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Predictors of students' mathematics problem-solving skills: Feedback, beliefs, learning support, and technology

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Abstract

This study examined how teacher instructional feedback quality, students' mathematical beliefs, and learning environment support influence senior high school students' mathematical problem-solving skills in Ghana. Technology integration was examined as a mechanism that may explain how these instructional and contextual factors support students' problem-solving development. Data were collected from 355 students selected through a multistage sampling approach from senior high schools in Ghana. The findings indicate that teacher instructional feedback quality, students' mathematical beliefs, and supportive learning environments significantly improve students' mathematical problem-solving skills. Using technology made the impact of teacher feedback and a supportive environment even stronger. However, technology did not significantly explain the link between what students believe about math and how well they solve problems. These findings show that teachers need to give clear feedback and create a positive classroom to help students think through complex math tasks. The study suggests that combining digital tools with high-quality teaching is a great way to improve how students learn to handle difficult problems.

Keywords: Problem-solving skills; Students' learning environment; Students' mathematical beliefs; Teacher instructional feedback quality; Technology integration

1. Introduction

Mathematics plays a central role in developing the cognitive and problem-solving skills that are essential for success in the twenty-first century. Beyond its disciplinary importance, it fosters analytical reasoning, creativity, and adaptability that are indispensable in modern economies (Darbellay, 2024; Fuchs et al., 2024). In the digital age, technology integration has become vital in improving how students conceptualize and apply mathematical ideas. According to Fülöp (2021) digital tools create interactive learning spaces that help students visualize problems, explore multiple solutions, and receive immediate feedback, which strengthens conceptual understanding. However, the development of strong problem-solving skills depends not only on access to technology but also on psychological, pedagogical, and environmental factors such as students' mathematical beliefs, teacher instructional feedback quality, and supportive learning environments (Akendita et al., 2025; Suliani et al., 2024). These dimensions interact to determine how effectively learners use digital resources to construct knowledge and solve complex mathematical tasks.

Students' mathematical beliefs, such as self-efficacy, determine persistence and motivation, and engagement in learning the subject (Jeong & González-Gómez, 2022). Learners with strong self-beliefs usually show resilience and are more willing to engage in challenging technology-based tasks (Boadu & Boateng, 2024; Suliani et al., 2024). The nature of instructional feedback also mediates how students reflect on their reasoning processes and make gains toward better performance (Hattie & Timperley, 2007; Yusof et al., 2022). Constructive and timely feedback helps learners connect their understanding with the intended performance, while weak or late feedback restrains progress. Besides, the physical and socio-emotional learning environment substantially fosters collaboration, experimentation, and inquiry (Li et al., 2025). Supportive environments that integrate digital tools facilitate engagement and creativity, whereas rigid, examination-focused classrooms dampen students' confidence and critical thinking (Davor et al., 2026). From the foregoing, there is a high need to further explore how teacher feedback, students' beliefs, and the learning environment interact in their influence through technology integration on problem-solving skills in students.

In Ghanaian senior high schools, mathematics instruction continues to focus on memorization and procedural fluency rather than conceptual understanding and creative problem-solving (Davor et al., 2025). This has contributed to persistent problems in the ability of students to apply math to real life, as revealed in the Programme for International Student Assessment and similar large-scale studies reporting lower problem-solving performance among sub-Saharan African learners (OECD, 2023). In Ghana, further constraints on problem-solving competence have been limited access to technology, inadequate digital pedagogy, and minimal use of formative feedback (Lotey et al., 2023). Addressing these challenges requires a comprehensive understanding of how teacher feedback quality, students' mathematical beliefs, and supportive learning environments interact with technology to influence problem-solving skills. Therefore, this study investigates the influence of teacher instructional feedback quality, students' mathematical beliefs, and students' learning environment support on problem-solving skills in mathematics, with technology integration serving as a mediating factor. By situating this inquiry within Ghana's senior high school context, the study contributes to both theoretical and practical understanding aimed at improving problem-solving pedagogy and technology use in mathematics education across African secondary schools.

2. Theoretical Framework

This work is therefore based on three complementary theoretical perspectives: the TPACK framework (Mishra & Koehler, 2006), Constructivist Learning Theory (Wertsch & Sohmer, 1995), and Schoenfeld's Theory of Mathematical Problem Solving (Schoenfeld, 1985). Together, these theories explain how teaching methods, student beliefs, and learning environments interact to influence students' ability to solve mathematical problems, especially in classrooms where technology is integrated to support instruction and engagement.

Constructivist learning theory holds that learners build knowledge through active engagement in their environment and through meaningful interactions with others. From this view, students improve problem-solving abilities by participating in activities that foster discovery, collaboration, and reflection. Teachers play an important role in creating such environments by guiding learners and providing structured feedback (Lotey et al., 2023). When technology is effectively integrated into instruction, it enhances this process by making feedback more immediate and personalized. Digital platforms allow teachers to adapt instruction, monitor progress, and support students' reasoning in real time. This allows a theoretical linkage to support the hypothesis that technology integration acts as a mediator between the quality of teacher instructional feedback and students' problem-solving skills. Technology strengthens the effectiveness of feedback in enabling students to more readily translate guidance into improved performance.

