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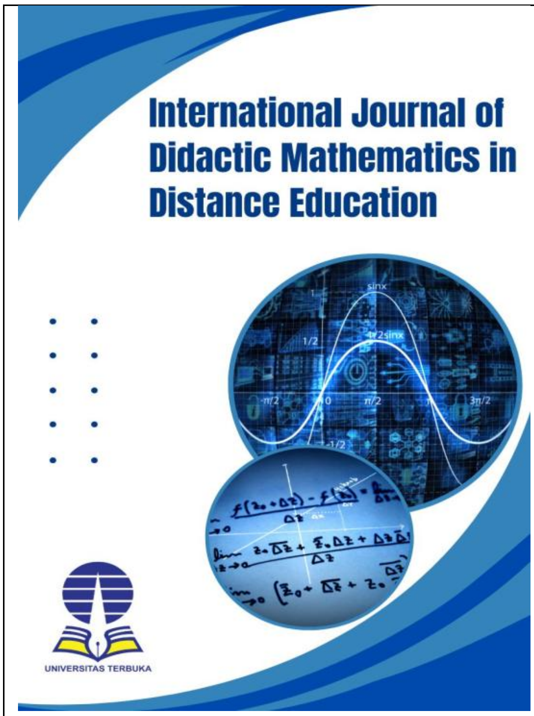

Guided teaching, technology integration, and learner engagement as predictors of mathematical problem-solving ability: A structural equation modeling study

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Guided teaching, technology integration, and learner engagement as predictors of mathematical problem-solving ability: A structural equation modeling study

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Abstract
Mathematical problem-solving remains a critical yet persistently underperformed competency among senior high school students in Ghana. This study examined the simultaneous influence of guided teaching approaches, technology integration, and learner engagement on mathematical problem-solving ability among second-year Senior High School (SHS 2) students in the Kumasi Metropolis, Ghana. Grounded in Vygotsky's Zone of Proximal Development, the Technology Acceptance Model, and Self-Determination Theory, the study adopted a quantitative descriptive-correlational survey design. A sample of 353 students was selected from two public senior high schools using purposive and stratified random sampling from a target population of 3,000 SHS 2 mathematics students. Data were collected via a validated 5-point Likert-scale questionnaire and analysed using Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), and Structural Equation Modelling (SEM) in AMOS 23. Results revealed that guided teaching approaches ($\beta = 0.216$, $p < 0.001$), technology integration ($\beta = 0.207$, $p < 0.001$), and learner engagement ($\beta = 0.252$, $p < 0.001$) each significantly and positively predicted students' mathematical problem-solving ability. Learner engagement emerged as the strongest predictor among the three variables. These findings underscore the importance of blended instructional frameworks that integrate structured pedagogical guidance, digital tools, and active student participation to improve mathematical competencies in sub-Saharan African educational contexts. Implications for mathematics educators, curriculum designers, and education policymakers in Ghana are discussed.

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1. Introduction

Mathematics is universally recognised as a cornerstone of modern education and a fundamental driver of economic and scientific development. Beyond its role as an academic subject, mathematics equips learners with the cognitive tools necessary to navigate an increasingly complex and technology-dependent world — chief among which is problem-solving ability (Foster, 2023; Sinaga et al., 2023). Problem-solving in mathematics is not merely the execution of learned procedures; it is a higher-order cognitive process that requires students to analyse unfamiliar situations, synthesise prior knowledge, generate creative strategies, and evaluate the effectiveness of potential solutions (Säfström et al., 2024; Schoenfeld, 2020). As education systems worldwide shift emphasis from rote content acquisition toward the cultivation of 21st-century competencies, mathematical problem-solving has emerged as the skill most strongly linked to readiness for STEM careers, higher education, and productive citizenship (English, 2023; Hillmayr et al., 2020).

At the SHS level, the stakes attached to mathematical problem-solving ability are particularly high. Students at this stage are preparing to transition into university education and the labour market, and their capacity to approach novel problems systematically and reason logically has direct implications for their academic and professional trajectories (Fülöp, 2021; Huang & Mok, 2025). Yet despite the centrality of problem-solving to mathematics education globally, large proportions of SHS students in many low- and middle-income countries consistently struggle to demonstrate adequate problem-solving competencies in national and international assessments (Sinaga et al., 2023; WAEC, 2023).

Ghana exemplifies this challenge with particular acuity. National assessment data from the West African Examinations Council (WAEC) document a persistent and troubling pattern of underperformance in Core Mathematics at the SHS level. In the 2023 West African Senior School Certificate Examination (WASSCE), only 62.23% of candidates obtained passing grades (A1–C6) in Core Mathematics — a marginal improvement from 61.39% in 2022 and 54.11% in 2021, but still well below the threshold expected of a subject that serves as a compulsory gateway to university admission across all disciplines (WAEC, 2023). More critically, WAEC (2025) reported a dramatic deterioration in mathematics performance in the 2025 WASSCE, with pass rates falling to 48.73% — the lowest recorded in the four-year period from 2022 to 2025. This sharp decline, attributed by WAEC to the elimination of systemic examination malpractice that had artificially inflated results in prior years, starkly exposes the depth of learning deficits in mathematical competency among Ghanaian SHS students. These data collectively underscore the urgent need for evidence-based pedagogical intervention.

Scholarship on mathematics education in Ghana attributes persistent underperformance to a complex interplay of structural and instructional factors. Overcrowded classrooms, insufficient instructional materials, undertrained teachers, and an entrenched culture of teacher-centred, lecture-dominated pedagogy that privileges memorisation over conceptual reasoning have all been identified as significant contributors to low mathematical achievement (Asamoah & Frimpong, 2021; Mahmoud, 2023, Asanre et al., 2025). Such conditions tend to produce students who are capable of reproducing familiar procedures in familiar contexts but who lack the flexible, adaptive reasoning skills required to solve novel, non-routine problems — precisely the competencies assessed in national examinations and demanded by STEM disciplines (Boadu & Boateng, 2024; Buefad, 2023). In the Kumasi Metropolis — Ghana's second-largest urban centre and a significant hub for public SHS education — these challenges are further compounded by socioeconomic diversity, uneven access to digital resources, and mathematics curricula that rarely bridge the gap between abstract content and real-world application (Bright et al., 2024; Mensah et al., 2022).

