflectively (Kolar & Hodnik, 2021; Bevan & Capraro, 2021; Skott, 2020). This orientation becomes increasingly important in response to the demands of the 21st century, which place higher-order thinking skills (HOTS) at the centre of essential competencies that students are expected to acquire. HOTS are integrated into the 4C skills of critical thinking, creativity, communication, and collaboration, which function as indicators of individuals' readiness to confront complex and dynamic global challenges (Thornhill-Miller et al., 2023; Sukatiman et al., 2020; Haryani et al., 2021; Tanudjaya & Doorman, 2020).

In the context of mathematics learning, the demands of the 21st century necessitate a fundamental transformation in pedagogical approaches. Learning is no longer sufficient if it focuses solely on the transfer of knowledge from teacher to student, but must instead be designed to foster students' active cognitive engagement, stimulate critical thinking processes, and relate mathematical concepts to authentic problems that are closely connected to students' lives (Antao & Morales, 2025; Orón & Lizasoain, 2023; Hetmanenko, 2024; Skott, 2020). This transformation represents a crucial prerequisite for strengthening numeracy and problem-solving skills, two interrelated and inseparable competencies in modern mathematics learning.

Numeracy is one of the basic literacy dimensions that plays a central role in mathematics education. Numeracy is not merely defined as the ability to calculate, but also encompasses the capacity to understand, interpret, and apply quantitative information to make rational decisions across various

life contexts (Langrall, 2019; Karaali, 2020; Sikko, 2022; Reyna & Brainerd, 2023; Pratiwi et al., 2024). Numeracy also requires mathematical reasoning skills, the ability to link symbolic representations with real-world situations, and the capacity to critically evaluate calculation results (Pratiwi et al., 2024; Heryani et al., 2023; Sikko, 2022). Numerical literacy serves as a fundamental foundation for the development of higher-order thinking skills, particularly in mathematical problem solving. Various empirical studies indicate that the numeracy literacy skills of primary school students in Indonesia continue to face substantial challenges. A number of studies report that although students' basic arithmetic skills fall within the moderate category, many students experience difficulties in understanding context-based questions, performing mathematisation, identifying relevant information, and selecting as well as communicating appropriate problem-solving strategies (Aini et al., 2025; Susandi et al., 2025). These weaknesses are particularly evident in symbolic operations, result interpretation, and mathematical reasoning, with mastery levels ranging from moderate to low. These findings are consistent with the results of a systematic literature review demonstrating the low level of numeracy literacy among Indonesian primary school students based on international assessments such as PISA, which is influenced by pedagogical factors, students' self-confidence, and limited learning facilities (Setiawan et al., 2024). Another study further revealed that difficulties in numeracy literacy arise not only in basic arithmetic contexts but also in understanding data and statistical outputs, even when students are supported by the use of software (Santia & Handayani, 2023). These difficulties not only reflect weak mastery of mathematical concepts but also indicate students' limitations in applying mathematical knowledge flexibly and adaptively in real-life situations.

Numeracy and problem-solving skills are key competencies in mathematics education; however, the most effective learning approach for developing both simultaneously remains a subject of academic debate (Lázaro et al., 2024; Alhusna et al., 2025). Procedural mastery-based approaches through structured practice are considered capable of strengthening conceptual understanding, but they are often criticised for their limited capacity to promote reflective and contextual thinking (De Jong, 2019). Conversely, contextual and problem-based learning is regarded as more relevant to real-life applications and capable of enhancing students' cognitive engagement, although its effectiveness is

frequently questioned in terms of learning outcome consistency and teacher readiness (Sainab & Herna, 2025; Hidayana & Lianingsih, 2025; Kartimi *et al.*, 2021). In this context, STEM (Science, Technology, Engineering, and Mathematics) learning has emerged as a promising interdisciplinary approach. However, empirical findings reveal mixed results, with some studies reporting a direct effect of STEM on problem-solving skills, while others emphasise the role of intermediate competencies, such as numeracy and mathematical reasoning, as the primary mechanisms underlying improvement. This variation in findings indicates that the relationship between STEM, numeracy, and problem-solving skills has not yet been comprehensively understood, particularly at the primary school level.

Recent studies indicate that STEM-based learning has considerable potential to enhance the quality of mathematics education. De Loof *et al.* (2022), Kurbanbekov *et al.* (2025), Forde *et al.* (2023), and Roberts *et al.* (2022) found that STEM integration can increase students' cognitive engagement and strengthen their understanding of mathematical concepts through the application of real-world contexts. Roberts *et al.* (2022), Siller *et al.* (2024), Laššová and Rumanová (2023), Mater *et al.* (2020), and Hebebcí and Usta (2022) reported that STEM learning encourages students to use mathematical knowledge flexibly when solving complex problems. Research on numeracy further demonstrates that this ability functions as a strong predictor of mathematical problem-solving skills (Xiao *et al.*, 2019; Santia & Handayani, 2023; Pratiwi *et al.*, 2024; Muhaimin *et al.*, 2024). Students with well-developed numeracy literacy tend to be better able to understand problem contexts, select appropriate strategies, and reflect on the solutions obtained. However, most of these studies continue to treat numeracy literacy and problem solving as independent variables, without examining more complex causal relationships.