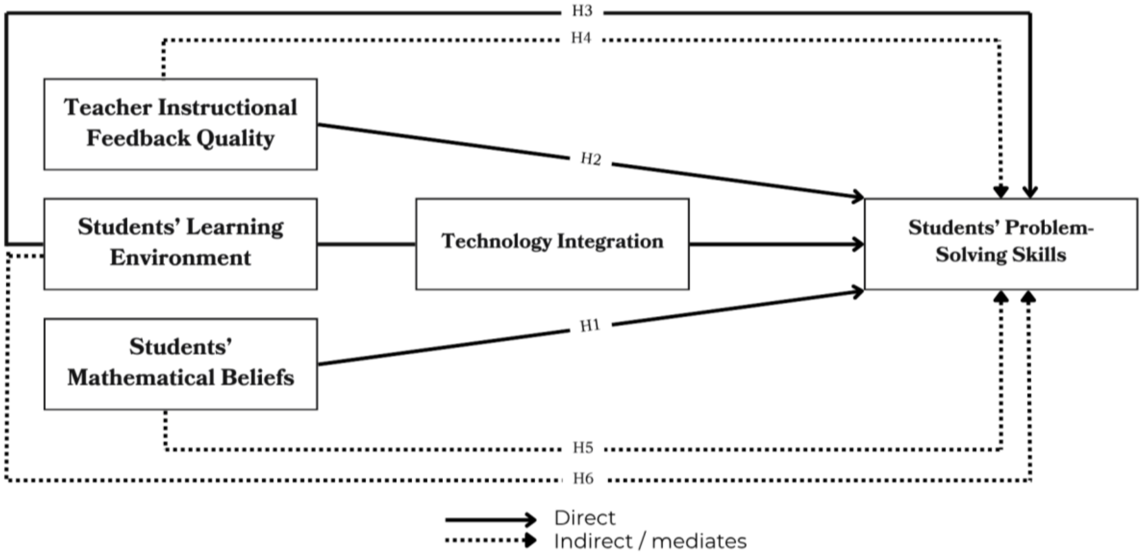
Schoenfeld's Theory of Mathematical Problem Solving describes how students' ideas about mathematics are linked to their motivation, persistence, and the strategies they employ. It is believed that students who view effort and reflection as paths to mathematical understanding will be more likely to build deep engagement and persevere through the complexity of problems (Wang et al., 2025). Technology can support these processes by providing opportunities for interactivity and illustrative resources, but its mediating effect on the relationship between students' mathematical beliefs and their problem-solving skills is expected to be weaker. This is because beliefs mainly operate at the level of motivations and cognitions rather than technological mechanisms. Nonetheless, positive beliefs may still inspire students to make productive use of technology, which in turn may positively affect the outcome of problem-solving.

The TPACK framework offers an in-depth look at the three intertwining components teachers use: content knowledge, pedagogical strategies, and technological tools, to design appropriate instruction. Within this study, the process of technology integration is viewed as the means through which high-quality feedback and supportive learning environments lead to better problem-solving outcomes. TPACK stresses how a teacher's ability to choose and then use the right technological tool enables more effective and interactive instruction, better articulation of mathematical ideas, and greater student engagement (Karataş & Ataç, 2025). This correlation reinforces the assumption that technology is a mediating factor in transforming instructional practices into improved learning results.

In general, Vygotsky's theory explains how guidance and collaboration engender learning; Schoenfeld's model clarifies how beliefs shape strategy use and persistence; and TPACK demonstrates how technology strengthens instructional processes. These theoretical perspectives collectively support the hypothesized relationships among teacher instructional feedback, students' mathematical beliefs, learning environment support, and students' problem-solving skills, while justifying the mediating role of technology integration. Figure 1 presents the conceptual framework of the study.

Figure 1

Conceptual Framework of the Study



Note: Arrows denote hypothesized directional relationships among constructs. TI = Technology Integration; SMB = Students Mathematical Beliefs; TSFQ = Teacher Instructional Feedback Quality; SLE = Students' Learning Environment; SPS = Students' Problem-Solving Skills

In this study, the following research hypotheses were formulated to examine the direct effects of the independent variables on students' problem-solving skills, as well as the mediating role of technology integration in these relationships.

H1. Students' mathematical beliefs have a direct influence on SPS
H2. Teacher instructional feedback quality has a direct effect on SPS
H3. Students' learning environment support has a direct effect on SPS
H4. TI partially mediates the connection between TSFQ and SPS.
H5. TI partially mediates the connection between SMB and SPS.
H6. TI partially mediates the connection between SLE and SPS.

3. Methodology

3.1. Research Approach

The research employed a quantitative design that focused on both correlation and explanation. A Structural Equation Modeling [SEM] framework was used to analyze the direct, indirect, and mediating effects between the variables. SEM was deemed suitable because it allows for the simultaneous examination of various relationships, manages latent variables, and tests the suggested theoretical model.

3.2. Population and Sampling

Senior High School [SHS] mathematics students in Ghana are the target population for the study. The population was drawn from selected SHS schools within the Kwadaso Metropolitan Assembly- Kumasi, chosen because they adopted digital learning resources and diverse instructional contexts in the region. A multistage sampling strategy was employed. In the first stage, purposive sampling was used to select schools with demonstrable integration of technology in teaching and learning. Schools included in this study were purposively selected based on their adoption of digital learning resources for mathematics, ensuring that participants had prior exposure to technology-enhanced instruction. Of the 375 students invited to participate, 355 completed the survey, yielding a response rate of 94.7 percent. Krejcie and Morgan (1970) recommend that the appropriate sample size requirements for a robust statistical analysis recommended for SEM should exceed the minimum threshold of 300. Again, a stratified sampling technique was employed to divide the students into similar groups according to the students' fields of study, which included Visual Arts, Business, Home Economics, General Science, General Arts, and Technical. This ensures that all courses have student representation. In the final stage, simple random sampling was applied to select participants within each stratum. Table 2 shows that the 355 respondents were relatively balanced by gender, with slightly more males than females. Most students were aged 16–17 years, followed by those aged 18 years and above, while the smallest group was aged 13–15 years. In terms of course of study, Business and Visual Arts had the highest representation, whereas General Arts had the lowest.

