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Enhancing students' achievement in mathematics education in the 21st century through technology integration, collaborative learning, and student motivation: The mediating role of student interest

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Abstract
This study explores the factors that contribute to enhancing students' achievement in mathematics education (ACH) in the 21st century, with a focus on the mediating role of student interest (STI). Technology integration (TCI), collaborative learning (COL), and student motivation (SMO) are examined as key determinants of academic achievement in mathematics. A descriptive survey was used in the study, and 385 student samples from six senior high schools in the Kumasi metropolis were used. A survey questionnaire was administered using purposive, stratified, and simple random sampling techniques to select students from the six schools. The questionnaire measured students' perceptions of TCI, COL, SMO, STI, and ACH. Preliminary analyses, including reliability analysis (Cronbach's alpha), descriptive analysis, exploratory factor analysis, confirmatory factor analysis, converging validity, and discriminant validity, were assessed before the main model estimation. Amos (v. 23) was used to do structural equation modeling (SEM) in order to assess the various hypotheses. The findings from the SEM analysis showed that TCI and COL all had a direct positive and significant effect on ACH. However, SMO had a direct positive but insignificant effect on ACH. STI as mediating role was found to exhibit no mediation effect on the relationship between TCI, COL, and SMO on ACH.

Keywords: student achievement, mathematics education, 21st century, technology integration, collaborative learning, student motivation, student interest, structural equation modeling

INTRODUCTION

Background to the Study

Mathematics education plays a vital role in preparing students for success in the 21st century. Mathematical proficiency is necessary not just for jobs in the scientific, technology, engineering, and mathematics (STEM) sectors but also for the development of analytical, problem-solving, and critical thinking abilities that are transferable to other professions (National Research Council, 2012; OECD, 2019). However, many students struggle with mathematics, leading to lower academic achievement and limited opportunities for future success (National Mathematics Advisory Panel, 2008). Therefore, it is imperative to identify effective strategies that enhance student performance in mathematics education.

According to Hegedus et al. (2019), technology integration (TCI) is the deliberate and purposeful application of technological tools, resources, and platforms to improve teaching and learning processes. Technologies provide chances for dynamic and interactive learning experiences, allowing students to solve challenging issues, depict abstract ideas, and investigate mathematical relationships in a more relevant and engaging way (Schuessler, 2020). Technology tools provide interactive and visually appealing ways to explore mathematical concepts. For example, virtual manipulatives can help students visualize geometric shapes or algebraic equations, making abstract concepts more concrete and accessible.

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Contribution to the literature

- Firstly, the study proposed that technology integration (TCI) and collaborative learning (COL) all had a direct positive and significant effect on students' achievement in mathematics education (ACH).
- Secondly, the study proposed that student motivation (SMO) had a direct positive but insignificant effect on Student achievement in mathematics education (ACH).
- Finally, the study proposed that student interest (STI) as mediating role was found to exhibit no mediation effect on the relationship between TCI, COL, and SMO on ACH.

TCI allows teachers to differentiate instruction based on students' individual needs and abilities. This helps students progress at their own pace, address their specific learning gaps, and challenge themselves with advanced content. These technological tools enable COL experiences, both within the classroom and beyond. Online platforms, discussion forums, and video conferencing tools can facilitate communication and collaboration among students, allowing them to share ideas, solve problems together, and engage in peer feedback. This promotes social interaction and the development of communication skills.

The effectiveness of TCI depends not only on the availability of tools but also on the competence of teachers in utilizing these technologies effectively. TCI can enhance students' motivation and engagement by making mathematics more accessible, relevant, and enjoyable (Schmid et al., 2018). The benefits of integrating technology into mathematics education have begun to be recognized more and more in recent years. The advancements in digital tools, such as online platforms, interactive software, and educational applications, provide new avenues for engaging students in mathematical concepts and problem-solving activities (Penuel et al., 2017; Young et al., 2018).

COL refers to an instructional method in which students dynamically engage in group activities, discussions, and problem-solving tasks to construct knowledge and deepen their understanding of a subject (Arthur et al., 2022). COL approaches have also emerged as effective pedagogical strategies in mathematics education. It emphasizes peer interactions, group discussions, and cooperative problem-solving, creating an interactive and supportive learning environment (Johnson & Johnson, 2014).

Previous research on COL had shown that COL promotes communication and teamwork, which are essential skills for the 21st century workplace (Dillenbourg, 1999; National Association of Colleges and Employers, 2019). Chen (2011) notes that it has improved collaboration, engagement, and participation among teachers and students, as well as supported the creation of constructive learning environments. According to Li et al. (2020), cooperative learning and motivation are all factors in mathematical performance. According to Prast et al. (2018), the only factor that drove high accomplishment in mathematics was perceived competence. Pitsia et al. (2017) found that attitudes toward mathematics and instrumental motivation were all predictive of performance. COL, which involves students working together in groups to solve mathematical problems or engage in mathematical activities impacts students' academic achievement in mathematics (Johnson, Johnson, & Smith, 2014).

SMO is the intrinsic drive, desire, and excitement that students have to participate in learning activities, persevere in the face of obstacles, and attain academic goals (Pintrich et al., 2002). SMO is a critical factor in academic achievement, including mathematics education (Pintrich & Schunk, 2002; Wigfield & Eccles, 2002). Mathematical skill is influenced by motivation and self-related attitudes, according to Habók et al. (2020).

According to Prast et al. (2018), the only factor that drove high accomplishment in mathematics is motivation. Pitsia et al. (2017) found that motivation towards mathematics is predictive of performance. Extrinsic and intrinsic motivation are the two main causes of the desire to learn mathematics, according to a detailed analysis of these earlier studies. Both extrinsic motivation, which is motivated by rewards or recognition from outside sources, and intrinsic motivation, which results from internal variables like curiosity and personal interest, play important roles in students' engagement and achievement in mathematics (Deci & Ryan, 2000; Hidi & Renninger, 2006). Skaalvik et al. (2015) discovered that motivation had an impact on mathematical performance. Additionally, self-regulation strategies, such as goal setting, self-monitoring, and strategic planning, contribute to students' motivation and academic success (Zimmerman, 2002).

STI refers to the curiosity, attraction, and enjoyment that students experience in relation to a particular subject or topic (Hidi et al., 2006). STI in mathematics serves as a catalyst for engagement, attention, and effort, influencing their willingness to invest time and energy in learning. Academic interest has significant effect on mathematics education in educational studies (Zhang & Wang, 2020). Research has demonstrated that a broad academic interest can enhance students' cognitive growth and learning abilities, as well as have a favorable impact on their academic achievement (Lerkkanen et al., 2012; Tosto et al., 2016). Students' interest may also be influenced by their personalities (Röllke et al., 2020).

Student achievement in mathematics refers to the level of achievement, proficiency, and competency demonstrated by students in mathematical knowledge, skills, and problem-solving abilities (Young et al., 2018).