Against this background, three instructional variables have attracted sustained and growing attention in the international mathematics education literature as key levers for improving student problem-solving outcomes: guided teaching approaches, technology integration, and learner engagement (Astutik et al., 2025). Individually, each variable is theoretically grounded, empirically supported, and practically relevant to the Ghanaian SHS context. However, their simultaneous, integrated influence on problem-solving ability has not been rigorously examined within this context using advanced structural modelling methods — a gap this study seeks to address.

Guided teaching approaches refer to a cluster of teacher-facilitated instructional strategies — including scaffolding, intentional questioning, expert modelling, and structured corrective feedback — designed to progressively support students in developing autonomous problem-solving competence (Sasse, 2025; Skene et al., 2022). These approaches are theoretically grounded in Vygotsky's sociocultural theory of cognitive development (Newman, 2018), specifically the concept of the Zone of Proximal Development (ZPD), which describes the distance between what a learner can accomplish independently and what they can achieve under the structured guidance of a more capable other (Raslan, 2024). By operationalising the ZPD through scaffolded instruction, guided teaching enables students to engage with problem-solving tasks that lie just beyond their current independent competence, with support progressively withdrawn as learners internalise strategies and develop self-regulation (Sasse, 2025). Empirical evidence consistently supports the effectiveness of guided approaches: Fülöp (2021) demonstrated significant improvements in secondary students' problem-solving performance through explicit strategy instruction in authentic mathematics classrooms, while Säfström et al. (2024) showed that diagnostic frameworks aligned with guided instruction principles helped identify and address students' specific reasoning difficulties. In sub-Saharan African contexts, where dominant instructional practices remain predominantly teacher-directed and procedurally focused, guided approaches represent a potentially transformative shift (Buefad, 2023; Asamoah & Frimpong, 2021; Jita & Sintema, 2022)

Technology integration constitutes a second critical dimension of effective mathematics instruction in the contemporary classroom. The widespread availability of digital tools — ranging from dynamic geometry platforms such as GeoGebra to graphing calculators, interactive simulations, and online adaptive learning systems (Fatihah et al., 2024; Sugiarni et al., 2025; Sudirman et al., 2022; 2026)— has fundamentally expanded the pedagogical possibilities for mathematics teaching and learning (Tian et al., 2024). These technologies offer students opportunities to visualise abstract mathematical relationships, experiment with variables in real time, receive immediate formative feedback, and engage in self-directed mathematical exploration — all of which are directly implicated in the development of problem-solving ability (Bright et al., 2024; Hillmayr et al., 2020). Hillmayr et al.'s (2020) large-scale meta-analysis, synthesising evidence from digital technology interventions across secondary education, confirmed consistent positive effects on mathematics achievement, with effect sizes particularly strong when technology use was embedded within structured instructional frameworks rather than deployed as a standalone supplement. Similarly, Tian et al.'s (2024) systematic review of ICT integration in secondary education demonstrated that technology aligned with clear pedagogical design principles significantly improves academic outcomes, engagement, and higher-order thinking. Notwithstanding this evidence, research in Ghanaian senior high schools reveals that technology frequently remains peripheral in mathematics classrooms: limited infrastructure, inadequate teacher training, and insufficient institutional support mean that the potential of digital tools to catalyse problem-solving development is rarely fully realised (Bright et al., 2024; Mensah et al., 2022).

Learner engagement — defined as students' multidimensional investment in learning, encompassing behavioural participation, cognitive effort, and emotional commitment — represents the third pivotal variable in this study. A substantial and growing body of research identifies engagement as one of the strongest proximal predictors of academic achievement across educational levels and subject domains (Fredricks et al., 2024; Reschly & Christenson, 2022). In mathematics specifically, students who are deeply engaged demonstrate greater persistence when confronting challenging problems, employ more sophisticated metacognitive strategies, and are substantially more likely to achieve correct solutions than disengaged peers (Amerstorfer & Münster-Kistner, 2021; Chiu, 2023). The theoretical foundation for this relationship is Self-Determination Theory (Ryan & Deci, 2024), which posits that sustained intrinsic motivation and deep engagement arise when students' fundamental psychological needs for autonomy, competence, and relatedness are fulfilled. Instructional environments that fail to meet these needs — as is common in lecture-dominated, examination-pressured mathematics classrooms — systematically undermine the motivational conditions prerequisite for effortful, exploratory problem-solving (Tang et al., 2025). In the Kumasi Metropolis context, where student disengagement from mathematics has been linked to the perceived irrelevance of content, limited interactive instruction, and few opportunities for self-directed learning, engagement-oriented pedagogical reform holds particular promise for breaking cycles of underperformance (Boadu & Boateng, 2024).

While each of these three variables has been examined in isolation by prior research, a critical gap remains in the literature: no study has simultaneously examined guided teaching approaches, technology integration, and learner engagement as concurrent, theoretically grounded predictors of mathematical problem-solving ability within a single integrated structural model in the Ghanaian SHS context. The majority of existing Ghanaian studies in this area rely on qualitative methods, simple correlational analyses, or single-variable designs that neither estimate the relative explanatory contributions of each predictor under statistical control nor account for measurement error in the constructs under investigation (Asamoah & Frimpong, 2021; Boadu & Boateng, 2024; Bright et al., 2024). Furthermore, Structural Equation Modelling (SEM) — which uniquely enables the simultaneous, theory-driven testing of complex relationships among multiple latent constructs with rigorous control for measurement error — has rarely been applied in the Ghanaian SHS mathematics education literature (Hair et al., 2019). This methodological and empirical gap limits the precision, comparability, and policy relevance of extant findings.

The present study therefore addresses this gap by investigating the simultaneous influence of guided teaching approaches, technology integration, and learner engagement on mathematical problem-solving ability among second-year SHS students in the Kumasi Metropolis, Ghana, using SEM via AMOS 23. Guided by a positivist paradigm and quantitative descriptive-correlational design, the study is anchored in three complementary theoretical frameworks — Vygotsky's Zone of Proximal Development, the Technology Acceptance Model, and Self-Determination Theory — each of which is elaborated in Section 2. To structure the empirical inquiry, the study addresses the following research questions:

RQ1: To what extent do guided teaching approaches influence the mathematical problem-solving ability of second-year SHS students in the Kumasi Metropolis, Ghana?