Table 2
Demographic Characteristics of Respondents (N = 355)

Variables	*Frequency (N)*	*Percentages (%)*
Gender		
Male	185	52.1
Female	170	47.9
Age		
13-15 yrs	91	25.6
16-17 yrs	153	43.1
18-Above	111	31.3
Course of study		
Home Economics	55	15.5
General Science	43	12.1
Business	83	23.4
General Arts	34	9.6
Visual Art	75	21.1
Technical	65	18.3

3.3. Research Instruments

A structured questionnaire was employed as the primary instrument for data collection to ensure consistency and uniformity in the responses obtained. The questionnaire had five sections (see Appendix 1). The first section was constructed to obtain demographic information from the participants, including their gender, age, and courses pursued. The other sections were focused on the four key variables of the study: Teacher instructional feedback quality [TSFQ], Students' mathematical beliefs [SMB], Students' Learning Environment [SLE], Technology integration [TI], and Students' problem solving in mathematics [SPS]. The items used for the study were structured on a five-point Likert scale, which ranged from (1=Strongly Disagree) to (5=Strongly Agree). However, questionnaire items used for the study were taken from a reliable instrument in the existing literature to ensure maximum reliability and relevance across different settings. Specifically, the section on students' problem-solving skills, students' mathematical beliefs, and technology integration was derived from the work of Boateng et al. (2024) and Fülöp (2021), respectively, with minor wording modifications to suit the Ghanaian senior high school context (e.g., replacing “university mathematics” with “senior high school mathematics”). Because English is the medium of instruction, no translation was required. Moreover, to ensure content validity, the questionnaire was reviewed by three experts in mathematics education and educational measurement. Their feedback guided minor revisions to ensure clarity and contextual relevance. A pilot test involving 30 students from two non-sampled schools was conducted to evaluate item clarity and reliability. Feedback from the pilot informed wording adjustments before the main data collection.

3.4. Common Method Bias

To mitigate common method bias [CMB], several procedural and statistical controls were applied following the recommendations of Podsakoff and Organ (1986). Since all variables were measured using self-reported data, procedural remedies focused on ensuring respondent anonymity and confidentiality to reduce social desirability bias. The questionnaire also included both positively and negatively worded items, varied Likert-scale anchors, and separated sections for predictor and criterion variables to minimize response patterns. Data on Teacher Instructional Feedback Quality, Students’ Mathematical Beliefs, and Students’ Learning Environment were collected in one session, followed by a separate session for Technology Integration and Students’ Problem-Solving skills [SPS], ensuring temporal separation. After data collection, statistical tests were performed to assess CMB. Harman’s single-factor test indicated that the first unrotated factor accounted for 29.4% of the total variance, which is below the 50% threshold, suggesting that no single factor dominated the data. Additionally, a confirmatory factor analysis [CFA] including a common latent factor revealed that the average shared variance among items was below 0.30, further confirming that common method bias was not a serious concern in this study.

3.5. Data Analysis Methods

The data analysis was executed in SPSS (v.27) and AMOS (v.23). The responses were entered and coded in SPSS to be analyzed as a first step. Descriptive statistics, percentage, and frequency were calculated to get an initial idea about the data. Reliability of the measured items was assessed by performing reliability analysis and exploratory factor analysis [EFA] to determine the underlying factor structure. Again, the measurement model was tested using CFA, with construct reliability, convergent validity, Average Variance Extracted [AVE], and discriminant validity assessed in line with established SEM guidelines (Hair et al., 2012). Also, the structural model was analyzed to test the hypothesized relationships between the variables of the construct. Direct effects of teacher instructional feedback quality, mathematical beliefs, and learning environment support on problem-solving skills were examined. The mediating role of technology integration was assessed using bootstrapping techniques, which provided bias-corrected confidence intervals for indirect effects (Hair, 2019).

3.6. Validity and Reliability

The essential components for forming accurate conclusions and making a reasonable decision based on research results are validity and reliability. The main variables being studied were assessed for internal consistency using the CA coefficient. According to Table 3, Teacher instructional feedback quality had a Cronbach’s Alpha [CA] value of .782, students’ mathematical beliefs had a CA value of .831, Students’ learning environment support returned Cronbach’s Alpha of .815, Technology integration obtained a CA of 0.782 and students’ problem-solving skills showed a CA value of .819. From Marsh et al. (2020), the acceptability of an instrument should be assessed based on its CA score, which should be 0.7 or greater. Table 3 shows an analysis of validity and reliability.

Table 3

Reliability Statistics for Study Constructs

Variables	*Number of items*	*CA value*
Technology Integration	4	.782
Teacher instructional feedback quality	3	.716
Students Problem-Solving skills	4	.819
Students' mathematical beliefs	4	.831
Students learning environment	4	.815

Note. Cronbach's alpha values above 0.70 indicate acceptable internal consistency (Hair et al., 2019).

3.7. Exploratory Factor Analysis [EFA]

The results of the EFA are graphed in Table 4. One method that prioritizes intercorrelated factors is exploratory factor analysis [EFA]. EFA is a variable reduction method that distinguishes between factors underlying an array of variable attributes and latent variables (Marsh et al., 2020). According to Table 4, the KMO measure of sampling adequacy is 0.814, which exceeds the minimum scaling requirement of 0.5. It is appropriate and fit to suggest that the items are strongly related (Fuchs et al., 2024; Hair et al., 2012). The Bartlett's Sphericity Test was significant with a Chi-square value of 2491.902 and 171 degrees of freedom, which provides a significant *p*-value of <.001for Bartlett's test.