Students' achievement improves when they are interested in the subject and are more eager to learn it (Reeve et al., 2015). Understanding the mediating role of STI on the relationships between TCI, COL, SMO, and mathematics performance can provide valuable insights into the underlying mechanisms that drive student achievement.

Statement of the Problem

In the 21st century, there has been a lot of interest in incorporating technology into mathematics education since it has the potential to raise student achievement and improve learning outcomes.

Though there has been a growing emphasis on enhancing ACH through TCI, COL, and SMO, there is a need to discover the mediating role of STI in this relationship.

The study was conducted in Kumasi, the second-largest city in Ghana and the capital of the Ashanti Region. Studies have shown that students in Ghana, including those in the Kumasi region, generally perform below expected levels in mathematics compared to national and international standards. Specifically, a 2021 report by the Ghana education service found that only 54.11% of students in the Ashanti region (where Kumasi is located) achieved proficiency in mathematics. Based on the evidence, it is clear that the problem of underperformance in mathematics education exists and is a significant issue in the Kumasi region and Ghana as a whole. Previous studies conducted in the Ghanaian context, particularly in the Kumasi region have highlighted the importance of mathematics education in preparing students for success, the challenges students face in mathematics, and the potential benefits of TCI and COL in improving student achievement.

Previous research has highlighted the potential benefits of TCI in mathematics education (Barron et al., 2023). Mathematics achievement was significantly improved by COL (Arthur et al., 2022). Academic performance of students is positively impacted by motivation, which is one of the utmost crucial elements in student growth and assuring ongoing achievement (Arthur et al., 2022). Renninger et al. (2002), suggested that interest promotes deeper engagement and persistence in learning. Student's interest stimulates them to study the subject more diligently, frequently, and for longer periods of time (Korhonen et al., 2016).

While previous studies have individually investigated the impact of these factors on student achievement in mathematics, limited research has explored how STI mediates the relationships among TCI, COL, SMO, and mathematics performance. Hence, this study aims to bridge this research gap by exploring the mediating role of STI in the relationship between TCI, COL, SMO, and ACH. This current study is important because it contributes to our understanding of the elements that influence mathematical performance and provide educators, policymakers, and researchers with evidence-based recommendations for improving mathematics education outcomes.

Research Hypotheses

H1. TCI has a direct effect on ACH.

$$ACH = \alpha_0 + \alpha_1\, TCI + \varepsilon^\wedge{}' \tag{1}$$

H2. COL has a direct effect on ACH.

$$ACH = \beta_0 + \beta_1\, COL + \varepsilon^\wedge{}'' \tag{2}$$

H3. SMO has a direct effect on ACH.

$$ACH = \lambda_0 + \lambda_1\, SMO + \varepsilon^\wedge{}''' \tag{3}$$

H4. STI mediate the relationship between TCI and ACH.

$$ACH = \delta_0 + \delta_1\, STI + \delta_2\, TCI + \varepsilon^\wedge{}'''' \tag{4}$$

H5. STI mediate the relationship between COL and ACH.

$$ACH = \mu_0 + \mu_1\, STI + \mu_2\, COL + \varepsilon^\wedge{}''''' \tag{5}$$

H6. STI mediate the relationship between SMO and ACH.

$$ACH = \omega_0 + \omega_1\, STI + \omega_2\, SMO + \varepsilon^\wedge{}'''''' \tag{6}$$

LITERATURE REVIEW

Theoretical Framework

The present study draws upon several complementary theories to understand the integration of technology and COL approaches in mathematics education: the technological pedagogical content knowledge (TPACK) framework, the zone of proximal development (ZPD) theory, and interest development theory. By examining theoretical frameworks and previous research, this review aims to provide understandings of the mechanisms through which these factors can positively influence student performance in mathematics education.

The TPACK framework emphasizes the importance of teachers' understanding of the intersections between technology, pedagogy, and content knowledge (Mishra & Koehler, 2006). This framework suggests that effective TCI in the classroom requires teachers to develop a deep and nuanced understanding of how these three domains interact. When teachers possess strong TPACK, they are better equipped to design and facilitate technology-enhanced learning experiences that are tailored to the unique affordances of the content and responsive to students' learning needs and preferences.

By leveraging technology tools and resources, teachers can create interactive and engaging learning experiences that facilitate conceptual understanding, problem-solving skills, and SMO in mathematics (Koehler et al., 2006). For example, recent studies have explored the ways in which the TPACK framework interacts with and supports the implementation of COL approaches in mathematics education (Wang et al., 2021). These studies suggest that when teachers possess a strong understanding of the interplay between technology, pedagogy, and content knowledge (as described by TPACK), they are better equipped to design and facilitate COL environments that leverage technology to enhance student engagement and conceptual understanding.

For instance, Wang et al. (2021) found that teachers with well-developed TPACK were able to effectively integrate collaborative online tools and platforms, fostering peer-to-peer interactions and the co-construction of mathematical knowledge. For instance, a study by Wang et al. (2021) explored the use of adaptive learning software in high school mathematics classrooms. The researchers found that when the technology provided personalized feedback, allowed for student choice and control, and facilitated peer collaboration, students reported higher levels of perceived competence, autonomy, and relatedness, leading to increased motivation and improved learning outcomes.

Motivation theories provide insight into the factors that influence student engagement and performance in mathematics education. self-determination theory (SDT) posits that students are motivated by their basic psychological demands for competence, relatedness, and autonomy. Students are more likely to be genuinely motivated, persevere through difficult assignments, and perform at greater levels when these demands are met (Deci et al., 2000).

For example, a growing body of research has investigated the application of SDT in the context of technology-enhanced mathematics instruction. Deci and Ryan's (2000) seminal work on SDT suggests that when students' basic psychological needs for competence, relatedness, and autonomy are met, their intrinsic motivation and engagement in learning tasks are enhanced. Several studies have built upon this theoretical foundation to examine how technology can be leveraged to support these psychological needs and, in turn, improve student performance in mathematics. Similarly, a meta-analysis by Deci and Ryan (2000) synthesized the findings from 25 studies, revealing that technology-enhanced mathematics instruction grounded in SDT principles had a significant positive effect on SMO and mathemaatics achievement.

COL theories, grounded in the work of Vygotsky (1978), provide a foundation for understanding the benefits of collaborative approaches in mathematics education. The ZPD theory suggests that learning occurs most effectively when students engage in tasks that are slightly beyond their individual capabilities, with the support and guidance of more knowledgeable peers. In COL environments, students can jointly construct knowledge, solve complex problems, and develop higher-order thinking skills that they may not be able to achieve independently (Vygotsky et al., 1978).

STI plays a crucial role as a mediator in the relationship between TCI, COL, SMO, and student performance in mathematics education. Interest development theory posits that when students perceive mathematics as personally interesting and relevant, their motivation and engagement increase, leading to improved performance (Hidi et al., 2006).