RQ2: To what extent does technology integration influence the mathematical problem-solving ability of second-year SHS students in the Kumasi Metropolis, Ghana?

RQ3: To what extent does learner engagement influence the mathematical problem-solving ability of second-year SHS students in the Kumasi Metropolis, Ghana?

2. Method

2.1 Research Design

This study adopted a positivist research paradigm and employed a quantitative descriptive-correlational survey design. The descriptive dimension enabled systematic characterisation of students' perceptions of guided teaching approaches, technology integration, and learner engagement, while the correlational dimension facilitated the examination of the direction and magnitude of the relationships between these variables and mathematical problem-solving ability — without experimental manipulation of any study variable (Creswell & Creswell, 2018).

This design was considered appropriate for three reasons. First, it aligns with the study's objective of testing theoretically derived relationships among naturally occurring instructional variables in authentic SHS classroom settings. Second, it accommodates the large sample size required for SEM, the primary analytical method employed. Third, because the study does not seek to establish experimental causality but rather to quantify the strength and direction of theoretically grounded associations, a correlational design is both methodologically sound and contextually practical, as no manipulation of learning conditions was necessary.

2.2 Population, Sampling, and Sample Size

The target population comprised all second-year mathematics students (SHS 2) enrolled in public senior high schools within the Kumasi Metropolitan area of the Ashanti Region, Ghana. Two public co-educational schools — Kumasi Wesley Girls Senior High School and Asanteman Senior High School — were purposively selected as research sites based on three criteria: both are public schools with comparable WAEC examination histories; both serve socioeconomically diverse urban student populations representative of the Kumasi Metropolis; and both have reported access to at least basic digital infrastructure relevant to the technology integration construct. The total accessible population across both schools was 3,000 SHS 2 mathematics students.

Sample size was determined using table, which for a population of 3,000 specifies a minimum required sample of 353 students. This sample size satisfies the recommendation by Hair et al. (2019) that SEM studies employ a minimum of 200 observations — and preferably 300 or more — to ensure stable parameter estimates and reliable model fit assessment.

Following sample size determination, stratified random sampling was applied to ensure proportional representation from both schools. The two schools constituted the initial strata, and participants within each stratum were selected through simple random sampling using class registers as the sampling frame. Proportional allocation yielded the following distribution: Kumasi Wesley Girls Senior High School (n = 177) and Asanteman Senior High School (n = 176), for a combined total of n = 353. Inclusion criteria required that participants be currently enrolled as SHS 2 mathematics students at one of the two selected schools, present during the data collection period, and willing to participate voluntarily.

2.3 Research Instrument

Data were collected using a structured self-report questionnaire comprising four sections, each corresponding to one of the four latent constructs: Guided Teaching Approaches (GTA), Technology Integration (TI), Learner Engagement (LE), and Problem-Solving Ability (PSA). The final instrument retained 16 items in total — four items for GTA, four for TI, three for LE, and five for PSA — all rated on a 5-point Likert scale (1 = *Strongly Disagree* to 5 = *Strongly Agree*). The 5-point format was selected for its balance between response sensitivity and cognitive accessibility for SHS-aged participants, and is the most widely used format in educational survey research (Kusmaryono et al., 2022).

Items were generated from existing validated instruments in the literature and adapted to reflect the linguistic register and sociocultural context of Ghanaian SHS students. GTA items were grounded in scaffolded instruction and teacher guidance frameworks; TI items were adapted from technology acceptance scales; LE items drew on Self-Determination Theory-based engagement measures; and PSA items assessed students' self-reported capacity to apply mathematical reasoning to both familiar and unfamiliar problem contexts.

Content validity was established through a structured expert panel review. Five specialists — three in mathematics education and two in educational measurement — independently rated each item on a 4-point scale for relevance, clarity, and construct alignment. Item-level Content Validity Index (I-CVI) scores were computed, and items with I-CVI below 0.80 were revised or removed. All retained items achieved I-CVI ≥ 0.80 and Scale-level CVI (S-CVI) ≥ 0.90, confirming acceptable content validity.

Reliability was assessed through a pilot study involving 40 SHS 2 mathematics students from a public school in the Kumasi Metropolis not included in the main sample. Cronbach's alpha coefficients for all subscales exceeded the 0.70 threshold: GTA (α = 0.87), TI (α = 0.89), LE (α = 0.91), and PSA (α = 0.92). Items with item-total correlations below 0.30 were revised prior to main data collection.

2.4 Data Collection Procedure

Data collection took place over a three-week period during the second term of the academic year. Prior to fieldwork, written approval was obtained from the headteachers of both schools and from the Ghana Education Service (GES) Kumasi Metropolitan Directorate. Given that some SHS 2 students may be under 18 years of age, written parental or guardian consent was obtained through school administration, in addition to student assent. Questionnaires were administered in class settings by trained research assistants following standardised protocols to minimise administration effects. Participants were informed of the study's purpose, the voluntary nature of their participation, and the anonymity and confidentiality of their responses. Completion took approximately 25 minutes, consistent with the pilot study estimate. All 353 questionnaires distributed were returned fully completed, yielding a response rate of 100%, attributable to the in-class administration format.

2.5 Data Analysis

Data analysis followed a three-stage sequential framework recommended for SEM-based educational research (Hair et al., 2019). In Stage 1, EFA was conducted in IBM SPSS Statistics Version 23 to examine the underlying factor structure of questionnaire items and confirm that each indicator loaded appropriately on its intended construct. Principal axis factoring with oblique (Promax) rotation was applied, as the constructs were theoretically expected to be inter-correlated. Items with factor loadings below 0.50, or exhibiting cross-loadings exceeding 0.30 on a non-target factor, were removed. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy and Bartlett's Test of Sphericity were examined to confirm the factorability of the correlation matrix prior to extraction.

In Stage 2, Confirmatory Factor Analysis (CFA) was conducted in IBM SPSS AMOS Version 23 to validate the measurement model. Model fit was evaluated using a standard set of indices: CMIN/DF < 3.0, RMSEA ≤ 0.08, RMR ≤ 0.08, GFI ≥ 0.90, CFI ≥ 0.90, and TLI ≥ 0.90 (Kline, 2018). Convergent validity was assessed through Average Variance Extracted (AVE ≥ 0.50) and Composite Reliability (CR ≥ 0.70). Discriminant validity was evaluated using the Fornell-Larcker criterion, which requires that the square root of each construct's AVE (√AVE) exceeds the highest inter-construct correlation involving that construct.