Table 4

Exploratory Factor Analysis and KMO and Bartlett's Test

Rotated Component Matrix

Measurement Items	*Component*				
	1	*2*	*3*	*4*	*5*
TI3	.717				
TI4	.757				
TI5	.775				
TI6	.761				
SLE1		.725			
SLE2		.810			
SLE4		.795			
SLE5		.780			
SPS2			.744		
SPS3			.779		
SPS5			.785		
SPS6			.768		
TSFQ1				.813	
TSFQ2				.781	
TSFQ3				.712	
SMB1					.786
SMB2					.802
SMB3					.811
SMB4					.803

	KMO and Bartlett's Test	
TVE		65.293
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.814
Bartlett's Test of Sphericity	Approx. Chi-Square	2491.902
	df	171
	Sig.	<.001
Determinant		.001

From Table 4, the determinant of .001 is significantly greater than zero, which is quite good to consider. The researcher used factor analysis to extract the four variables from the questionnaire's instructions. The selected five components, resulting in a 65.293% cumulative variance explained, are displayed in Table 4. In summary, the rotated component matrix, a factor loading, and a turn varimax were also displayed. The rotated varimax could raise the normal yield while dropping the number of compound parameters. The items' significance and applicability were assessed to decide whether to keep or remove them. Items loaded with low factor loadings and those loaded at different components were removed iteratively, and each time an item with low factor loading is removed, the fit indices are checked. According to the rotated component matrix, 11 items were removed (refer to Table 5) because they were loaded on different components. The study recognized that the right certainty number of observed variables for technology integration was four (4), students learning environment support was four (4), students' problem-solving abilities was four (4), teacher instructional feedback quality was three (3) and students mathematics beliefs was four (4). Table 2 displays factor loadings for each component greater than 0.5.

3.8. Confirmatory Factor Analysis [CFA]

Confirmatory Factor Analysis run in Amos (v. 23) was performed after EFA analysis. The measurement items loaded in their rightful constructs were used to perform CFA analysis. After performing the CFA, we noticed that all the measurement items' loadings were above the minimum threshold of 0.5. Confirmatory Factor Analysis is reported in Table 5.

Table 5

Confirmatory Factor Analysis (CFA) and Model Fit Indices

Model Fit: *CMIN = 252.161; DF = 139; CMIN/DF = 1.814; TLI = .941; NFI = .901; CFI = .952; SRMR = .055; RMSEA = .048; PClose = .628*	*Loadings*
Technology Integration: CR = .783; CA = .782; AVE = .476	
TI1: I often use technology (like calculators or computers) to do mathematics	1.000 (fixed)
TI2: Using technology helps me understand mathematics better	1.000 (fixed)
TI3: Technology use supports my comprehension of mathematical ideas.	.681
TI4: Digital tools and resources encourage me to take a more active role in mathematics lessons.	.694
TI5: I can deal with technical difficulties that arise during technology-based mathematics activities without much trouble.	.754
TI6: I feel capable of integrating technology effectively into my study of mathematics.	.622
Students Learning Environment: CR = .816; CA = .815; AVE = .526	
SLE1: The learning environment makes me feel comfortable asking questions.	.690
SLE2: My classmates and I help each other when learning mathematics.	.759
SLE: My teacher encourages us to work together in groups during math lessons.	1.000 (fixed)
SLE4: The classroom provides the resources I need to learn mathematics (e.g., technology).	.711
SLE5: The school provides enough support for learning mathematics.	.739
SLE6: I feel respected and supported by my teacher and classmates	1.000 (fixed)
Students' Problem-Solving Ability: CR =.820; CA = .819; AVE = .533	
SPS1: I can understand what a math problem is asking me to do.	1.000 (fixed)
SPS2: I can break down complex problems into smaller, more manageable parts	.692
SPS3: I can develop an effective plan or strategy to solve mathematics problems.	.735
SPS4: I can check my answers to see if they are correct	1.000 (fixed)
SPS5: I persist in solving challenging mathematics problems until I find a solution.	.755
SPS6: I apply logical reasoning when solving mathematics problems.	.736
Teacher Instructional Feedback Quality: CR = .730; CA = .716; AVE= .478	
TSFQ1: The teacher explains clearly how I can improve my work	.634
TSFQ2: The teacher's feedback helps me understand what I did right or wrong	.806
TSFQ3: The feedback I receive makes me more confident in solving mathematics problems.	.619
TSFQ: My teacher gives feedback quickly after I finish my work.	1.000 (fixed)
TSFQ: My teacher's comments help me correct my mistakes.	1.000 (fixed)
TSFQ: My teacher gives examples that help me understand the feedback.	1.000 (fixed)

Table 5 continued

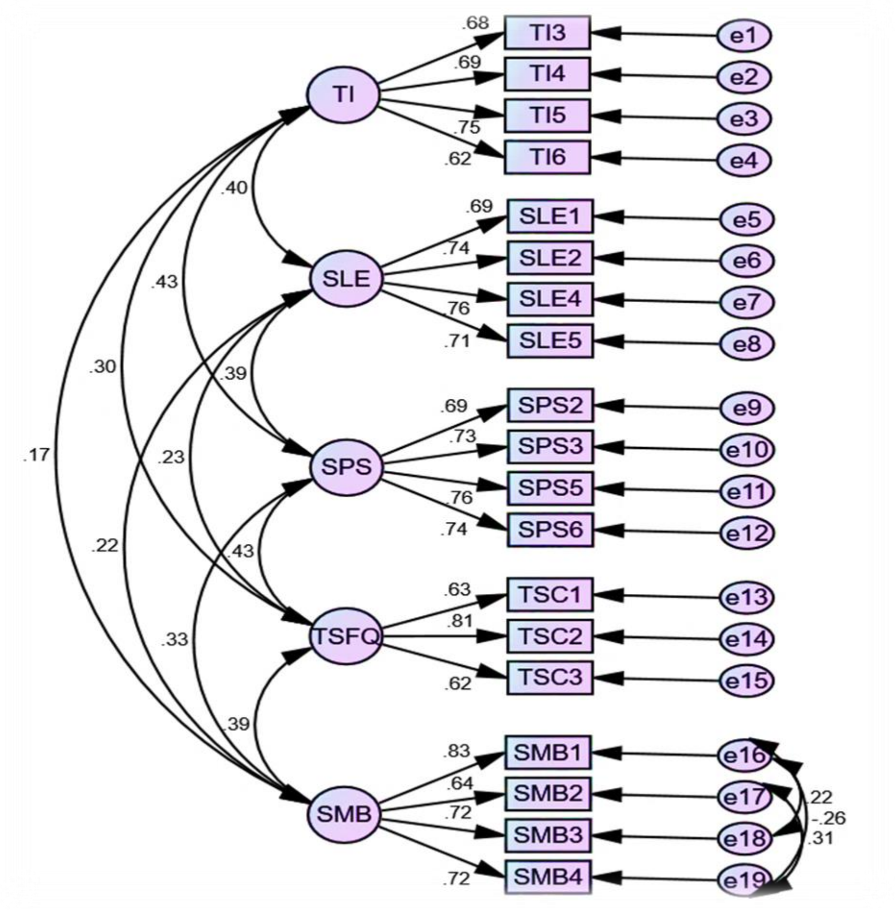
Students' Mathematical beliefs: CR= .818; CA = .831; AVE= .531	
SMB1: I believe I can understand difficult mathematical concepts.	.826
SMB2: I am confident that I can succeed in mathematics exams or tests	.639
SMB3: Mathematics is one of my strengths compared to other subjects	.719
SMB4: I feel capable of learning new mathematics topics on my own.	.718
SMB5: I believe hard work and practice help me get better at mathematics.	1.000 (fixed)
SMB6: I believe I can do well in mathematics if I keep trying.	1.000 (fixed)