By integrating technology, fostering COL environments, and promoting SMO, educators can cultivate STI, which in turn enhances student performance in mathematics. By creating engaging, relevant, and challenging tasks that promote peer-to-peer interactions and the co-construction of knowledge, teachers can enhance students' perceptions of the personal relevance and value of mathematics, as suggested by interest development theory.

Conceptual framework

Conceptual framework is usually a diagrammatical representation of variables to be studied. This is developed based on the relevant theory reviewed and the gaps identified in the empirical study. The research questions are connected to broad theoretical constructs through the conceptual framework.

It describes how the study's variables contribute to the greater information in the field and how they shed light on more general issues (Marshall & Rossman, 2014). This conceptual framework highlights the importance of leveraging technology tools, promoting COL experiences, fostering SMO, and cultivating STI to enhance mathematics achievement in the 21st century classroom. The arrows in the conceptual framework depict the hypothesized relationships among the components. The framework consists of three independent variables (technology integration - TCI, collaborative learning - COL, and student motivation - SMO), one mediating variable (STI), and one dependent variable (student achievement in mathematics - ACH). By considering these factors, educators can design effective instructional strategies and create an engaging learning environment that supports students' learning and success in mathematics. **Figure 1** shows conceptual framework.

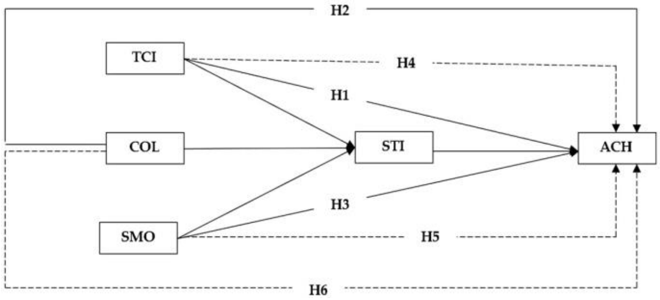

Figure 1. Conceptual framework (Field Survey, 2024) (⟶ Direct effect & ⇢ Indirect/mediating effect)

MATERIALS AND METHODS

Research Paradigm and Research Design

The research paradigm is the conceptual framework that researchers use to examine the methodology component of their work and determine the techniques to be used and the manner in which the data will be analyzed (Nguyen, 2019). In this study, positivism was used as the research paradigm by the researcher. Establishing scientific laws and putting theories to the test are aspects of positivism. Positivist researchers conduct studies using quantitative methods like surveys and empirical testing of hypotheses. The foundation of the positivist research paradigm is deductive reasoning. That is, formulating theories, analyzing them through computations, providing justification based on the tests carried out, and drawing conclusions. A descriptive survey was used as the research design for this study since it facilitated the collection and quantitative analysis of data (Saunders et al., 2012).

Population and Sample

Most studies take data from individuals to create results and conclusions. In research, the term "population" refers to all members of a specific group of people, events, or things (Ary et al., 1972). The population of the study comprised 10,400 senior high schools' students of Opoku Ware School (2,500 students), Prempeh College (3,000 students), Kumasi Anglican Senior High School (1,000 students), Yaa Asantewaa Girls Senior High School (1,500 students), St Louis Senior High School (1,000 students), and Asanteman Senior High School (1,400 students). Mathematics was a required core subject for these students.

The students selected were general arts, visual arts, general science, technical, business and home Economics departments comprising of 164 males and 221 females. A sample is a subset of a population that has been deliberately chosen for research reasons. To enable for extrapolation of the results to the entire population, the sample should be as representative as feasible. When the sample represents the population, the researcher can reliably generalize the findings (Ary et al., 1972). A sample of 385 students from the target population was used for the study. The study's sample size was determined in accordance with Boadu et al. (2023) use of Yamane's (1973) formula, which contained a technique for figuring out the ideal sample size. The formula is given in Eq. (1):

$$n = \frac{N}{1+Ne^2} = \frac{10{,}400}{1+10{,}400\times 0.05^2} = 385, \tag{1}$$

where n is sample size (n = 385), N is population size (N = 10,400), and e is error (e = 0.05), where confidence level is 95%.

Sampling Techniques and Data Collection Instruments

Sampling techniques, according to Haviz et al. (2020), are procedures, methods, or strategies used to gather evidence for analysis or data in order to discover new information or improve subject-matter expertise. The study used three sampling techniques which were made up of purposive, stratified and simple random sampling. The purposive sampling technique was used to select the six senior high schools in the Kumasi metropolitan area. Bernard (2006) states that this technique involves identifying the information that should be highlighted and then seeking out individuals who are willing to provide the information to the best of their ability. The stratified sampling technique was used to divide a population into homogeneous subgroups of level SHS1, SHS2 and SHS3 students. The students who were in class when the data was gathered were selected for the sample using a simple random sampling technique.

The research questions were divided into two sections by the researcher: part B was based on the five factors under investigation, while part A included sociodemographic data. The current study consists of three independent variables (TCI, COL, SMO), one mediator (STI) and (ACH) as the dependent variable. The study also took into consideration the age, gender, form, and study program of the students. The questionnaire used in this study was developed based on a thorough review of the relevant literature and input from subject matter experts. A pilot study was conducted with a sample of 30 students to assess the clarity and relevance of the items. The results of the pilot testing were used to refine the questionnaire, and the final instrument demonstrated good internal consistency (Cronbach's alpha [CA] = 0.84). There were 50 measuring items based on the five constructs and the measurement items were modified to suit the current study.

The measurement items for mathematics achievement, COL, SMO, TCI was adapted from Boadu et al., (2023); those for STI was adapted from Arthur et al., (2022). The questionnaire included both Likert-scale items to measure students' academic achievement, as well as open-ended questions that asked students to

Table 1. Demographics of students

Demographics	Frequency (N)	Percentages (%)
Gender	385	100
Male	175	45.5
Female	210	54.5
Age (years)	385	100
11-5	35	9.1
16-20	340	88.3
21-25	8	2.1
26-30	2	0.5
Form	385	100
SHS 1	13	3.4
SHS 2	330	85.7
SHS 3	42	10.9
Program of study	385	100
General arts	80	20.8
Visual arts	61	15.8
General science	105	27.3
Technical	40	10.4
Home economics	99	25.7

describe the most valuable aspects of the instructional approach and any areas for improvement. A 5-point Likert scale, ranging from 1 (strongly disagree) to 5 (strongly agree), was used to score section B. While the questionnaire provided valuable insights into students' perspectives, the researchers also conducted classroom observations and interviews with a sample of participants to further explore the implementation and perceived effectiveness of the instructional approach. The convergence of findings from these multiple data sources lends greater confidence to the study's conclusions.