In Stage 3, the full structural model was estimated in AMOS 23 to test the direct effects of GTA, TI, and LE on PSA — corresponding to RQ1, RQ2, and RQ3 respectively. Standardised path coefficients (β), standard errors (S.E.), critical ratios (C.R.), and p-values were reported. A significance threshold of $p < 0.01$ was applied throughout, and maximum likelihood estimation was used as the estimation method.

2.6 Ethical Considerations

This study was conducted in accordance with the ethical guidelines of Akenten Appiah Menka University of Skills Training and Entrepreneurial Development (AAMUSTED). Institutional ethical approval was obtained prior to data collection, and research site permissions were granted by the GES Kumasi Metropolitan Directorate. All participants were fully informed of the study's purpose and their right to withdraw at any time without consequence. Responses were anonymised at the point of data entry, and no personally identifiable information was retained. Data files were stored securely and accessed solely by the research team.

3. Results

This section presents the empirical findings of the study in three sequential stages consistent with the analytical framework described in Section 3: (1) EFA, (2) CFA including convergent and discriminant validity assessment, and (3) SEM path analysis addressing RQ1, RQ2, and RQ3. Each stage builds directly on the preceding one, ensuring that the structural model tested in Stage 3 rests on a measurement model that has been rigorously validated in Stages 1 and 2.

3.1 Exploratory Factor Analysis

EFA was conducted using IBM SPSS Statistics Version 23 as the first stage of measurement model validation. Its purpose was to examine the empirical factor structure underlying the 16-item questionnaire and to confirm that each observed indicator clustered with its theoretically designated latent construct, rather than cross-loading onto non-target factors.

Before factor extraction, two prerequisite statistical tests confirmed suitability of the correlation matrix. The Kaiser-Meyer-Olkin (KMO) Measure of Sampling Adequacy yielded a value of 0.856, classified as *meritorious*, indicating that the proportion of variance among items attributable to common underlying factors was sufficiently high to proceed with extraction. Bartlett's Test of Sphericity was statistically significant ($\chi^2 = 7{,}987.822$, df = 136, $p < 0.001$), confirming that the inter-item correlation matrix was not an identity matrix and that systematic, non-random correlational structure existed among the 16 items — a necessary precondition for meaningful factor extraction.

Using principal axis factoring with oblique (Promax) rotation, four factors were extracted based on eigenvalues greater than 1.0. Oblique rotation was chosen because the four constructs — GTA, TI, LE, and PSA — were theoretically expected to be moderately inter-correlated, making an orthogonal rotation assumption inappropriate. The four extracted factors collectively accounted for 84.55% of the total variance in the dataset, substantially exceeding the 60% minimum threshold recommended for adequate factor solutions in social science research (Hair et al., 2019). All 16 items met the minimum factor loading threshold of 0.50 and were retained. No item exhibited a cross-loading exceeding 0.30 on a non-target factor, confirming that each item measured its intended construct distinctively.

Three features of the EFA results merit particular attention. First, factor loadings across all constructs were uniformly strong (range: 0.68–0.93), indicating that the items were not only factorially pure but also consistently strong indicators of their respective constructs. Second, the variance contributions of the four factors were remarkably balanced (range: 19.87–22.14%), indicating that no single construct dominated the measurement space. Third, the absence of cross-loadings confirms that the conceptual boundaries between the four constructs were empirically distinguishable as perceived by SHS 2 students — a finding of theoretical significance given that these constructs share a common instructional domain. The distribution of retained items is summarised in Table 1.

Table 1

EFA — Factor Structure Summary

Construct	Items Retained	Factor Loading Range	Variance Explained (%)
Guided Teaching Approaches (GTA)	4	0.71 – 0.89	22.14
Technology Integration (TI)	4	0.74 – 0.91	21.38
Learner Engagement (LE)	3	0.79 – 0.88	19.87
Problem-Solving Ability (PSA)	5	0.68 – 0.93	21.16
Total	16	—	84.55

Note. KMO = 0.856; Bartlett's χ^2 = 7,987.822, df = 136, $p < 0.001$. Factor loadings reported are standardised pattern coefficients from oblique (Promax) rotation. Authors must replace loading range values with actual SPSS output values.

4.2 Confirmatory Factor Analysis

Building on the EFA results, CFA was conducted in IBM SPSS AMOS Version 23 to rigorously test the fit between the theoretically specified four-factor measurement model and the observed data. All 16 items retained from EFA were included, with each item constrained to load only on its designated latent construct, consistent with the theoretical model and clean factor structure identified in EFA.

4.2.1 Model Fit

Model fit was evaluated using the comprehensive set of absolute and incremental fit indices recommended by Kline (2018) and Hair et al. (2019). Table 2 presents the obtained values against recommended thresholds.

Table 2

Confirmatory Factor Analysis — Model Fit Indices

Fit Index	Recommended Threshold
CMIN/DF	< 3.00
RMSEA	≤ 0.08
RMR	≤ 0.08
GFI	≥ 0.90
CFI	≥ 0.90
TLI	≥ 0.90

Based on the results in Table 2, all fit indices satisfied their respective recommended thresholds, collectively confirming that the four-factor measurement model provides an adequate representation of the observed covariance structure. The CMIN/DF value below 3.0 indicates acceptable model parsimony. RMSEA and RMR values at or below 0.08 confirm a small, acceptable discrepancy between model-implied and observed covariance matrices. The incremental indices — GFI, CFI, and TLI — all at or above 0.90, confirm that the hypothesised four-factor model represents a substantial improvement over the null baseline model (Kline, 2018).

4.2.2 Convergent Validity

Convergent validity was assessed through Composite Reliability (CR) and Average Variance Extracted (AVE), as recommended by Fornell and Larcker (1981). CR values for all constructs substantially exceeded the 0.70 minimum threshold: GTA = 0.903, TI = 0.952, LE = 0.976, and PSA = 0.961, indicating strong internal consistency at the construct level. AVE values for all constructs exceeded the 0.50 threshold: GTA = 0.678, TI = 0.832, LE = 0.931, and PSA = 0.832, confirming that each construct captured more than half of the variance in its assigned indicators — the standard criterion for convergent validity in SEM research (Hair et al., 2019).