Note. One indicator per latent construct was fixed to 1.00 to establish model identification in the CFA. All other values represent standardized factor loadings.

The Chi-Square test evaluates the difference between the model's predicted and observed covariance matrices, with a lower value preferred. However, it is sensitive to sample size, potentially showing significant results even when the model fits well. Moreover, the degree of freedom (df), which is dependent on the total number of observed variables and model parameters, influences the CMIN/df ratio, which should be between 1 and 3 for a good fit (Marsh et al., 2020). According to Table 5, a CMIN/DF value of 1.814 indicates a good model fit. In addition, the CFI compares the model's fit to a baseline model, with a value above 0.95 considered excellent (Asare et al., 2025); here, a value of 0.952 indicates a near-perfect fit. The (SRMR) value of 0.055, below 0.08, suggests minimal residuals and indicates a perfect fit (Marsh et al.,2020). The RMSEA value of .048 indicates a good fit (below the threshold of .08) cited by Shimizu (2025) TLI = .941, an excellent fit (above the threshold of .90). Also, the PClose *p*-value value of .628 supports the model's fit, as it suggests that PClose *p*-value is considered excellent if it is greater than .05.

Figure 2

Confirmatory Analysis of the study



3.9. Discriminant Validity

Discriminant validity was assessed using the Fornell-Larcker criterion. According to Fornell and Larcker (1981) criterion, a construct demonstrates discriminant validity when the square root of its AVE (diagonal values in Table 6) is greater than its correlations with all other constructs in the model. Table 6 presents the full Fornell-Larcker matrix, where the diagonal shows the square root of AVE for each construct and off-diagonal values show inter-construct correlations. All constructs met this criterion, indicating that each construct is empirically distinct from the others.

Table 6

Discriminant Validity of Constructs

Variables	*CR*	*AVE*	*TI*	*TSFQ*	*SPS*	*SLE*	*SMB*
TI	0.783	0.476	***.690***				
TSFQ	0.730	0.478	.173***	***.691***			
SPS	0.820	0.533	.435***	.332***	***.730***		
SLE	0.816	0.526	.397***	.224***	.390***	***.725***	
SMB	0.818	0.531	.303***	.389***	.433***	.228***	***.729***

Note. ***Denotes *p*-value less than 1% significance level; $\sqrt{\text{AVE}}$s values are in bold and italic.

3.8. Convergent Validity

Convergent validity was evaluated through AVE and CR values. As recommended by Fornell and Larcker (1981) AVE values should be at least 0.50 to demonstrate that the construct explains more than half of the variance in its indicators. The results in Table 6 show that three constructs (SPS, SLE, and SMB) were all above 0.50, which meets the standard requirement for convergent validity. However, the AVE values for TI (0.476) and TSFQ (0.478) were slightly below the threshold. Despite this, their composite reliabilities were above 0.70 (TI = 0.783; TSFQ = 0.730). Following Hair et al. (2012), the retention of these constructs is justified, as the CR and factor loadings indicate acceptable internal consistency and reliability despite slightly lower AVE values. During model refinement, low-loading items were carefully evaluated. No items were removed because all contributed meaningfully to the construct theoretically and statistically, and their exclusion did not appreciably improve AVE or model fit. Therefore, the final measurement model was retained as specified.

4. Results

4.1. Path Analysis

The researchers employed a path analysis diagram (see Figure 3) to create the structural model for the study. A structural model that can be viewed as an extension of multiple analysis, which assesses the relationship between dependent variables and two or more independent variables (Li et al., 2025). Researchers start the path analysis by developing a path diagram that illustrates the relationships among the variables. Arrows in the measurement model show the pathway of the effects. The application of path analysis was performed to examine the relationships of cause and effect between dependent and independent variables.