The statistical analysis of the questionnaire data revealed a significant positive correlation between students' academic achievement and their perceived engagement with the instructional activities ($r = 0.72$, $p < 0.001$). These findings are consistent with the existing literature on the importance of active learning strategies in promoting student learning. By employing these strategies, the researchers strengthening the credibility and persuasiveness of the questionnaire-based findings. The data was collected using a structured questionnaire over a one-week period. The chosen schools received a letter asking for approval to carry out the study. Confidentiality and privacy of the participants were respected.

Validity and Reliability or Trustworthiness

Validity and reliability are two essential criteria that assess the quality and rigor of research instruments and measurements.

Understanding the distinction between these two concepts is crucial for ensuring the credibility and trustworthiness of research findings. Validity refers to the extent to which a research instrument accurately measures the construct or phenomenon it is intended to measure. Reliability concerns the consistency and stability of the measurement results over time and across different researchers or situations. Together, validity and reliability provide a solid foundation for drawing meaningful conclusions and making informed decisions based on the research findings.

According to Ary et al. (1972), the trustworthiness of a measuring equipment is determined by how well it measures whatever it is measuring. The key variables under study were evaluated for internal consistency using the CA coefficient. TCI had a CA value of 0.817, COL had a CA value of 0.767, SMO had a CA value of 0.725, STI had a CA value of 0.760 and student achievement in mathematics had CA value of 0.814. According to Arthur et al. (2022) recommendation, an instrument's acceptability should be determined by its CA score, which is 0.7 or higher. This coefficient was found sufficient to justify the instrument's use in the study (Boadu et al., 2023).

DATA ANALYSIS

The computer software SPSS (version 23) and AMOS (version 23) were used to code and enter quantitative data into order to enable study analysis. The structural equation model (SEM) was then used to analyze the quantitative data.

Demographics of Students

Table 1 shows that, of the 385 students that took part in the study, 175 were male denoting 45.5% of the sample and 210 were female designating 54.5%. 35 respondents, or 9.1%, were between the ages of 11 and 15; 340 respondents, or 88.3%, were between the ages of 16 and 20; 8 respondents, or 2.1%; and 2 respondents, or 0.5%, were between the ages of 26 and 30. Students from the chosen schools in Kumasi, Ghana comprised the respondents: 43 students from SHS3 representing 10.9%, 330 students from SHS2 representing 85.7%, and 13 students from SHS 1 representing 3.4%. The outcomes of the participants' program of study indicated that 80 offered general arts representing 20.8%, 61 offered visual arts representing 15.8%, 105 offered general science representing 27.3%, 40 offered technical representing 10.4%, and 99 offered home economics representing 25.7%.

Descriptive Statistics

The study used descriptive analysis to test the questionnaire's normality using mean and standard deviation values. In statistics, a normality test is a procedure used to determine whether a given dataset follows a normal distribution. The normal distribution is a symmetric probability distribution that is commonly observed in many natural and social phenomena. The purpose of a normality test is to assess whether the data

Table 2. Descriptive analysis

	Mean	Standard deviation	Skewness Statistic	Skewness Standard error	Kurtosis
ACH2	3.77	1.104	-.963	.124	.369
ACH6	3.95	1.079	-1.057	.124	.603
ACH7	4.16	.992	-1.566	.124	2.472
ACH10	3.91	1.111	-1.023	.124	.449
COL4	3.86	.983	-1.017	.124	.905
COL6	3.85	1.059	-1.037	.124	.653
COL7	3.86	1.093	-1.008	.124	.492
COL9	3.94	1.055	-1.167	.124	.936
SMO1	3.96	1.065	-1.322	.124	1.509
SMO2	4.01	1.047	-1.083	.124	.735
SMO3	3.90	1.026	-1.087	.124	.975
SMO4	3.81	1.074	-.947	.124	.378
TCI1	3.29	1.407	-.408	.124	-1.146
TCI2	3.62	1.102	-.755	.124	-.047
TCI3	3.66	1.058	-.717	.124	.059
TCI6	3.53	1.197	-.610	.124	-.485
STI7	3.68	1.157	-.717	.124	-.215
STI8	3.60	1.061	-.600	.124	-.019
STI9	3.71	1.159	-.762	.124	-.157
STI10	3.63	1.152	-.707	.124	-.197

can be reasonably assumed to be sampled from a population that follows a normal distribution.

This assumption is often important for many statistical methods and techniques that rely on the normality assumption, such as parametric hypothesis testing, confidence intervals, and regression analysis. The results given showed that respondents ranked the measuring items favorably, with all of them having a mean score larger than three (average). The mean and standard deviation for each concept indicated a passing normality test (see **Table 2**). The results of the analysis indicate that the distribution of scores on each question is appropriately normal. Specifically, the skewness and kurtosis indices for the score distribution fall well within the recommended guidelines of "less than |4|" and "less than |8|," respectively (Kline, 2011).

Exploratory Factor Analysis

Finding the latent components or underlying structure in a set of observable variables is possible with the use of the exploratory factor analysis (EFA) technique.

It seeks to determine the covariation patterns between variables and classify them into factors according to the variances they share. EFA helps to reduce the dimensionality of data and provides insights into the basic constructs of the observed variables (Hair et al., 2010). In EFA, the researcher starts with a set of observed variables and uses statistical methods to extract and interpret factors. Additionally, EFA provides information about the uniqueness of each observed variable, representing the variance that is unique to that variable and not shared with the other factors (Kline, 2011). The factor model can be written, as follows: $X = LF + \varepsilon$, where ε is the matrix of error terms, F is the matrix of factors, and X is the matrix of observed variables. L is the matrix of factor loadings, which shows the relationships between the factors and the observed variables.

EFA aims to determine the underlying causes. Factor loadings matrix (L) and factor scores matrix (F) is estimated using factor extraction techniques like principal component analysis (PCA) or maximum likelihood estimation. Each observable variable's loading on its matching latent variable was ascertained using the EFA. The sampling adequacy of Kaiser-Meyer-Olkin (KMO) value was 0.832, higher than 0.5. This excellent number shows that all of the components are strongly related, and the sample is sufficient as well (Hair et al., 2010). There was sufficient correlation to support component analysis, as indicated by the significant results of the Bartlett's sphericity test (p = 0.000). The Chi-square value was 2670.989 with 190 degrees of freedom. To ascertain how many factors needed to be retrieved, the researcher employed factor analysis. After extracting and rotating five components, the total variance explained was found to be 62.062%, with a determinant of 0.001, indicating that the factor is positively defined (see **Table 3**). Iteratively, items with

Table 3. EFA

	Rotated component matrix[a] Component 1	2	3	4	5
ACH2					.715
ACH6					.699
ACH7					.689
ACH10					.654
COL4		.726			
COL6		.819			
COL7		.798			
COL9		.785			
SMO1	.749				
SMO2	.798				
SMO3	.760				
SMO4	.772				
TCI1				.798	
TCI2				.746	
TCI3				.623	
TCI6				.605	
STI7			.770		
STI8			.787		
STI9			.801		
STI10			.795		
Total variance explained					62.062%
KMO measure of sampling adequacy					.832
Bartlett's test of sphericity	Approximate Chi-square				2,670.989
	df				190
	Significance				.000
Determinant					.001

Note. Extraction method: PCA; Rotation method: Varimax with Kaiser normalization; & [a]Rotation converged in 6 iterations low factor loadings were eliminated, and the fit indices were examined for each eliminated item.