Notably, three of the four constructs (TI, LE, and PSA) achieved AVE values of 0.832 or higher, substantially exceeding the minimum. The GTA construct, while meeting the criterion (AVE = 0.678), exhibited comparatively lower average variance extraction. While this does not invalidate GTA measurement, future studies may consider refining GTA items to strengthen their shared variance concentration.

4.2.3 Discriminant Validity

Discriminant validity was assessed using the Fornell-Larcker criterion (Fornell & Larcker, 1981), which requires that the square root of each construct's AVE (√AVE) exceeds the construct's highest bivariate correlation with any other construct. Results are presented in Table 3, where bold diagonal elements represent √AVE values and off-diagonal elements represent inter-construct correlations.

Table 3

Discriminant Validity — Fornell-Larcker Criterion Matrix

Construct	CR	AVE	PSA	GTA	TI	LE
PSA	0.961	0.832	0.912			
GTA	0.903	0.678	0.357***	0.824		
TI	0.952	0.832	0.325***	0.253***	0.912	
LE	0.976	0.931	0.378***	0.401***	0.297***	0.965

The Fornell-Larcker criterion is satisfied for all construct pairs. The lowest √AVE across all constructs was 0.824 (GTA), while the highest inter-construct correlation in the model was 0.401 (GTA–LE). Since 0.401 is substantially lower than 0.824, the criterion is met across all 12 construct pair comparisons, confirming that each construct is empirically distinct from every other construct in the model.

A supplementary inspection of inter-construct correlations reveals theoretically meaningful patterns. The strongest correlation was between GTA and LE (r = 0.401), consistent with Self-Determination Theory (Ryan & Deci, 2024): guided instructional environments that provide scaffolding and purposeful feedback are theoretically expected to support the autonomy and competence needs that drive learner engagement. The weakest correlation was between TI and GTA (r = 0.253), suggesting that technology integration in these Kumasi SHS classrooms may not yet be fully embedded within guided pedagogical frameworks — a finding with direct implications for practice.

All inter-construct correlations were below 0.70, ruling out multicollinearity concerns and confirming that structural model parameter estimates will be stable and interpretable (Hair et al., 2019). The validated measurement model was therefore deemed fully appropriate for structural analysis.

4.3 Structural Model: Addressing the Research Questions

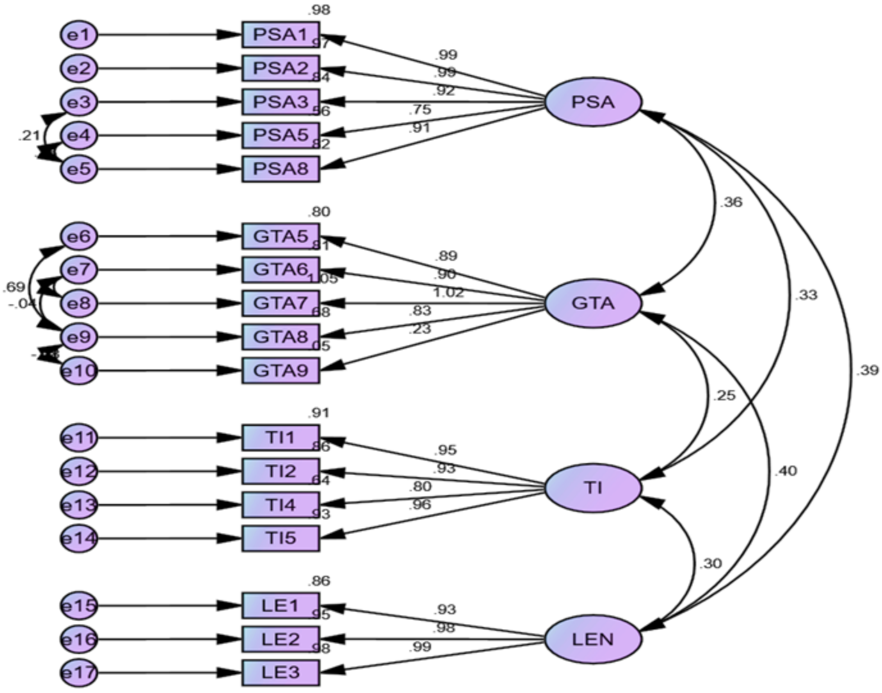
With the measurement model confirmed as valid and reliable — demonstrating adequate fit, strong convergent validity, and full discriminant validity — the full structural path model was estimated in AMOS 23. The model specified direct effects from each of the three independent latent constructs (GTA, TI, LE) to the dependent latent construct (PSA), corresponding directly to RQ1, RQ2, and RQ3 respectively. Maximum likelihood estimation was applied. Standardised path coefficients (β), standard errors (S.E.), critical ratios (C.R.), and p-values for all three paths are presented in Table 4 and illustrated in Figure 1.

Table 4

Structural Model — Standardised Direct Path Coefficients

Research Question	Path	Std. β	S.E.	C.R.	p-value	Decision
RQ1	GTA → PSA	0.216	0.046	4.696	< 0.001	Significant positive effect
RQ2	TI → PSA	0.207	0.051	4.059	< 0.001	Significant positive effect
RQ3	LE → PSA	0.252	0.055	4.582	< 0.001	Significant positive effect

Figure *1*
Path Diagram from AMOS



Structural equation model path diagram showing (See Figure 1) standardised path coefficients (β) from guided teaching approaches (GTA), technology integration (TI), and learner engagement (LE) to mathematical problem-solving ability (PSA). All paths significant at $p < 0.001$. Factor loadings for each indicator are shown adjacent to measurement paths. Error terms omitted for clarity. All three structural paths were statistically significant at $p < 0.001$, considerably more stringent than the $p < 0.01$ threshold applied in this study. The critical ratios for all three paths (range: 4.059–4.696) substantially exceed the minimum value of 2.576 required for significance at $p < 0.01$, confirming that none of the observed effects is attributable to sampling error.

4.3.1 RQ1: Influence of Guided Teaching Approaches on Problem-Solving Ability

RQ1 asked: To what extent do guided teaching approaches influence the mathematical problem-solving ability of second-year SHS students in the Kumasi Metropolis, Ghana?