A number of previous studies support the assumption that STEM learning can improve numeracy and problem-solving skills. Supianti *et al.* (2025), Diana and Saputri (2021), Vistara *et al.* (2022), Kwon *et al.* (2021), and Oyewo *et al.* (2022) demonstrate that project-based STEM learning can enhance students' numeracy skills through activities that require calculation, data analysis, and decision making. Nevertheless, these studies have not examined whether improvements in numeracy directly contribute to enhanced problem-solving skills. Conversely, Tselegkaridis and Sapounidis (2022), along with several other studies, report

inconsistent findings, particularly when STEM implementation is not systematically designed or aligned with the characteristics of primary school students. This suggests that the effectiveness of STEM learning is highly dependent on instructional design and the cognitive mechanisms involved.

A review of the literature reveals several research gaps. Studies on STEM-based learning in primary schools generally examine direct effects on learning outcomes or problem-solving skills, while the internal mechanisms that mediate these effects remain underexplored. Research that explicitly positions numeracy as a mediating variable in the relationship between STEM learning and problem-solving skills is still limited. Moreover, most empirical evidence originates from secondary and higher education contexts, meaning that its generalisability to primary school settings, which involve distinct cognitive developmental characteristics, requires further investigation. Studies that integrate the local Indonesian context, particularly in urban areas, are relatively scarce, even though social factors and educational policies play an important role in the implementation of STEM learning. Therefore, research is needed that not only examines the relationship between STEM-based learning and problem-solving skills but also elucidates the role of numeracy as a mediating mechanism within the primary school context.

Based on the theoretical foundation and previous empirical findings, this study proposes the hypothesis that STEM-based learning has a positive effect on the problem-solving skills of primary school students. This effect occurs not only directly but is also mediated by numeracy, which functions as an important cognitive mechanism in linking the implementation of STEM learning to improvements in students' problem-solving abilities. Accordingly, this study aims to analyse the effect of STEM-based learning on primary school students' problem-solving skills by positioning numeracy as a mediating variable. Specifically, this study seeks to: (1) examine the direct effect of STEM learning on numeracy; (2) examine the effect of numeracy on problem-solving skills; and (3) examine the mediating role of numeracy in the relationship between STEM learning and problem-solving skills.

Through testing these structural relationships, this study is expected to clarify the underlying mechanisms of STEM learning in the context of primary school mathematics education, while also providing practical implications for the development of contextual learning oriented towards strengthening students' numeracy and problem-

solving skills.

2. METHODOLOGY

2.1. Research Design

This study utilised a quantitative approach with an explanatory ex post facto design employing a posttest-only framework. This design was chosen because the study aimed to model structural relationships among variables based on learning conditions that had occurred naturally in primary schools, without variable manipulation or the establishment of control groups. STEM-based learning was positioned as the learning condition for Grade V mathematics on the topic of area and perimeter of flat shapes, implemented through teaching modules and lesson plans based on the integration of Science, Technology, Engineering, and Mathematics (STEM) within the framework of Problem-Based Learning. Therefore, this study did not emphasise experimental causal relationships, but rather focused on structural causal relationships examined both theoretically and empirically. Data analysis was conducted using Structural Equation Modelling-Partial Least Squares (SEM-PLS) to test the direct and indirect effects among variables simultaneously. This approach was deemed appropriate given the characteristics of the non-experimental design and the study's objective of testing a mediation model.

2.2. Research Subjects and Context

This study was carried out in two public primary schools located in the Danurejan Cluster of Yogyakarta City, consisting of SD Negeri Lempuyangan 1 and SD Negeri Lempuyangwangi. The research sites were purposively selected based on the implementation of the Merdeka Curriculum, institutional readiness for STEM-based learning, and the relative homogeneity of student characteristics. The research population included all fifth-grade students in the Danurejan Cluster. The sample was determined purposively at the school and class levels, involving all students from five selected fifth-grade classes using the intact group approach. The number of respondents, a total of 138 students, was considered adequate for SEM-PLS analysis and met the recommended sample size criteria for structural modelling. In addition to the main sample, this study involved students from other schools for the purpose of instrument pilot testing and validation prior to the main data collection.

2.3. Research Variables and Operational Definitions

This study examined three main variables within a structural model, with STEM-based learning serving as the exogenous variable, numeracy as the mediating variable, and problem-solving skills as the endogenous variable. STEM-based learning is defined as a pedagogical approach that integrates science, technology, engineering, and mathematics into contextual learning activities oriented towards problem solving. This variable was measured based on students' perceptions and learning experiences regarding the implementation of STEM-based mathematics learning. Numeracy was positioned as a mediating variable that reflects students' ability to use and interpret quantitative information, process various numerical representations, and draw logical conclusions in the context of real-life quantitative situations. Problem-solving skills, as an endogenous variable, refer to students' systematic thinking abilities, which include understanding problems, planning strategies, implementing solutions, and evaluating results.