Confirmatory Factor Analysis

A statistical method called confirmatory factor analysis (CFA) is employed to examine hypotheses regarding the nature of the connections between latent components and observable variables. It is a confirmatory approach that aims to evaluate the extent to which the observed variables align with the hypothesized latent factors. Researchers build a theoretical model in CFA that explains the connections between hidden components and observable data. A collection of structural equations that specify how the latent components affect the observed variables often serve as the model's representation.

The SEM can be expressed mathematically as $X = \Lambda\xi + \delta$. Where X is the observed variable matrix, Λ is the factor loadings matrix (which shows how latent factors and observed variables are related), ξ is the latent factor vector, and δ is the error term vector. Using CFA, researchers can evaluate the model's goodness-of-fit by contrasting the covariance matrix predicted by the model with the observed covariance matrix. The fit indices that are used to evaluate the model fit include the chi-square test, Tucker-Lewis index (TLI), comparative fit index (CFI), root mean square error of approximation (RMSEA), and standardized root mean square residual (SRMR).

The observed variables are compatible with the proposed factor structure if the model fit is adequate. CFA allows for the estimation of factor correlations, which indicate the relationships between different latent factors in social sciences to validate or refine theoretical models, assess construct validity, and examine the underlying structure of multi-item scales or questionnaires.

Amos software (v.23) was used to conduct the CFA as part of the reliability and validity assessment.

CFA evaluates the degree to which the study model and the data match. Its greater versatility over other statistical methods is demonstrated by the employment of CFA in multiple relevant articles. This is because a range of statistical tests can be estimated by the CFA (Dogbe et al., 2020; Lahey et al., 2012). The CFA approach was chosen by the researcher due to its advantages, as demonstrated by (Lahey et al., 2012). It first makes it possible to test various aspects of hypothesis models statistically. Second, statistical data on the prevalence and source of inaccurate models is provided by CFA, and this information is utilized to enhance the model. Moreover, the CFA forecasts that the variance difference in error is different from the unexplained variance in the underlying constructs, with small measurement errors in latent variables relative to the network's interest regions.

Lastly, CFA makes it possible to compare rival models using a range of analytical data constraints. The CFA approach was used to remove variables with low factor loadings (less than 0.5) from further investigation. The CFA results are shown in **Table 4**. Ten measurement items were initially included for technological integration, STI, motivation, and COL, as well as for students' math success. Six (6) of each of the observed variables in the areas of SMO, curiosity, COL, and math achievement were eliminated after the CFA process.

The fitness of the model is a crucial consideration when doing CFA. The recommendations made by Anderson et al. (2010) state that P-close should be more than 0.05, RMR and RMSEA should be less than 0.08, CFI and TLI should be at least 0.9, and CMIN/df should be fewer than 3. RMR and RMSEA represent perfectly identical indices by assessing the hypothesis model's deviation from the ideal model, CMIN measures the least amount of inconsistency in the model, and CFI and TLI represent incremental agreement indices by comparing how well the hypothesis model fits the baseline model (evaluating least agreement) (Xia & Yang, 2019). Normal continuous data theory's maximum probability is used to compute the CFI and TLI limit values. **Table 4** shows that all of these were satisfied. With a CFI of 0.952 a number higher than 0.90 it was clear that this model was valid and that there was a high correlation between the data and the model. The GFI's

Table 4. CFA

Model fit indices: CMIN = 276.815; df = 156; CMIN/df = 1.774; CFI = 0 .952; TLI = 0.942; RMR = 0 .057; RMSEA = 0.045; P-close = 0.831; GFI=0.934; & AGFI = 0.911	SFL
TCI	
Using technology enhances my understanding of mathematical concepts (TCI 1)	1.312
I feel confident in my ability to effectively integrate technology into my mathematics learning (TCI 2)	1.349
Technology tools and resources help me engage more actively in mathematics lessons (TCI 3)	1.349
I find it easy to troubleshoot technical issues arising during technology-enhanced mathematics activities (TCI 6)	1.000
COL	
I face difficulties when working in groups to solve mathematical problems (COL 4)	0.894
Collaborative learning has a positive impact on mathematics (COL 6)	1.023
I actively contribute and provide feedback during collaborative mathematics activities (COL 7)	1.094
I find it challenging to hold myself accountable and contribute to the success of my collaborative mathematics group (COL 9)	1.000

Note. SFL: Standard factor loading

Table 4 (continued). CFA

Model fit indices: CMIN = 276.815; df = 156; CMIN/df = 1.774; CFI = 0 .952; TLI = 0.942; RMR = 0 .057; RMSEA = 0.045; P-close = 0.831; GFI=0.934; & AGFI = 0.911	SFL
SMO	
I am motivated to actively participate in mathematics classroom (SMO 1)	1.000
I set goals for myself to improve my performance in mathematics (SMO 2)	1.019
My effort and attitude towards learning mathematics impact my overall performance (SMO 3)	1.045
Rewards or incentives increase my motivation to succeed in mathematics (SMO 4)	1.053
STI	
My interest in mathematics influences my elective course choices or future career aspirations (STI 7)	1.280
I pursue independent learning in mathematics based on my interest (STI 8)	0.994
Teachers play a crucial role in fostering and nurturing student interest in mathematics (STI 9)	1.291
Schools and educators can make mathematics more interesting and relevant to students' lives (STI 10)	1.000
ACH	
Strategies or study techniques I use significantly improve my performance in mathematics (ACH 2)	1.000
I track and monitor my own progress and performance in mathematics (ACH 6)	1.116
My level of interest or motivation correlates with my performance in mathematics (ACH 7)	0.964
I have concrete recommendations or strategies for improving my own performance in mathematics (ACH 10)	1.090

Note. SFL: Standard factor loading

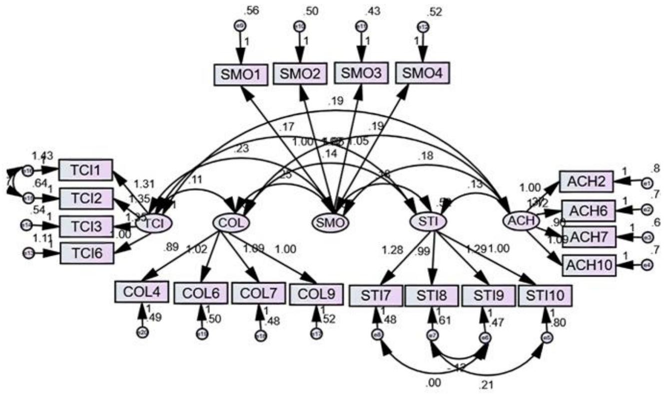

Figure 2. Diagrammatic presentation of confirmatory factor (Source: Field Survey, 2024)

final result was 0.934. This suggests that the final model was well-made. Additionally, the RMR yielded a value of 0.057 and the resulting RMSEA value was 0.045, which was less than 0.08 and so regarded as an acceptable value for RMSEA. These show that the five constructions' essential elements were legitimate and appropriate. According to Hair et al. (2010), the CMIN/DF value for the fitness assessments was 1.774, which was less than 3, and the P-close value of 0.831 showed statistical insignificance at 5%. **Figure 2** shows diagrammatic presentation of CFA.