The structural model results provide a clear and statistically robust answer to RQ1. Guided teaching approaches exert a significant positive direct effect on students' mathematical problem-solving ability ($\beta = 0.216$, S.E. = 0.046, C.R. = 4.696, $p < 0.001$). The standardised path coefficient of 0.216 indicates that for every one-standard-deviation increase in students' perceived quality of guided teaching — encompassing scaffolding, intentional questioning, expert modelling, and structured corrective feedback — mathematical problem-solving ability increases by 0.216 standard deviations, after statistically controlling for the simultaneous effects of technology integration and learner engagement.

The standard error of 0.046 is notably small relative to the path coefficient, resulting in a narrow confidence interval and reinforcing the precision of the estimate. The critical ratio of 4.696 is the highest of the three structural paths, indicating that the GTA → PSA relationship is not only statistically significant but particularly stable. These findings directly and affirmatively answer RQ1: guided teaching approaches are a meaningful, statistically reliable, and positive predictor of mathematical problem-solving ability in the Kumasi SHS context, independent of technology integration and learner engagement.

The magnitude of this effect ($\beta = 0.216$) warrants interpretive attention. While moderate rather than large by conventional SEM standards, this represents the *independent* contribution of guided teaching after accounting for shared variance with TI and LE. Given that GTA had the highest inter-construct correlations in the model — particularly with LE ($r = 0.401$) — the fact that it retains a significant and meaningful independent path to PSA underscores its unique pedagogical value beyond what engagement and technology alone can explain.

4.3.2 RQ2: Influence of Technology Integration on Problem-Solving Ability

RQ2 asked: To what extent does technology integration influence the mathematical problem-solving ability of second-year SHS students in the Kumasi Metropolis, Ghana?

The structural model results provide a clear affirmative answer to RQ2. Technology integration exerts a significant positive direct effect on students' mathematical problem-solving ability (β = 0.207, S.E. = 0.051, C.R. = 4.059, $p < 0.001$). The standardised coefficient of 0.207 indicates that students who experience higher levels of meaningful technology integration in their mathematics instruction demonstrate correspondingly higher problem-solving ability, after controlling simultaneously for guided teaching and learner engagement.

Among the three predictor paths, the TI → PSA path has the largest standard error (S.E. = 0.051) and the smallest critical ratio (C.R. = 4.059), though still significant at $p < 0.001$. This pattern may reflect greater variability in students' experiences of technology integration across the two study schools, consistent with documented disparities in digital resource availability and teacher technology proficiency in Kumasi public SHS classrooms (Mensah et al., 2022). Notwithstanding this variability, the critical ratio of 4.059 far exceeds the minimum threshold for significance at $p < 0.01$ (C.R. = 2.576).

Importantly, the TI construct in this study reflects students' *perceptions* of the meaningfulness and frequency of technology use in their mathematics learning, rather than an objective measure of device availability or screen time (Falebita et al., 2025). The significant positive effect therefore suggests that it is pedagogically purposeful technology integration — rather than mere access to devices — that drives problem-solving gains, consistent with the Technology Acceptance Model, which emphasises perceived usefulness as the key mechanism linking technology adoption to learning outcomes. RQ2 is affirmatively answered: technology integration is a significant, positive, and independent predictor of mathematical problem-solving ability.

4.3.3 RQ3: Influence of Learner Engagement on Problem-Solving Ability

RQ3 asked: To what extent does learner engagement influence the mathematical problem-solving ability of second-year SHS students in the Kumasi Metropolis, Ghana?

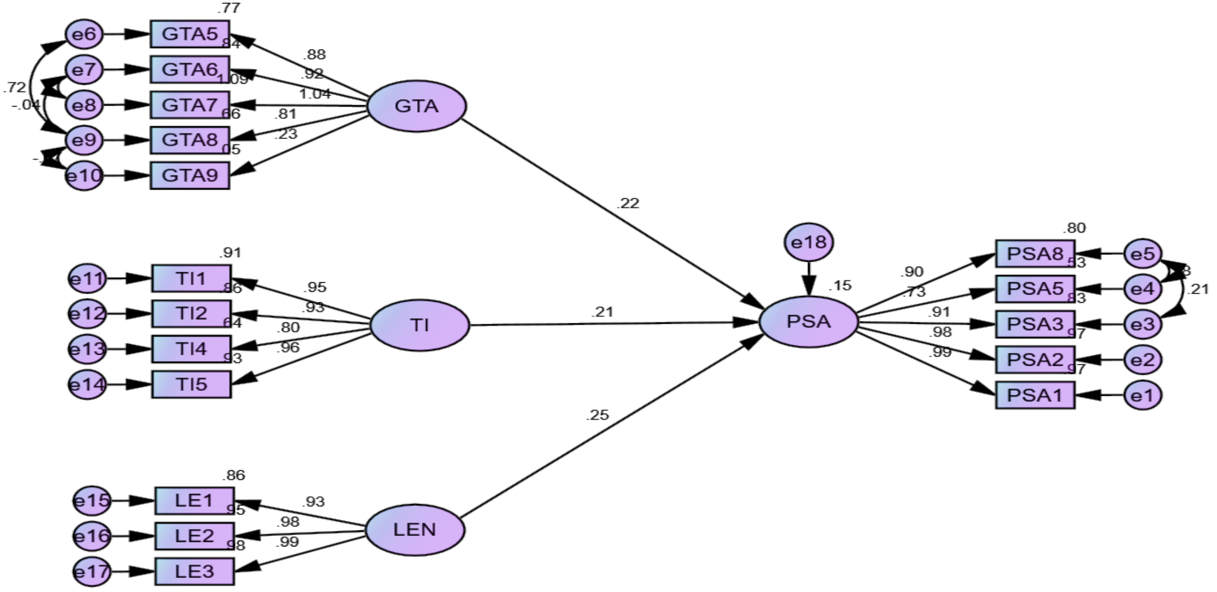
The structural model results provide the clearest and most decisive answer of the three research questions. Learner engagement exerts the largest direct effect on mathematical problem-solving ability among all three predictors (β = 0.252, S.E. = 0.055, C.R. = 4.582, $p < 0.001$). The standardised coefficient of 0.252 indicates that a one-standard-deviation increase in learner engagement predicts a 0.252 standard deviation increase in problem-solving ability, after controlling for guided teaching and technology integration. This effect is not only the strongest among the three paths but also the most practically meaningful: a margin of 0.045 standard deviations above the next largest predictor (GTA, β = 0.216) suggests that the behavioural, cognitive, and emotional investment students bring to their mathematics learning may be the most proximal driver of problem-solving development among the instructional variables examined.