4.2. Direct Effect

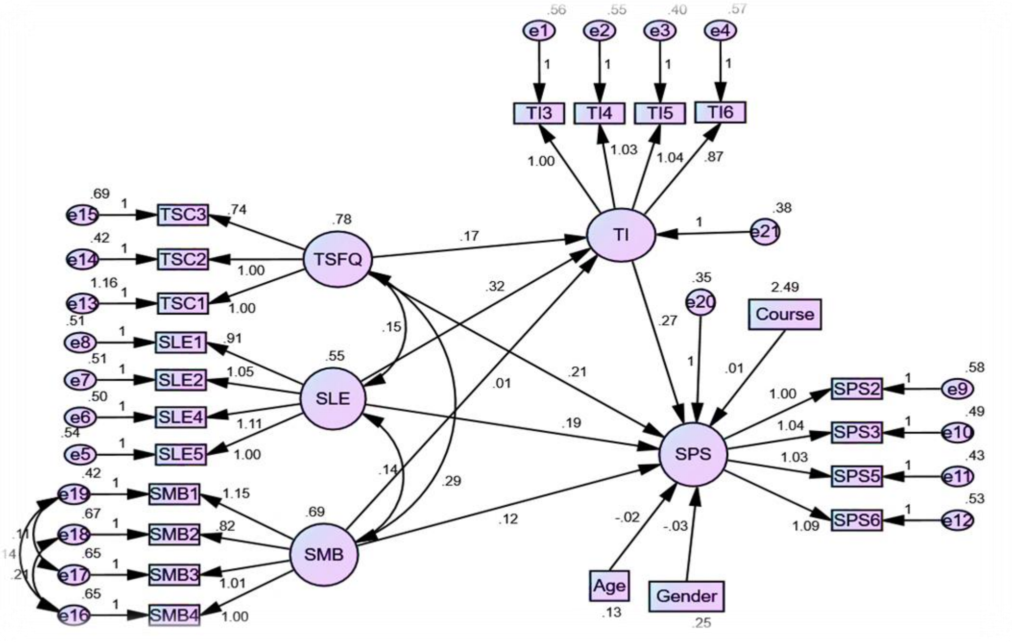
Table 7 presents the standardized path coefficients for the effects of teacher instructional feedback quality, students' mathematical beliefs, and students' learning environment on students' problem-solving skills, including the mediator, technology integration.

Students' mathematical beliefs had a positive and statistically significant effect on SPS (β = 0.124, CR = 2.138, p < .05). This indicates that a one standard deviation increase in SMB is associated with a 0.124 standard deviation increase in SPS, confirming that SMB directly influences problem-solving performance.

Teacher instructional feedback quality also had a significant positive effect on SPS (β = 0.213, CR = 3.492, $p < .01$). This means that a one standard deviation increase in TSFQ corresponds to a 0.213 standard deviation increase in SPS. These results are consistent with prior research showing that high-quality feedback enhances students' engagement, reasoning, and problem-solving skills (Webb, 2009).

Figure 3

Analysis of the Path diagram



SLE positively influenced SPS (β = 0.195, CR = 2.955, $p < .01$). A one standard deviation improvement in SLE is associated with a 0.195 standard deviation increase in students' problem-solving abilities. The model demonstrated acceptable fit indices (CFI = 0.952, TLI = 0.941, RMSEA = 0.048, SRMR = 0.055), suggesting that the structural model adequately represents the relationships among variables.

Table 7

Path Summary of the study

Direct Effect	*Std. Est.*	*S.E.*	*C.R.*	*p-value*
Gender→ SPS	−.028	.075	−.373	.707
Age→ SPS	−.022	.103	−.214	.831
Course→ SPS	.011	.024	.458	.649
TSFQ→ SPS	.213	.061	3.492	<.001
SMB→ SPS	.124	.058	2.138	.032
SLE→ SPS	.195	.066	2.955	<.001
Indirect Effect	*Std. Est.*	*L. B*	*U. B*	*p-value*
TSC→TI→SPS	.026	.010	.123	<.001
SMB→TI→SPS	.021	−.035	.054	837
SLE→ **TI** →SPS	.037	.032	.181	<.001

4.3. Mediating Effect

The mediation analysis examined whether technology integration mediates the relationship between teacher instructional feedback quality, students' mathematical beliefs, and students' learning environment on students' problem-solving skills. Bootstrapped indirect effects were estimated using 5,000 resamples, with bias-corrected 95% confidence intervals.

H4**:** Technology integration partially mediates the relationship between TSFQ and SPS. The standardized indirect effect was 0.026, with a 95% confidence interval of [0.010, 0.123], excluding zero and indicating significance. The proportion mediated was 10.9%, showing that TI explains a modest portion of the total effect of TSFQ on SPS. Because both the direct and indirect paths are significant, TI acts as a partial mediator.

H5: Technology integration does not mediate the relationship between SMB and SPS. The standardized indirect effect was 0.021, with a 95% confidence interval of [-0.035, 0.054], which includes zero, indicating a non-significant indirect effect. The proportion mediated is 14.5%, but because the indirect effect is not significant, TI does not mediate the effect of SMB on SPS.

H6: Technology integration partially mediates the effect of SLE on SPS. The standardized indirect effect was 0.037, with a 95% confidence interval of [0.032, 0.181], excluding zero and indicating significance. The proportion mediated was 15.9%, showing that TI explains a meaningful portion of the total effect of SLE on SPS. Since both the direct and indirect effects are significant, TI partially mediates the relationship between SLE and SPS.

5. Discussion

5.1. Hypothesis 1: Students' mathematical beliefs have a direct influence on SPS

The study indicates that SMB directly influences SPS. This finding aligns with earlier studies conducted by Suliani et al. (2024) and Roorda et al. (2024), whose findings indicate that students' beliefs about mathematics influence their methods for tackling problem-solving tasks. Schoenfeld (1985) showed that students who perceive mathematics as making sense of concepts are more likely to use effective strategies and continue working on difficult problems. Grigaliūnienė et al. (2025) also indicate that beliefs influence motivation, regulation, and the use of strategies. This current study has also confirmed that beliefs about mathematics focused on growth, like the idea that effort leads to skills development, are closely linked to better problem-solving results.