Composite Reliability, Average Variance Explained and Cronbach Alpha

The CA was determined using SPSS (v.23) and the retained items. CA values for TCI, COL, SMO, STI, and ACH variables were 0.817, 0.767, 0.725, 0.760, and 0.814, respectively. According to Taber's recommendation, the study verified that each construct's CA stayed at the necessary level of 0.70 (Taber, 2018).

When the composite reliability (CR) is greater than or equal to 0.7 and the average variance extracted (AVE) of the observed variables is larger than or equal to 0.5, convergent validity is attained (Bornmann et al., 2009; Carlson & Herdman, 2012). The study's convergent validity was demonstrated by the results, which indicate that 0.5015 of students' math achievement had the lowest AVE and lowest 0.83285 CR. As advised by Boadu et al. (2023), the average variance extracted was greater than the minimum criteria of 0.50 and 0.70. As a result, the instrument used in the study had the required convergent validity, as shown in **Table 5**.

Table 5. CR, AVE, and CA

	CR	AVE	CA
TCI	0.84416	0.52715	0.817
COL	0.89357	0.61155	0.767
SMO	0.88560	0.59180	0.725
STI	0.89663	0.61796	0.760
ACH	0.83285	0.50150	0.814

Discriminant Validity

Similar to previous research by Bamfo et al. (2018), this study examined discriminant validity by contrasting correlation coefficients with the square root of average extracted variances, or AVEs. The degree to which measurement items in one construct are uncorrelated with measurement items in another is evaluated by discriminant validity (Trochim & Donnelly, 2001). When the smallest √AVE surpasses the largest correlation coefficient as advised, discriminant validity is achieved (Arthur et al., 2022). **Table 6** displays that the highest correlation coefficient was 0.549 and the lowest √AVE value was 0.7082. Thus, the dataset proved to have discriminant validity. This study demonstrated convergent validity, as evidenced by the average variance retrieved and composite reliability for each component meeting the respective standards (Fornell & Larker, 1981). The findings indicated that the lowest

Table 6. Discriminant validity

Variables	TCI	COL	SMO	STI	ACH
TCI	**0.7261**				
COL	0.263***	**0.7820**			
SMO	0.549***	0.426***	**0.7693**		
STI	0.429***	0.253***	0.339***	**0.7861**	
ACH	0.547***	0.396***	0.382***	0.301***	**0.7082**

Note. ***Values represent correlations between variables & √AVE are **bold**

AVE was found in 0.7082 of the students' mathematics achievement.

RESULTS

Path Analysis

Researchers build the structural model through path analysis. It is a form of multiple regression statistical analysis that assesses causal models by examining how dependent variables relate to two or more independent variables (Afthanorhan & Ahmad, 2014). To conduct path analysis; researchers begin by creating a path diagram which visually depicts the relationships between variables. Arrows in the diagram indicate the direction of effects. Path analysis is computed to investigated cause-effect relations between dependent and independent variables (Nayebi & Nayebi, 2020).

Direct Effect

Direct effects represent the direct relationship between two variables without the influence of any other variables. The regression equation for direct effects can be written as: $Y = \beta_0 + \beta_1 X + \varepsilon$ Where: Y is the dependent variable; X is the independent variable; $\beta_0$is the intercept; $\beta 1$ is the coefficient representing the direct effect of X on Y; ε is the error term. The outcomes of the direct effects of the independent variables (TCI, COL, SMO), mediator (STI) against the dependent variable (ACH) are presented in **Table 7**. SEM was employed by Amos (v.23) to evaluate the many paths that were hypothesized in the research.

Based on the hypothesized paths, the results show that students' achievement in mathematics was positively impacted by TCI (β = 0.366; C.R. = 3.873). Thus, about a 36.6% increase in TCI had direct positive effect on student achievement in mathematics. Multiple studies that confirmed the current study have consistently demonstrated that TCI has a direct positive impact on student mathematics achievement (Johnson & Smith, 1998). While many studies suggest that technology has a positive impact on student mathematics achievement, it is possible that there are studies that find no direct positive impact. *H1. TCI has a direct effect on ACH was thus confirmed*.

COL has a direct effect on students' achievement in mathematics (β = 0.201; CR= 0.059). Thus, about a 20.1% increase in COL had a direct positive effect on students' achievement in mathematics. Multiple studies that confirmed the current study have consistently demonstrated that COL has a direct positive impact on students' achievement in mathematics (Webb, 2009). By engaging students in collaborative activities, they can construct and share mathematical knowledge, develop reasoning skills, and deepen their understanding of mathematical concepts.

Table 7. Path estimates

Direct paths	UE	CR	SE	p
TCI → ACH	0.366	3.873	0.094	***
TCI → SMO	0.498	5.316	0.094	***
TCI → COL	0.273	3.753	0.073	***
TCI → STI	0.376	3.261	0.115	0.001
COL → SMO	0.312	4.936	0.063	***
COL → STI	0.170	2.163	0.079	0.031
SMO → STI	0.143	1.517	0.094	0.129
SMO → ACH	0.026	0.375	0.069	0.707
STI → ACH	0.024	0.634	0.037	0.526
COL → ACH	0.201	3.390	0.059	***

Model fit indices: CMIN = 274.239; df = 157; CMIN/df = 1.747; CFI = 0.954; TLI = 0.944; GFI = 0.934; RMR = 0.057; RMSEA = 0.044; & P-close = 0.867

Note. *** & ~ p significant at 1% (0.01); UE: Unstandardized estimates; CR: Critical ratio; SE: Standard error

For instance, a meta-analysis conducted by Johnson, Johnson, and Smith (2007) examined the effects of cooperative learning, a form of COL, and found significant positive effects on academic achievement across different grade levels and subject areas. COL promotes active engagement, critical thinking, and the development of important skills such as communication and problem-solving, which can contribute to improved academic performance (Kirschner et al., 2006). *H2. COL has a direct effect on ACH was thus confirmed*.