2.4. Data Collection Techniques and Instruments

Data collection was conducted using questionnaires and essay tests. Questionnaires were used to measure students' perceptions of the application of STEM-based mathematics learning, while essay tests were used to assess numeracy and problem-solving skills. The STEM questionnaire was developed based on indicators representing the four STEM dimensions and was presented on a Likert scale adapted to the cognitive characteristics of primary school students. The numeracy and problem-solving tests were designed in the form of contextual essay questions that emphasised the mathematical reasoning process rather than solely the final answer. All instruments were developed based on a specification grid that systematically mapped theoretical indicators to test items, thereby ensuring alignment between the constructs measured and the instruments employed.

2.5. Instrument Validity and Reliability

The quality of the instruments was ensured through validity and reliability testing. Content validity was examined through expert judgement involving experts in basic education and mathematics education. The level of agreement among experts was analysed using Aiken's V coefficient, which indicated that all instrument items fell within the valid to highly valid categories. Construct validity was further assessed using Confirmatory Factor Analysis (CFA) within the SEM-

PLS framework. Convergent validity was evaluated through outer loading values and Average Variance Extracted (AVE), and all indicators met the criteria recommended in structural modelling analysis. Instrument reliability was tested using Cronbach's Alpha and Composite Reliability. All constructs demonstrated reliability values above the minimum required thresholds; therefore, the instruments were considered to have good internal consistency and were suitable for subsequent analysis.

3. DATA ANALYSIS TECHNIQUES

Data analysis was performed using path analysis based on Structural Equation Modelling-Partial Least Squares (SEM-PLS). This approach was selected because it is appropriate for testing direct and indirect relationships among variables in the research model, while also being adaptable to ordinal-scale data and moderate sample sizes. The analysis procedure comprised two main stages, namely evaluation of the measurement model to ensure construct validity and reliability, and

evaluation of the structural model to test the direction, strength, and significance of relationships among variables. Testing the role of numeracy as a mediating variable was conducted through indirect effect analysis using the bootstrapping technique. All data analyses were performed using the 4.0 version of SmartPLS software.

3.1. Results

3.1.1. Respondent Characteristics and Data Validity

This study involved 138 fifth-grade students from two public primary schools in the Danurejan Cluster, Yogyakarta City, consisting of SD Negeri Lempuyangwangi and SD Negeri Lempuyangan 1, distributed across five parallel classes. The distribution of respondents based on school, class, and gender is presented in Table 1 and shows a relatively balanced composition, thereby adequately representing the characteristics of the student population.

Table 1: Distribution of Respondents Based on School and Grade.

School	Class	Male	Female	Total
SD Negeri Lempuyangwangi	VA	16	12	28
SD Negeri Lempuyangwangi	VB	15	13	28
SD Negeri Lempuyangwangi	VC	15	13	28
SD Negeri Lempuyangan 1	VA	10	16	21
SD Negeri Lempuyangan 1	VB	15	13	26
Total		71	67	138

All respondents participated in the data collection process, which included completing a STEM-based learning questionnaire and taking numeracy and mathematical problem-solving tests. Data completeness screening revealed two missing data points in the numeracy indicators, resulting in 136 respondents meeting the eligibility criteria and being included in further analysis. This sample size was deemed sufficient for structural model analysis and mediation effect testing within the SEM-PLS framework.

3.2. Descriptive Statistics of STEM-Based Learning

STEM-based learning in this study was measured using a three-point scale questionnaire representing students' levels of engagement across four main dimensions, namely Science, Technology, Engineering, and Mathematics. Descriptive statistics were employed to describe trends in the

implementation of the STEM approach in mathematics learning as experienced by students.

Table 2: Descriptive Statistics of STEM-Based Learning.

Indicator	Mean	Std. Deviation	Minimum	Maximum
S1	2.29	0.653	1	3
S2	1.88	0.541	1	3
S3	2.09	0.466	1	3
T1	2.13	0.827	1	3
T2	2.68	0.498	1	3
T3	2.22	0.808	1	3
E1	2.03	0.782	1	3
E2	1.91	0.763	1	3
E3	1.90	0.643	1	3
M1	2.41	0.493	2	3
M2	2.43	0.525	1	3
M3	2.43	0.661	1	3

Based on the analysis results presented in Table 2, the mean values of the STEM-based learning indicators ranged from 1.88 to 2.68, indicating that the implementation of the STEM approach was

generally at a moderate to high level. The Technology and Mathematics dimensions obtained relatively higher mean scores than the Science and Engineering dimensions, indicating the dominance of technology utilisation and the application of mathematical concepts and procedures in classroom practices. The standard deviation values, which fall within the moderate range, indicate that there is variation in student engagement across STEM dimensions, although this variation remains within acceptable limits for the context of primary school learning.

3.3. Descriptive Statistics of Numeracy Skills

Students' numeracy skills were measured using an essay test with a scoring scale of 0 to 3, which represents mastery of mathematical concepts, procedures, and reasoning in the context of real-life quantitative situations. Descriptive statistics of students' numeracy skills are presented in Table 3.

Table 3: Descriptive Statistics of Numeracy Skills.