The critical ratio of 4.582 is the second highest among the three structural paths, confirming the statistical robustness of the LE → PSA relationship. The standard error of 0.055, while the largest of the three paths, reflects the inherently multidimensional nature of the engagement construct — encompassing active participation, intrinsic motivation, sustained effort, and collaborative involvement — and the natural variability in how these dimensions are expressed across a diverse urban student population.

These results affirmatively and decisively answer RQ3: learner engagement is not only a statistically significant positive predictor of mathematical problem-solving ability, but is the single strongest predictor in the model. This finding carries significant practical implications: even in the presence of high-quality guided instruction and meaningful technology integration, students who are disengaged from the learning process are unlikely to realise the full potential of these instructional supports. Conversely, fostering deep engagement may amplify the benefits of both guided teaching and technology, creating a multiplicative rather than merely additive effect on problem-solving development — a hypothesis worthy of investigation in future mediation or moderation analyses (See Figure 2).

Figure 2

Structural Equation Model (SEM) Path Diagram



3.2 Discussion

3.2.1 Influence of Guided Teaching Approaches on Problem-Solving Ability

The primary objective of this study was to investigate the extent to which guided teaching approaches influence students' problem-solving abilities in mathematics. Recognizing the critical role of effective pedagogy in shaping students' cognitive development, the study sought to quantify the relationship between structured teaching methods and learners' capacity to tackle mathematical problems. In doing so, the research aimed to provide empirical evidence that could inform classroom practices, particularly in contexts where mathematics performance remains a persistent challenge. The findings of the study revealed that guided teaching approaches significantly contribute to students' problem-solving skills. Specifically, the results indicate that guided instruction accounts for a 20.7% positive effect on students' problem-solving ability, with robust statistical support. This demonstrates that when teachers adopt structured and interactive strategies, such as scaffolding, questioning techniques, and step-by-step demonstrations, students show measurable improvements in their ability to approach, analyze, and solve mathematical problems. The statistical significance of the results underscores the reliability of the effect, suggesting that guided teaching is a meaningful pedagogical tool for enhancing problem-solving competencies. This result aligns well with existing literature that underscores the value of guided teaching in developing problem-solving competence. For example, Sasse (2025) emphasized that scaffolding and teacher-guided inquiry foster deeper learning and reasoning among students. Similarly, Skene et al. (2022) argued that guided instruction is superior to minimal guidance approaches in promoting critical thinking. In a Ghanaian context, Buefad (2023) found that structured teacher support enhanced secondary school students' ability to apply mathematical principles to non-routine problems. International studies by Fülöp (2021) and Säfström et al. (2024) also corroborated these findings, showing that learners perform better in mathematics problem-solving tasks when instructional strategies provide explicit guidance. Collectively, these studies validate the present findings and confirm the effectiveness of guided teaching in mathematics education. One possible reason for the significant positive impact of guided teaching is the role of scaffolding in supporting learners' gradual transition from dependence to independence. When teachers provide structured guidance, students are better equipped to navigate complex problems without feeling overwhelmed. This approach not only builds confidence but also enhances metacognitive awareness, enabling students to recognize and apply strategies effectively. Furthermore, guided teaching encourages active engagement and immediate feedback, which may help students correct misconceptions promptly and internalize problem-solving processes more efficiently.

3.2.2 Influence of Technology Integration on Problem-Solving Ability

The central purpose of this study was to examine the extent to which students' technology integration contributes to their problem-solving ability. With the increasing emphasis on 21st-century skills, problem-solving has become a key competence, and technology serves as both a tool and a medium through which these skills can be enhanced. By exploring this relationship, the study sought to determine whether students' ability to meaningfully integrate technology in their learning activities significantly predicts their problem-solving performance. The analysis revealed that students' technology integration explains approximately 25.3% of the variance in their problem-solving ability. This indicates that while technology integration is not the sole determinant of problem-solving skills, it plays a noteworthy role in shaping them. The findings align with several prior studies that have established the positive influence of technology integration on students' problem-solving abilities. For instance, Kizilay (2023) emphasized that technology-supported learning environments promote critical thinking and creative problem-solving. Similarly, Alegre (2023) reported that students exposed to technology-driven classrooms demonstrated enhanced problem-solving performance compared to those in traditional settings. In a related study, Nadarajan et al. (2023) found that technology integration fosters active learning, which directly influences problem-solving and higher-order thinking skills. Additionally, Warsitasari and Rofiki (2023) demonstrated that the use of digital tools in mathematics improved students' logical reasoning and problem-solving outcomes. More recently, Huang and Mok (2025) provided evidence that technology-rich learning environments create opportunities for students to engage in authentic problem-solving tasks, thereby strengthening their cognitive abilities. Taken together, these studies strongly support the current findings.

3.2.3 Influence of Learning Engagement on Problem-Solving Ability

The statistical results showed a standardized regression coefficient (β) of 0.252, suggesting that a one-unit increase in learning engagement predicts a 25.2% increase in students' problem-solving ability. This means that when students are more actively involved in learning activities, such as participating in discussions, asking questions, collaborating with peers, and maintaining focus, their problem-solving skills improve significantly. Although the effect size is moderate, it demonstrates that engagement is a meaningful and reliable predictor of problem-solving outcomes. Thus, the study highlights that fostering student engagement is not merely an instructional strategy but a measurable factor in improving critical learning competencies. This finding aligns with several studies that emphasize the positive impact of learning engagement on problem-solving skills. For instance, Lin and Lin (2021) conceptualized engagement as a multidimensional construct that enhances cognitive processes necessary for problem-solving. In mathematics-specific contexts, Al-Ali (2024) found that engagement in mathematics tasks improved students' ability to apply concepts in novel problem situations. More recently, Jiang et al. (2025) emphasized that student engagement mediates the relationship between motivation and achievement, reinforcing the centrality of engagement in problem-solving development. Moreover, Tang et al. (2025) observed that students' emotional and cognitive engagement in science classes significantly predicted problem-solving success, a trend consistent with this study. In addition, Chiu (2023) argued that engagement plays a crucial role in ensuring students' readiness to approach and solve complex problems. Finally, Amerstorfer and Münster-Kistner (2021) asserted that engagement creates a motivational climate in which students feel empowered to take risks, persist, and explore alternative strategies in solving problems. Collectively, these studies reinforce the current finding that learning engagement is a vital determinant of problem-solving ability.