The impact of SMO on mathematics achievement was directly favorable but statistically insignificant (β = 0.026; CR = 0.375). *H3. SMO has a direct effect on ACH was thus not confirmed*. While the current confirmed that SMO had no effect on students' achievement, other studies such as Arthur et al. (2022), Froiland and Davison (2016) suggested that motivation has a positive impact on student mathematics achievement. These studies highlight the importance of SMO as a predictor of student performance in mathematics.

Mediating Effect

Through an intermediary variable, mediation analysis investigates the impact of an independent variable on a dependent variable (**Table 8**). In mediation analysis, there are typically three regression equations. The regression equation of the mediator on the independent variable: $M = \gamma_0 + \gamma_1 X + \eta$, Regression of the dependent variable on the mediator: $Y = \alpha_0 + \alpha_1 M + \varepsilon'$, Regression of the dependent variable on both the

Table 8. Mediating effect

Indirect paths	UE	LBC	UBC	TE
TCI → STI → ACH	0.082	-0.027	0.224	0.119
COL → STI → ACH	0.013	-0.044	0.077	0.532
SMO→ STI → ACH	0.003	-0.007	0.039	0.369

Note. UE: Unstandardized estimates; LBC: Lover bias-corrected; UBC: Upper bias-corrected; & TE: Total effect

independent variable and the mediator: $Y = \beta_0 + \beta_1 X + \beta_2 M + \varepsilon$, where: M is the mediator variable, γ_0 and γ_1 are the coefficients representing the effect of M on X, β_0, β_1, and β_2 are the coefficients representing the direct effect of X on Y and the mediated effect of M on Y, α_0 and α_1 are the coefficients representing the direct effect of M on Y, η, ε, and ε' are error terms.

The study also assessed the mediation effect of STI as another hypothesized path analysis between TCI, COL and SMO on students' achievement in mathematics. Their indirect effects were calculated using SEM from Amos (ver.23). STI as mediator was also evaluated in the study.

H4 states that STI mediates the relationship between TCI and students' achievement in mathematics. The analysis supported this, showing that the indirect effect of TCI on math success among children (TCI → STI → ACH) had a coefficient of 0.082 and was statistically insignificant (lower BC was negative and upper BC positive). However, given STI had no direct impact on students' mathematics achievement and TCI had a direct impact on students' mathematical achievement, this does not indicate a mediating influence.

Also, p-value of the total (indirect) effect of TCI on students 'achievement in mathematics is significantly different from zero at the 0.05 level (p = 0.119 two-tailed). It was also found that zero falls within the path coefficient of the indirect effect's 95% confidence interval (−0.027 and 0.0224), making it non-significant, and therefore, hypothesis H4 should be considered to exhibit no relationship with the mediation. Another current that is in conformity with the current is students' academic interests had no mediating effect on the relationship between self-efficacy and students' achievement (Oppong et al., 2023).

H5 states that STI mediates the relationship between COL and ACH. The analysis supported this, showing that the coefficient for the indirect influence of TCI on mathematics achievement (COL → STI → ACH) was 0.013 and statistically insignificant (lower BC was negative and upper BC was positive).

However, since STI had no direct impact on students' mathematics achievement and COL had a direct impact on students' mathematical achievement, this does not indicate a mediating influence. Also, p-value of the total (indirect) effect of COL on students 'achievement in mathematics is significantly different from zero at the 0.05 level (p = 0.532 two-tailed). It was also found that zero falls within the path coefficient of the indirect effect's 95% confidence interval (−0.044 and 0.077), making it non-significant, and therefore, hypothesis H5 should be considered to exhibit no relationship with the mediation.

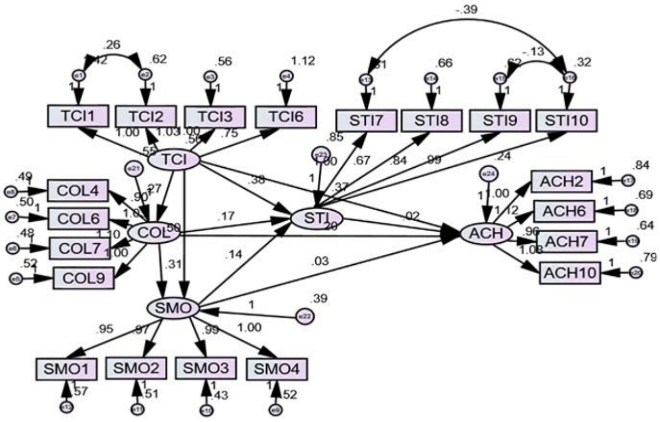

Figure 3. Mediation structural paths (Source: Field Survey, 2024)

H6 states that STI mediates the relationship between SMO and ACH. The analysis supported this, as the coefficient for the indirect effect of TCI on students' mathematical achievement (SMO → STI → ACH) was 0.003, which was statistically insignificant (because the lower BC was negative, and the upper BC was positive).

This, however, does not reflect a mediating effect because SMO and interest have no direct effect on students' mathematics achievement. Also, the p-value of the total (indirect) effect of COL on students 'achievement in mathematics is significantly different from zero at the 0.05 level (p = 0.369 two-tailed). It was also found that zero falls within the path coefficient of the indirect effect's 95% confidence interval (−0.007 and 0.039), making it non-significant, and therefore, hypothesis **H6** should be considered to exhibit no relationship with the mediation. **Figure 3** depicts mediation structural paths.

DISCUSSION

In the 21st century, enhancing ACH requires a comprehensive approach that incorporates TCI, COL, SMO, and the mediating role of STI.

The findings of the study suggest that technological integration, when effectively implemented, can positively impact students' achievement in mathematics. By leveraging technology tools and resources, educators can create engaging and interactive learning environments that cater to students' diverse learning needs and preferences.

TCI can enhance students' access to mathematical content, provide opportunities for personalized learning experiences, and foster their motivation and interest in the subject. Past studies on TCI have largely focused on tertiary level with very little attention on the secondary.

This study therefore contributes to literature on TCI at the secondary level.

Similarly, Boswell (2024) conducted a quasi-experimental study and reported that students who received technology-enhanced instruction outperformed their peers who received traditional instruction. These findings provide empirical support for the positive relationship between TCI and student performance in mathematics. Studies have shown that technology-enhanced instruction can promote conceptual understanding, problem-solving abilities, and higher-order thinking skills among students (Schmid et al., 2018). We find that TCI was a strong predictor of students' achievement in mathematics at all educational levels (from basic to tertiary) when comparing these studies to our current findings.

Results from this present study indicated that COL had a positive significant effect on students' achievement in mathematics. This relationship is consistent with previous research findings. Studies on COL found that it had various advantages over individual learning. These benefits include improved performance, increased motivation, increased academic accomplishment, enhanced thinking skills, and increased student satisfaction. In Ghana a study conducted by Arthur et al. (2022) concluded that cooperative learning had direct positive effect on mathematics achievement.