Indicator	Mean	Standard Deviation	Minimum	Maximum
N1	2.31	0.626	1	3
N2	2.00	0.639	0	3
N3	2.09	0.693	0	3
N4	2.15	0.801	0	3
N6	2.31	0.702	0	3

The analysis results show that the average numeracy scores ranged from 2.00 to 2.31, indicating that students' numeracy abilities were in the moderate to high category. However, the minimum score of 0 observed in several indicators indicates that some students still experienced difficulties in interpreting quantitative information or applying numeracy strategies appropriately. This variation in numeracy achievement among students supports the relevance of numeracy as a mediating variable in examining the relationship between STEM-based learning and mathematical problem-solving skills.

3.4. Descriptive Statistics of Problem-Solving Skills

Problem-solving skills were measured based on Polya's four stages of problem solving, including understanding the problem, planning a strategy, implementing the solution, and evaluating the results. The descriptive statistics for these skills are presented in Table 4.

Table 4: Descriptive Statistics of Mathematical Problem-Solving Ability.

Indicator	Mean	SD	Min	Max
PS1	2.12	0.695	1	3

PS2	2.39	0.677	1	3
PS3	2.08	0.513	1	3
PS4	2.48	0.543	1	3

The results indicate that the mean scores for problem-solving skills ranged from 2.08 to 2.48, suggesting that students' performance was within the moderate to high category. The highest mean scores were observed in indicators PS2 and PS4, indicating that students were relatively more proficient in executing solution procedures and obtaining final results than in the planning and reflection stages.

Overall, the descriptive statistical findings indicate that STEM-based learning, numeracy skills, and problem-solving skills were generally at a moderate to high level, although individual differences in achievement remain evident. The predominance of the Technology and Mathematics dimensions in STEM implementation aligns with students' numeracy and mathematical problem-solving outcomes, suggesting a functional relationship among the variables examined. These descriptive findings provide an adequate empirical foundation for subsequent structural model analysis, particularly for testing the effect of STEM-based learning on mathematical problem-solving skills and the mediating role of numeracy in accordance with the proposed research hypothesis.

3.5. Measurement Model Test Results (Outer Model)

Measurement model testing was conducted to ensure that the research indicators were able to validly and reliably represent the latent constructs of STEM-based learning, numeracy, and mathematical problem-solving abilities. The outer model evaluation included testing convergent validity, construct reliability, and discriminant validity using the Partial Least Squares-Structural Equation Modelling (PLS-SEM) approach.

3.5.1. Convergent Validity

Convergent validity was evaluated based on the outer loading values of the indicators and Average Variance Extracted (AVE), with criteria of outer loading ≥ 0.70 and AVE ≥ 0.50 . The test results (Table 5) show that most indicators have outer loading values above 0.70, with the majority even in the range of >0.80 , indicating a strong contribution of the indicators in reflecting the latent construct.

Table 5: Outer Loading Values of Measurement Model Indicators.

Item	Numeracy	Problem Solving	STEM
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E1			0.861
E2			0.859
E3			0.911
M1			0.897
M2			0.819
M3			0.883
N1	0.907		
N2	0.700		
N3	0.670		
N4	0.889		
N6	0.884		
PS1		0.856	
PS2		0.972	
PS3		0.970	
PS4		0.871	
S2			0.931
S3			0.794
T1			0.849
T2			0.880
T3			0.915
S1			0.906

Within the STEM-based learning construct, all indicators representing the Science, Technology, Engineering, and Mathematics dimensions demonstrated high and consistent outer loading values ranging from 0.794 to 0.931, confirming that STEM was empirically represented as an integrated construct. In the numeracy construct, indicators N1, N4, and N6 exhibited excellent outer loading values, while indicator N2 reached the minimum acceptable

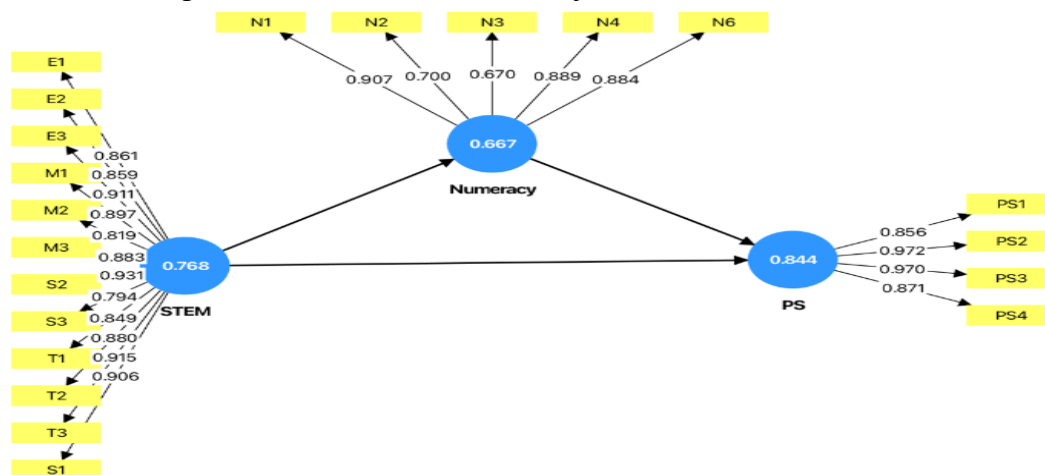
threshold. Conversely, indicator N3 demonstrated an outer loading value below the recommended criterion and was therefore excluded from the model. Consequently, numeracy was subsequently measured using four valid indicators. Meanwhile, all indicators of mathematical problem-solving skills (PS1-PS4) demonstrated very high outer loading values ranging from 0.856 to 0.972, indicating a strong representation of the construct. The convergent validity of the constructs is confirmed by the Average Variance Extracted (AVE) values presented in table 6.