5.2. Hypothesis 2: Teacher instruction feedback quality has a direct effect on SPS

H2 revealed that teacher instructional feedback quality is positively associated with students' problem-solving skills. This finding supports meta-analytic evidence by Holzberger et al. (2020) indicating the strong association of high-quality feedback with student achievement in mathematics. Effective feedback helps students refine strategies, monitor their thinking, and regulate their learning processes (Ma et al., 2022; Zheng et al., 2025). In technology-supported contexts, digital platforms can enhance feedback by providing immediate and adaptive responses, which may further support problem-solving engagement. However, the strength of this association will vary according to how such feedback is implemented and according to the teacher's capability to integrate technology effectively, highlighting issues of teacher training and professional development. In the Ghanaian SHS context, where large class sizes along with resource constraints are common, digital feedback tools may offer scalable support, but their effectiveness depends on thoughtful integration aligned with pedagogical goals. These findings support socio-constructivist perspectives emphasizing guided interaction and scaffolding as mechanisms through which feedback supports cognitive and metacognitive skill development.

5.3. Hypothesis 3: Students' learning environment support has a direct effect on SPS

H3 revealed that SLE is positively related to SPS. This extends previous research supporting that supportive classrooms characterized by safety, respect, cooperation, and intellectual risk-taking opportunities are associated with higher levels of engagement and persistence during challenging tasks (Suliani et al., 2024). In mathematics, these environments support experimentation, exploration, and the development of multiple problem-solving strategies believed to be central to effective learning (Darbellay, 2024). In Ghanaian SHS classrooms, where traditional teacher-centered approaches and memorization tend to dominate, the development of supportive and resource-rich environments may enable better problem-solving by allowing students to apply knowledge, collaborate, and reflect on problem-solving processes. Technology can serve as an amplifier in such contexts, supporting interactive learning, peer collaboration, and multiple representations of mathematical problems (Shimizu, 2025). These relationships are correlational. It can be assumed that school resources, teacher practices, and variation in implementation fidelity may affect the relationships. Such an approach has been confirmed by research into how the specific features of technology use in combination with certain aspects of learning environments relate to sustained problem-solving skills improvements.

5.4. Hypothesis 4: TI partially mediates the connection between TSFQ and SPS.

From the results of the study, the research revealed that the integration of technology into mathematics education influences how teacher feedback quality influences problem-solving skills. Situating this in learning mathematics, digital learning platforms improve the speed and engagement of feedback, which improves their effectiveness in learning. Grigaliūnienė et al. (2025) and Zheng et al. (2025) stated that digital feedback systems provide prompt and flexible support. Again, the study conducted by Roorda et al. (2024) also shows that teachers' feedback assisted by technology enhances perseverance and efficiency in problem-solving activities. These results also indicate that technology enhances the influence of feedback by formulating learning more centered on processes and easier to access. This is a key contribution that the study adds to the literature.

5.5. Hypothesis 5: TI partially mediates the connection between SMB and SPS.

The results of this study indicate that technology does not affect the relationship between students' mathematical beliefs and their problem-solving skills. The results indicate that students' views on mathematics have a direct impact on their problem-solving skills, regardless of the use of technology. Webb (2009) found that teachers' beliefs, along with their understanding of the subject, had a significant impact on how they taught problem-solving. This underscores the nexus between beliefs and abilities. The results show that merely adding technology to mathematics classrooms does not enhance students' beliefs. Deliberate teaching strategies are vital to improve their beliefs and problem-solving skills. This perspective of the study is consistent with criticisms in the "math wars" debate, where scholars argue that technology by itself cannot guarantee a better comprehension of mathematics. It is important to note, however, that the schools in this study were purposively selected for existing technology adoption. Therefore, the low association between TI and SMB may reflect differences in implementation quality, fidelity of use, or how technology was integrated into instruction, rather than a general absence of effect. This suggests that technology alone may not automatically enhance students' mathematical beliefs, and deliberate instructional strategies remain critical to support belief development. Future research using longitudinal or experimental designs is recommended to more robustly assess whether technology can influence students' beliefs over time. This is a key novelty that the study added to the literature.

5.6. Hypothesis 6: TI partially mediates the connection between SLE and SPS.

The study indicates that technology influences how learning environments impact problem-solving. This study's results align with studies indicating that digital platforms promote collaboration, independence, and peer interaction, thereby enhancing and strengthening positive classroom environments (Li et al., 2025; Szabo et al., 2020). Abdigapbarova and Zhiyenbayeva (2023) also highlight that environments equipped with technology support student-centered learning and encourage constructive challenges, which are important for building resilience in problem-solving. The current findings suggest that supportive environments are more effective when they are paired with technological features that promote exploration and ongoing participation. This is another contribution that the study adds to the literature.

6. Practical Implications and Recommendations

The results of this investigation support that problem-solving competencies in mathematics are not developed only by cognitive processes but also by pedagogy, learning context, and students' disposition, with technology acting as an enhancer of instructional and contextual effects. From the socio-constructivist view, learning always results from interaction between the cognitive and social conditions. These findings can be converted into actionable suggestions as follows:

Accordingly, schools should adopt digital platforms that support immediate, personalized, and interactive feedback. Features such as automated hints, stepwise problem-solving guides, and progress dashboards enable students to monitor their understanding and adjust their strategies in real time. Again, workshops should approach the development of TPACK principles in which teachers are given hands-on experiences in the integration of content, pedagogy, and technology. Training should include modeling effective feedback, designing interactive problem-solving lessons, and creating model lesson plans that promote active learning and student engagement. In addition, digital assessment platforms may track students' progress, highlighting areas for improvement, while providing scaffolded guidance. Tools such as interactive quizzes, virtual manipulatives, and online problem-solving modules encourage persistent engagement and self-reflection. Finally, school leaders need to structure classrooms in ways that encourage group problem-solving, experimentation, and intellectual risk-taking. Technology can facilitate small-group activities, peer feedback, and simulations that reinforce both conceptual understanding and creativity. Accordingly, the implementation of these evidence-based, concrete strategies by policymakers and school leaders has the potential to enhance teacher feedback practices, support positive student dispositions toward mathematics, and ultimately lift problem-solving outcomes in senior high school students.