Thurston et al. (2020) evaluated the impact of social interactions on mathematics outcomes when peer tutoring is used in primary school. They discovered that a student's performance in mathematics was significantly improved by their perception of the mathematics tutoring partner's cognitive competence and level of trust. According to Alegre et al. (2019), cooperative learning was found to be a highly significant predictor of mathematics achievement in secondary education. When a student assumes the position of tutor and instructs peers who assume the role of a tutee, COL takes place. The engagement is focused on curriculum content (Ginsburg-Block et al., 2006). This research revealed that COL is an important factor in predicting students' mathematical achievement, which this current study validated.

The current study's findings indicated that there was no discernible relationship between SMO mathematics achievement. This association defies previous research findings. For instance, Wang and Eccles (2013) conducted a longitudinal study and found that students' intrinsic motivation in mathematics positively predicted their performance over time.

A longitudinal study on the effects of enrollment in mathematics courses and motivation on high school mathematics performance was carried out by Froiland and Davison (2016). They concluded that students' mathematics performance in the eleventh grade was significantly impacted by their intrinsic motivation for mathematics in the ninth grade. These researchers revealed that SMO is a critical determinant in affecting students' mathematical achievement, which the current study could not establish. The results also showed that there is no STI mediation and a direct impact of TCI on mathematics achievement. The immediate impact of TCI on kids' mathematical achievement was good. Zhang and Wang (2020) found, among other things, that students' performance in mathematics is positively and directly impacted by their enthusiasm in the subject.

Tosto et al. (2016) found that mathematics performance is significantly impacted by subject interest. But the current study established no significant effect of STI on students' achievement in mathematics.

The results of this study also showed that there is no STI-related mediation between the direct effects of TCI and mathematics achievement. TCI had a positive direct effect on students' achievement in mathematics. COL had a direct influence on students' mathematics achievement, with STI having no significant effect on students' mathematics achievement and hence the current study established no mediation effect by STI. The analysis supported this shows that, the indirect effect of TCI on mathematics achievement (TCI → STI → ACH) had a coefficient of 0.082 and was statistically insignificant (lower BC was negative and upper BC positive). Even though TCI had a positive direct effect on mathematics achievement, the lack of a mediation effect through STI suggests that the impact of technology may not necessarily be dependent on or channeled through students' level of interest.

The results of this current study also showed that there is no STI-related mediation between the direct effects of COL and mathematics achievement. COL also emerged as a significant factor influencing students' achievement in mathematics. When students engage in COL activities, they have the opportunity to actively construct knowledge, engage in meaningful discussions, and learn from their peers' perspectives.

A study by Slavin (2011) synthesized the findings of various research studies and concluded that cooperative learning approaches, which emphasize collaboration among students, have consistently shown positive effects on academic achievement.

But the current study established no significant effect of STI on students' achievement in mathematics. The analysis supported this, showing that the coefficient for the indirect influence of TCI on mathematics achievement (COL → STI → ACH) was 0.013 and statistically insignificant (lower BC was negative and upper BC was positive). The lack of a mediation effect of STI suggests that the benefits of COL on mathematics achievement are more directly related to the cognitive and social processes inherent in the collaborative activities, rather than being contingent on students' individual interest levels in the subject matter.

Finally, the current study failed to established a mediation effect of STI on the relationship between SMO and students' achievement in mathematics. SMO from other studies was found to be a crucial determinant of achievement in mathematics education. This intrinsic motivation is linked to increased effort, persistence, and academic success. Educators play a vital role in nurturing students' motivation by providing meaningful and relevant mathematical tasks, setting clear goals, and offering recognition and support.

The influence of motivation on mathematics achievement among sixth and eighth grade students, and the findings revealed a considerable beneficial effect (Habók et al., 2020). But the current study established no significant effect of SMO and STI on students' achievement in mathematics. The analysis supported this, as the coefficient for the indirect effect of TCI on students' mathematical achievement (SMO → STI → ACH) was 0.003, which was statistically insignificant (because the lower BC was negative, and the upper BC was positive).

It is possible that in the specific context of the study, other factors, such as teaching strategies, peer support, or prior knowledge, may have played a more dominant role in shaping students' mathematics achievement than the individual motivational and interest-related factors. The lack of a significant mediation effect suggests that the direct influences of TCI and COL on mathematics achievement may not be strongly contingent on students' motivational and interest levels.

CONCLUSIONS

The findings of the present study indicated that TCI and COL all had a direct and significant impact on students' mathematics achievement. However, SMO had a direct but insignificant effect on students' mathematics achievement. The mediating role of STI was found to be exhibit no mediation effect on the relationship between TCI, COL, and SMO on ACH.

Implications for Instructional Practices and Theoretical Implications

Implications for instructional practices

The findings suggest that educators should focus on integrating technology and implementing COL strategies in mathematics classrooms, as these approaches can directly improve student achievement, even when SMO is not a strong mediating factor. The results indicate that creating a learning environment that emphasizes collaborative problem-solving, peer interaction, and the effective use of technology can be a powerful approach to enhance students' understanding and performance in mathematics.

This implies that educators should prioritize the design and implementation of COL activities and the integration of technology-based tools and resources, rather than solely relying on strategies to increase SMO.

Theoretical implications

The lack of a mediation effect of SMO suggests that the direct impact of TCI and COL on mathematics achievement may be more prominent than the influence of individual SMO. This finding challenges some existing theories that emphasize the central role of SMO in academic achievement. The results imply that the cognitive and social processes inherent in COL and the affordances of TCI can directly enhance learning outcomes, even when SMO is not a strong mediating factor. The study's findings contribute to the ongoing theoretical discourse on the complex relationships between various instructional approaches, student factors, and academic achievement in mathematics education. The results suggest the need to re-evaluate or refine existing theoretical models that may have overemphasized the mediating role of SMO, and instead consider the direct and collective contributions of COL and TCI.

Recommendations and Future Research Directions

Based on the study's findings, the recommendations made to support ACH was that management of the senior high schools should embrace and effectively integrate technology into mathematics instruction. They should explore various technological tools, such as interactive simulations, educational apps, and online resources, to enhance students' access to mathematical content and foster their engagement and interest. Also, COL should be incorporated into mathematics classrooms.

Further research is needed to explore the underlying mechanisms and contextual factors that contribute to the direct impact of COL and TCI on mathematics achievement. Investigating potential moderating variables or alternative mediating factors could provide a more nuanced understanding of the complex relationships between these instructional approaches, student factors, and academic outcomes. Also, employing diverse research methodologies, such as longitudinal studies or experimental designs, could shed light on the long-term and causal effects of these instructional practices on students' mathematics learning and achievement.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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