Table 6: Construct-Level Convergent Validity (AVE Values).

Construct	AVE	Description
STEM	0.768	Valid
Numeracy	0.667	Valid
Problem Solving	0.844	Valid

All constructs demonstrated AVE values exceeding 0.50 (STEM = 0.768; numeracy = 0.667; problem solving = 0.844), indicating that each construct explains an adequate proportion of variance in its indicators. After refinement of the measurement model, convergent validity at both the indicator and construct levels was satisfactorily achieved. The final measurement model structure is presented in Figure 2.

Figure 2: Measurement Model Analysis Results (Outer Model).



Source: Data processed using SmartPLS 4.0

3.6. Construct Reliability

Construct reliability was assessed to evaluate the internal consistency of indicators in measuring latent constructs. Reliability testing was conducted using Cronbach’s Alpha and Composite Reliability (CR), with values of 0.70 or higher considered acceptable.

Table 7: Construct Reliability Values.

Construct	Cronbach’s Alpha	CR (pa)	CR (pc)
Numeracy	0.874	0.912	0.908
Problem Solving	0.937	0.942	0.956
STEM	0.972	0.974	0.975

The results presented in Table 7 show that all constructs achieved Cronbach’s Alpha and

Composite Reliability values exceeding the minimum threshold. Numeracy, mathematical problem-solving skills, and STEM-based learning each demonstrated a very high level of internal consistency, indicating that all constructs are reliable and suitable for inclusion in structural model analysis.

3.6.1. Discriminant Validity

Discriminant validity was assessed to ensure that each construct represented empirically distinct concepts. This evaluation was conducted using the Heterotrait-Monotrait Ratio (HTMT) criterion, with values below 0.90 considered acceptable.

Table 8: HTMT Values Between Constructs.

Construct	STEM	Numeracy	Problem Solving
Numeracy	-	-	-
Problem Solving	0.809	-	-
STEM	0.780	0.879	-

The HTMT results presented in Table 8 indicate that all inter-construct values fall below the recommended threshold. These findings confirm that although STEM-based learning, numeracy, and problem-solving skills are conceptually related, each construct remains empirically distinct and free from measurement overlap.

Overall, the measurement model evaluation demonstrates that all constructs satisfy the criteria for convergent validity, reliability, and discriminant validity. The indicators exhibit strong contributions in representing their respective latent constructs, as reflected in the high AVE, Cronbach's Alpha, and Composite Reliability values. With all outer model requirements fulfilled, subsequent analysis can proceed to testing the structural model to evaluate the direct and indirect relationships among variables as specified in the research hypotheses.

3.7. Structural Model Test Results (Inner Model)

After the measurement model was confirmed to be valid and reliable, the analysis proceeded to the evaluation of the structural model (inner model) to examine the predictive accuracy and the direction and strength of relationships among the latent constructs, namely STEM-based learning, numeracy, and problem-solving skills. The evaluation of the inner model was conducted through the assessment of the coefficient of determination (R^2), effect size (f^2), and path coefficients. Statistical significance was tested using a bootstrapping procedure with 5,000 subsamples.

3.7.1. Coefficient of Determination (R^2)

The coefficient of determination (R^2) represents the proportion of variance in an endogenous construct that can be explained by its predictor variables. Following established criteria, R^2 values of 0.25, 0.50, and 0.75 indicate weak, moderate, and strong explanatory power, respectively.

Table 9: Coefficient of Determination (R^2) Values.

Endogenous Variable	R^2	Adjusted R^2
Numeracy	0.758	0.756
Problem Solving	0.849	0.847

The results presented in Table 9 show that the R^2 value for numeracy is 0.758, indicating that STEM-based learning explains 75.8% of the variance in students' numeracy skills. This value falls within the strong category, highlighting the substantial role of STEM-based learning as a predictor of numeracy development at the primary school level. Meanwhile, the R^2 value for problem-solving skills is 0.849, indicating that the combined influence of STEM-based learning and numeracy explains 84.9% of the variance in students' problem-solving performance. This high value reflects the excellent predictive capability of the proposed structural model.

The minimal differences between the R^2 and adjusted R^2 values for both endogenous constructs further indicate model stability and suggest the absence of overfitting. Overall, these findings confirm that the structural model demonstrates strong explanatory power and is empirically robust in explaining the mechanism through which STEM-based learning influences problem-solving skills through numeracy.

3.7.2. Effect Size (f^2)

In addition to overall predictive power, the inner model was evaluated using effect size (f^2) analysis to determine the relative contribution of each exogenous construct to the endogenous variables. According to established benchmarks, f^2 values of 0.02, 0.15, and 0.35 indicate small, medium, and large effects, respectively.

Table 10: Effect Size Values (f^2).