7. Conclusion

The present study examined the effects of teacher instructional feedback quality, students' mathematical beliefs, and learning environment support on senior high school students' problem-solving skills in mathematics, with technology integration as a mediating factor. Using CB-SEM in AMOS (v.23), the findings show that all three factors significantly and positively predict problem-solving skills, with teacher instructional feedback quality emerging as the strongest predictor. This indicates that clear, timely, and constructive feedback is central to students' effective mathematical problem solving. Students' mathematical beliefs also play a significant role, highlighting the importance of confidence and persistence in solving mathematical tasks, while supportive learning environments further enhance engagement and strategic thinking. The mediation analysis revealed that technology integration partially mediates the relationship between teacher instructional feedback quality and problem-solving skills, as well as between learning environmental support and problem-solving skills, but not between students' mathematical beliefs and problem-solving skills. This suggests that technology strengthens instructional and environmental support, while students' beliefs influence problem-solving largely through internal motivational processes. The study concludes that improving mathematical problem-solving skills requires a balanced focus on high-quality feedback, positive student beliefs, supportive learning environments, and purposeful technology integration.

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Appendix 1: Research Questionnaire

Section A. Demographics

1. Gender of the respondent: Male [ ] Female [ ]
2. Age of the respondent: 13–15 years [ ] 16–17 years [ ] 18 years or above [ ]
3. Course of study of the respondent: Home Economics [ ] General Science [ ] Business [ ] General Arts [ ] Visual Art [ ] Technical [ ]

Section B. *Teacher Instructional Feedback Quality, Students' Mathematical Beliefs, Students' Learning Environment Support, Students' Problem-Solving Skills, Technology Integration*

Q4. Please indicate your level of agreement or disagreement with the statement below. They have been rated in the form 5-strongly agree (SA), 4-agree (A), 3-neutral (N), 2-disagree (D), and 1-strongly disagree (SD).

Please tick (√) in the box where appropriate

Codes	**1 = SA 2 = A 3 = N 4 = D 5 = SD**					
TI (Boadu & Boateng, 2024)						
TI1	I often use technology (like calculators or computers) to do mathematics	[1]	[2]	[3]	[4]	[5]
TI2	Using technology helps me understand mathematics better	[1]	[2]	[3]	[4]	[5]
TI3	Technology use supports my comprehension of mathematical ideas.	[1]	[2]	[3]	[4]	[5]
TI4	Digital tools and resources encourage me to take a more active role in mathematics lessons.	[1]	[2]	[3]	[4]	[5]
TI5	I can deal with technical difficulties that arise during technology-based mathematics activities without much trouble.	[1]	[2]	[3]	[4]	[5]
TI6	I feel capable of integrating technology effectively into my study of mathematics	[1]	[2]	[3]	[4]	[5]
SLE (Szabo et al., 2020)						
SLE1	The learning environment makes me feel comfortable asking questions.	[1]	[2]	[3]	[4]	[5]
SLE2	My classmates and I help each other when learning mathematics.	[1]	[2]	[3]	[4]	[5]
SLE3	My teacher encourages us to work together in groups during math lessons**.**	[1]	[2]	[3]	[4]	[5]
SLE4	The classroom provides the resources I need to learn mathematics (e.g., technology).	[1]	[2]	[3]	[4]	[5]
SLE5	The school provides enough support for learning mathematics.	[1]	[2]	[3]	[4]	[5]
SLE6	I feel respected and supported by my teacher and classmates	[1]	[2]	[3]	[4]	[5]
TSFQ (Hattie & Timperley, 2007)						
TSFQ1	The teacher explains clearly how I can improve my work	[1]	[2]	[3]	[4]	[5]
TSFQ2	The teacher's feedback helps me understand what I did right or wrong	[1]	[2]	[3]	[4]	[5]
TSFQ3	The feedback I receive makes me more confident in solving mathematics problems.	[1]	[2]	[3]	[4]	[5]
TSFQ4	My teacher gives feedback quickly after I finish my work**.**	[1]	[2]	[3]	[4]	[5]
TSFQ5	My teacher's comments help me correct my mistakes.	[1]	[2]	[3]	[4]	[5]
TSFQ6	My teacher gives examples that help me understand the feedback.	[1]	[2]	[3]	[4]	[5]
SMB (Davor et al, 2025)						
SMB1	I believe I can understand difficult mathematical concepts.	[1]	[2]	[3]	[4]	[5]
SMB2	I am confident that I can succeed in mathematics exams or tests.	[1]	[2]	[3]	[4]	[5]
SMB3	Mathematics is one of my strengths compared to other subjects.	[1]	[2]	[3]	[4]	[5]
SMB4	I feel capable of learning new mathematics topics on my own.	[1]	[2]	[3]	[4]	[5]
SMB5	I believe hard work and practice help me get better at mathematics.	[1]	[2]	[3]	[4]	[5]
SMB6	I believe I can do well in mathematics if I keep trying.	[1]	[2]	[3]	[4]	[5]
SPS (Asare et al., 2025)						
SPS1	I can understand what a math problem is asking me to do.	[1]	[2]	[3]	[4]	[5]
SPS2	I can break down complex problems into smaller, more manageable parts.	[1]	[2]	[3]	[4]	[5]
SPS3	I can develop an effective plan or strategy to solve mathematics problems.	[1]	[2]	[3]	[4]	[5]
SPS4	I can check my answers to see if they are correct.	[1]	[2]	[3]	[4]	[5]
SPS5	I persist in solving challenging mathematics problems until I find a solution.	[1]	[2]	[3]	[4]	[5]
SPS6	I apply logical reasoning when solving mathematics problems.	[1]	[2]	[3]	[4]	[5]