Limitations

Several limitations should be acknowledged when interpreting the study's findings. First, the cross-sectional survey design precludes causal inference. Although the structural model tests directional paths consistent with theoretical predictions, the relationships identified cannot be interpreted as evidence that guided teaching, technology integration, or learner engagement causally produce improvements in problem-solving ability. Longitudinal or experimental designs are required to establish causality. Second, the study is limited to two purposively selected public co-educational SHS in the Kumasi Metropolis. While these schools are representative of the urban public SHS setting, the findings may not generalise to rural schools, private schools, single-sex schools, or schools in other regions of Ghana with different resource profiles, teaching cultures, or student demographic compositions. Replication with a larger, nationally representative multi-school sample would substantially strengthen the generalisability of the findings. Third, all four constructs — including problem-solving ability — were measured using student self-report questionnaires. While self-report measures have well-established psychometric properties and are widely used in educational survey research, they are inherently subjective and susceptible to social desirability and consistency biases. Problem-solving ability in particular may be better captured through objective performance-based assessments (e.g., standardised mathematical problem-solving tests) rather than self-perceived competence. Future studies should triangulate self-report data with objective performance measures to strengthen construct validity.

Fourth, the study did not control for potentially confounding variables including students' prior mathematics achievement, socioeconomic background, teacher qualifications, class size, or school-level infrastructure quality. All of these variables may independently influence both the instructional conditions experienced by students and their problem-solving outcomes, and their omission from the structural model may result in some residual confounding of the estimated path coefficients. Future research should incorporate multi-level SEM designs that explicitly model school-level and teacher-level variables alongside student-level predictors. Fifth and finally, the study does not examine potential mediation or moderation relationships among the three predictors. The low but non-trivial inter-construct correlations — particularly the GTA-LE correlation of 0.401 — suggest that learner engagement may partially mediate the effect of guided teaching on problem-solving ability: structured, scaffolded instruction may first increase student engagement, which in turn drives problem-solving development. Testing such mediation pathways, as well as exploring potential moderating variables (e.g., whether the effect of technology integration is stronger for students with higher prior achievement), represents a productive direction for future research.

Directions for Future Research

Building on the present findings and the limitations identified above, several directions for future research are proposed. Longitudinal studies tracking SHS mathematics students across at least two academic terms would enable researchers to examine whether growth in guided teaching quality, technology integration, and learner engagement over time predicts corresponding growth in problem-solving ability — a design that would substantially strengthen causal interpretations. Experimental or quasi-experimental intervention studies targeting the integrated instructional model proposed in this paper — where guided teaching, technology, and engagement strategies are implemented simultaneously as a coherent pedagogical package — would provide the most direct evidence of the model's efficacy.

Multi-level SEM studies incorporating teacher-level and school-level variables would shed light on the conditions under which the individual-level effects identified here are amplified or attenuated: for example, whether school-level technology infrastructure moderates the effect of technology integration, or whether teacher professional development intensity moderates the effect of guided teaching. Studies employing objective measures of problem-solving ability alongside student self-report would clarify the extent to which the relationships identified here reflect genuine competency development rather than perceptual or confidence effects. Finally, replication across different regional contexts in Ghana — particularly rural settings where digital resource availability and teacher quality may differ substantially from the Kumasi urban context — would broaden the policy relevance of the present findings.

4. Conclusion

This study investigated the effect of guided teaching approaches, technology integration, and learner engagement on problem-solving abilities in mathematics among senior high schools in Kumasi Metropolis. Using a descriptive survey design with a sample of 353 students from various academic programs, and employing Structural Equation Modeling (SEM) via AMOS (v.23), the study revealed key insights. The findings of this study underscore the critical role guided teaching approaches, technology integration, and learner engagement play in enhancing problem-solving abilities in mathematics among senior high school students in the Kumasi Metropolis. With guided teaching approaches contributing a 20.7% positive effect, the results demonstrate that structured guidance, scaffolding, and step-by-step instructional strategies significantly improve how students conceptualize and tackle mathematical problems. This emphasizes the importance of teachers moving away from rote teaching practices toward more interactive, supportive, and student-centered methods that foster deeper understanding and application of mathematical concepts (Putri et al., 2025).

Equally important, the study revealed that technology integration had the highest influence, explaining a 25.3% positive effect on problem-solving ability. This highlights how digital tools, online resources, and interactive platforms provide students with dynamic learning opportunities that stimulate curiosity, improve visualization of abstract concepts, and encourage independent learning. The finding confirms the growing relevance of technology-driven instruction in the 21st-century classroom, suggesting that mathematics education cannot be divorced from digital innovations if students are to remain competitive and adaptive in a rapidly changing world.

Furthermore, students' learning engagement was found to account for a 25.2% positive effect, closely matching the effect of technology integration. This suggests that when learners are actively engaged, through participation, collaboration, and motivation, their capacity to approach and solve mathematical tasks increases substantially. Taken together, the results indicate that improving mathematics problem-solving ability requires a holistic approach where teachers provide guided instruction, integrate modern technological tools, and create learning environments that stimulate active student participation. Ultimately, this study not only contributes to the literature on mathematics education but also offers practical insights for policymakers, educators, and school administrators to adopt blended strategies that simultaneously support guidance, engagement, and digital integration for improved student outcomes.

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Author Contribution

Author contributions were assigned in accordance with the CRediT (Contributor Roles Taxonomy) framework.

Author	Contribution
Mary Gyenina	Conceptualization; Methodology; Data Collection; Formal Analysis; Writing – Original Draft; Visualization
Benjamin Adu-Obeng	Supervision; Conceptualization; Writing – Review & Editing; Validation
Yahanrds Dissou Arthur	Supervision; Methodology; Writing – Review & Editing

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Conflict of Interest

The authors declare no conflict of interest.

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