Influence Path	f^2	Category
STEM → Numeracy	3.13	Large
Numeracy → Problem Solving	0.927	Large
STEM → Problem Solving	0.052	Small

Source: Data processed using Smart PLS 4.0

As shown in Table 10, the effect of STEM-based learning on numeracy literacy yields an exceptionally large f^2 value (3.13), indicating that STEM-based learning provides a dominant substantive contribution to students' numeracy

development. Similarly, the effect of numeracy on problem-solving skills is also categorised as large ($f^2 = 0.927$), confirming numeracy as a critical determinant of students' success in solving mathematical problems.

In contrast, the direct effect of STEM-based learning on problem-solving skills shows a small effect size ($f^2 = 0.052$). This result suggests that, although STEM-based learning contributes strongly to numeracy, its direct contribution to problem-solving skills is relatively limited when numeracy is included in the model. These findings provide early empirical support for the mediating role of numeracy in the relationship between STEM-based learning and problem-solving ability.

3.7.3. Path Coefficients

Path coefficient analysis was conducted to assess the direction, magnitude, and statistical significance of the direct relationships among constructs. A relationship was considered significant if the t-statistic was ≥ 1.96 and the p-value was ≤ 0.05 .

Table 11. Path Coefficients of the Structural Model.

Path Influence	Original Sample (O)	T-statistics	P-values	Description
Numeracy → Problem Solving	0.760	6.265	0.000	Significant
STEM → Numeracy	0.871	29.986	0.000	Significant
STEM → Problem Solving	0.180	1.414	0.158	Not significant

The results in Table 11 indicate that STEM-based learning has a positive and statistically significant effect on numeracy literacy ($\beta = 0.871$; $t = 29.986$; $p < 0.001$). This finding demonstrates that high-quality implementation of STEM learning strongly enhances students' numeracy skills. Furthermore, numeracy literacy shows a positive and significant effect on mathematical problem-solving skills ($\beta = 0.760$; $t = 6.265$; $p < 0.001$), confirming that numeracy serves as a crucial prerequisite for effective mathematical problem solving.

However, the direct effect of STEM-based learning on problem-solving skills is not statistically significant ($\beta = 0.180$; $t = 1.414$; $p = 0.158$). This result indicates that STEM-based learning does not directly improve students' problem-solving abilities in the absence of enhanced numeracy skills.

Taken together, the path coefficient results suggest that the influence of STEM-based learning on problem-solving skills operates primarily through numeracy rather than through a direct pathway. This pattern further strengthens the theoretical and

empirical rationale for testing numeracy as a mediating variable.

3.8. Numeracy Skills Mediation Test

A mediation analysis was conducted to examine the role of numeracy as an intervening variable in the relationship between STEM-based learning and students' problem-solving skills. The analysis employed SEM-PLS with a bootstrapping procedure of 5,000 subsamples to obtain stable estimates of direct, indirect, and total effects.

3.8.1. Indirect Effect

The bootstrapping results indicate that STEM-based learning has a positive and statistically significant indirect effect on problem-solving skills through numeracy ($\beta = 0.662$; $t = 7.019$; $p < 0.001$), as presented in Table 6. This finding confirms that numeracy functions as a key cognitive mechanism through which STEM-based learning enhances students' problem-solving abilities.

Table 6: Results of the Indirect Effect Test.

Mediation Path	Coefficient (O)	t-statistics	p-values	Description
STEM → Numeracy → Problem Solving	0.662	7.019	0.000	Significant

Source: Data processed using SmartPLS 4.0

3.8.2. Total Effect

The total effect analysis (Table 7) shows that numeracy has a strong and significant total effect on problem-solving skills ($\beta = 0.760$; $p < 0.001$). In addition, STEM-based learning also shows a very large total effect on problem-solving skills ($\beta = 0.842$; $p < 0.001$), reflecting the accumulation of direct effects and indirect effects through numeracy. This indicates that the effectiveness of STEM learning in improving problem-solving skills is highly dependent on strengthening students' numeracy skills.

Table 7: Results of Total Influence Analysis.

Influence Path	Coefficient (O)	t-statistics	p-values	Description
Numeracy → Problem Solving	0.760	6.265	0.000	Significant
STEM → Numeracy	0.871	29,986	0.000	Significant
STEM → Problem Solving	0.180	1.414	0.0158	Not Significant

Source: Data processed using SmartPLS 4.0.

Based on the comparison of direct, indirect, and total effects, the results clearly indicate that

numeracy fully mediates the relationship between STEM-based learning and problem-solving skills. Conceptually, these findings confirm that STEM-based learning enhances students' problem-solving abilities primarily by strengthening numeracy as a foundational cognitive competence, rather than by directly influencing problem-solving performance. This mediation mechanism reinforces the central role of numeracy in STEM-oriented mathematics instruction and supports the conceptual coherence and statistical validity of the proposed structural model.

3.9. Research Hypothesis Testing

Hypothesis testing was conducted based on the results of the structural model evaluation, including path coefficients, significance levels, coefficients of determination (R^2), effect sizes (f^2), and indirect effect analysis. The summary of hypothesis testing results presented in Table 8 provides an integrated overview of the direction, magnitude, and statistical significance of the relationships among the research variables.

Table 8: Summary of Hypothesis Testing Results.

Hypothesis	Path Effect	Path Coefficient (O)	t-statistics	p-values	Supporting Indicators	Decision
H1	STEM → Numeracy	0.871	29.986	0.000	R^2 Numeracy = 0.758 (strong)	Accepted
H2	Numeracy → Problem Solving	0.760	6.265	0.000	$f^2 = 0.927$ (large)	Accepted
H3	STEM → Problem Solving	0.180	1.414	0.158	$f^2 = 0.052$ (small)	Rejected
H4	STEM → Numeracy → Problem Solving	0.662	7.019	0.000	Full mediation; total effect = 0.842	Accepted

Based on Table 8, Hypothesis 1 (H1) is accepted, indicating that STEM-based learning has a positive and statistically significant effect on primary school students' numeracy ($\beta = 0.871$; $p < 0.001$). The high coefficient of determination ($R^2 = 0.758$) further confirms the strong predictive power of STEM-based learning in explaining variations in students' numeracy skills. This finding highlights the effectiveness of STEM-oriented instruction in fostering students' understanding and application of numerical concepts.

Hypothesis 2 (H2) is also accepted, demonstrating that numeracy has a significant and substantial effect on students' problem-solving skills ($\beta = 0.760$; $p < 0.001$). The large effect size ($f^2 = 0.927$) indicates that numeracy plays a dominant role in determining students' ability to solve mathematical problems, reinforcing its position as a core cognitive competence in mathematics learning at the primary school level.

In contrast, Hypothesis 3 (H3) is rejected, as the direct effect of STEM-based learning on problem-solving skills is not statistically significant ($\beta = 0.180$; $p = 0.158$), and its effect size is categorised as small ($f^2 = 0.052$). This result suggests that the implementation of STEM-based learning alone does not directly translate into improved mathematical problem-solving performance when numeracy is accounted for in the model.

Hypothesis 4 (H4) is accepted, indicating that numeracy literacy significantly mediates the relationship between STEM-based learning and problem-solving skills. The indirect effect of STEM-based learning on problem-solving through numeracy is positive and significant ($\beta = 0.662$; $p < 0.001$), and the total effect of STEM-based learning on problem-solving skills remains substantial ($\beta = 0.842$). Importantly, because the direct effect of STEM-based learning on problem-solving skills is non-significant while the indirect effect is significant, this mediation pattern indicates full mediation.

Overall, the hypothesis testing results confirm that STEM-based learning influences students' problem-solving abilities primarily through the enhancement of numeracy literacy. Numeracy functions as the central cognitive mechanism that transmits the effect of STEM learning to problem-solving outcomes. These findings strengthen the theoretical model by demonstrating that improvements in problem-solving skills derived from STEM instruction are largely dependent on the extent to which such instruction successfully develops students' numeracy competencies.

4. DISCUSSION

This study examined the effect of STEM-based learning on primary school students' problem-solving skills with numeracy as a mediating variable.

The results of the SEM-PLS analysis showed that the pattern of relationships between variables was generally in line with the conceptual framework and hypotheses proposed, although not all effects were direct. The main findings confirm that STEM-based learning has a positive and significant effect on numeracy, while numeracy has a strong direct effect on mathematical problem-solving skills. Conversely, the direct effect of STEM on problem-solving skills is not significant. However, the indirect effect of STEM through numeracy is proven to be significant, which places numeracy as a full mediator in the structural model. The high coefficient of determination values for numeracy ($R^2 = 0.758$) and problem-solving skills ($R^2 = 0.849$) indicate that the model has excellent explanatory power. Conceptually, these findings confirm that the effectiveness of STEM-based learning in improving problem-solving skills does not occur instantly, but rather works through strengthening students' fundamental cognitive abilities, particularly numeracy.

The significant impact of STEM-based learning on numeracy can be understood through the pedagogical characteristics of STEM, which emphasise cross-disciplinary integration, contextual problem solving, and active student engagement. STEM not only functions as an integrative approach, but also as a learning environment that encourages the use of numbers as tools for thinking, analysis, and decision-making (Ilyas *et al.*, 2022; Berisha & Vula, 2021; Tashtoush *et al.*, 2024; Changtong *et al.*, 2020). Typical STEM activities, such as simple data analysis, estimation, use of visual representations, and evaluation of solutions, provide authentic and meaningful numerical experiences (Lasa *et al.*, 2020; Laššová & Rumanová, 2023; Ishikawa & Newcombe, 2021). Numeracy skills develops optimally when students are faced with demands for quantitative meaning-making, data interpretation, and evidence-based reasoning (Gal & Geiger, 2022; Pratiwi *et al.*, 2024; Reyna & Brainerd, 2023; Reder *et al.*, 2020; Bolstad, 2021). These findings are consistent with previous research showing that STEM learning, especially when combined with problem-based and inquiry-based learning approaches, contributes significantly to improving students' numeracy skills (Kong & Matore, 2021; Blancia, 2025; AlAli, 2024; Ješková *et al.*, 2022; Vistara *et al.*, 2022). At the primary education level, this approach is regarded as effective as it aligns with students' cognitive developmental characteristics, which emphasize reliance on concrete and contextual learning experiences.

The results of the study indicate that numeracy is

a very strong predictor of students' problem-solving skills. These findings confirm that successful problem solving does not depend solely on procedural mastery, but on students' ability to understand, interpret, and process numerical information meaningfully. Conceptually, problem solving involves the stages of understanding the problem, designing a strategy, implementing the solution, and evaluating the results (Susanti, 2021; Hodnik & Kolar, 2022; Olivares *et al.*, 2020). All of these stages require adequate numerical literacy, as numeracy skills enable students to accurately interpret the context of the problem, choose relevant strategies, and reflectively evaluate solutions (Kolar & Hodnik, 2021; V. Aini *et al.*, 2024; Pratiwi *et al.*, 2024). These findings are in line with previous research that places numeracy as the main cognitive foundation in mathematical problem solving, especially in contextual and non-routine problems (Kolar & Hodnik, 2021; Xiao *et al.*, 2019; Pratiwi *et al.*, 2024e).

The insignificant direct effect of STEM-based learning on problem-solving skills is an important finding that provides theoretical clarification. This finding shows that the implementation of STEM does not automatically improve problem-solving skills if it is not supported by students' cognitive readiness. In this framework, STEM serves as a contextual and experiential learning environment, while numeracy functions as a cognitive prerequisite that enables students to effectively utilise these experiences. Without adequate numeracy, STEM activities may increase learning engagement, but do not necessarily result in improved problem-solving skills (Santia & Handayani, 2023; Changtong *et al.*, 2020; Uzpen *et al.*, 2019). These findings are in line with previous research confirming that the effectiveness of STEM learning is greatly influenced by students' basic abilities, particularly numeracy and mathematical reasoning (Ibrahim *et al.*, 2024; Ishikawa & Newcombe, 2021; Han *et al.*, 2021; Fowler *et al.*, 2021). Therefore, STEM is more appropriately understood as a facilitative context that supports problem-solving development, rather than as a single determining factor.

The mediation test results show that numeracy literacy plays a significant full mediating role in the relationship between STEM-based learning and mathematical problem-solving skills. The dominance of indirect effects over direct effects confirms that numeracy is the main mechanism that channels the impact of STEM learning on problem-solving abilities. This finding is in line with the process-oriented learning perspective, which emphasises that

higher-level cognitive achievements develop through the strengthening of intermediate cognitive processes (Peng & Kievit, 2020; Christ et al., 2022). In this model, numeracy bridges STEM learning experiences with problem solving through contextual understanding, numerical representation, and logical evaluation of solutions (Hallström & Schönborn, 2019; Dewi & Maulida, 2023; Pratiwi et al., 2024g).

The findings of this study reinforce the results of previous studies that confirm the contribution of STEM-based learning to the development of numeracy and mathematical reasoning in primary school students (Susanta et al., 2023; Nuraeni et al., 2021; Elsayed, 2022; Zainil et al., 2022), as well as the central role of numeracy in determining mathematical problem-solving skills (Santia & Handayani, 2023; Muhaimin et al., 2024; Mutaf-Yıldız et al., 2020). Unlike studies that emphasise the direct influence of STEM on problem solving, this study shows that this influence occurs indirectly through numeracy. These findings provide empirical clarification of the variations in previous research results, particularly in the context of primary education, by confirming that the effectiveness of STEM is greatly influenced by students' numerical readiness.

Theoretically, this study expands the conceptual model of STEM learning by emphasising the role of numeracy as a crucial mediating construct in bridging STEM-based approaches and problem-solving skills. These findings enrich mathematics education studies by providing a deeper understanding of the internal cognitive mechanisms underlying the effectiveness of STEM learning. In practical terms, the results of this study indicate that the implementation of STEM learning in primary schools needs to be designed in a more targeted manner to develop numeracy skills, not only through cross-disciplinary integration, but also by placing numerical exploration, the use of authentic data, and mathematical reflection as core components in every learning activity.

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This study has limitations that need to be considered, particularly regarding the use of an ex post facto design that limits causal conclusions, the measurement of STEM learning based on student perceptions that may contain subjective bias, and the research context being limited to one school cluster, thereby limiting the generalisation of findings. Future research is recommended to apply longitudinal or quasi-experimental designs, combine quantitative and qualitative approaches, and explore other cognitive mediators, such as metacognition, critical thinking, and self-regulated learning, to enrich the understanding of STEM-based learning mechanisms.

5. CONCLUSION

This study concludes that STEM-based learning has a significant effect on primary school students' problem-solving skills, both directly and indirectly through numeracy. The results of structural modelling show that the application of STEM learning in the context of Year 5 mathematics learning is able to improve students' numeracy skills, which in turn contributes positively to students' ability to understand problems, design solution strategies, and reason logically and systematically. Numeracy skills not only plays a role as a learning outcome, but also as a key cognitive mechanism that bridges the effectiveness of STEM learning to problem-solving skills. STEM learning places numeracy as an important mediator in the relationship between contextual learning approaches and the development of higher-order thinking skills in primary school students. The implementation of STEM learning needs to be consciously designed to foster numeracy through problem-based and contextual activities, not merely procedural cross-disciplinary integration. Thus, STEM learning has the potential to be a strategic approach in supporting the objectives of the Merdeka Curriculum to develop students' numeracy and problem-solving competencies in a sustainable manner.

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