RESEARCH ARTICLE

Journal of Pedagogical Sociology and Psychology
Volume 8, Issue 2, 2026, e34699
https://doi.org/10.33902/JPSP.202634699

# Modeling the impact of collaborative learning and motivation on senior high school mathematics achievement

**Paul Agmabire Akendita[1], Ato Kwamina Arhin[2] and Yarhands Dissou Arthur[3]**

[1]Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Ghana (ORCID: 0009-0006-9500-2800)
[2]Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Ghana (ORCID: 0000-0002-7702-5869)
[3]Akenten Appiah-Menka University of Skills Training and Entrepreneurial Development, Ghana (ORCID: 0000-0002-8950-1367)

**Corresponding Author:** Paul Agmabire Akendita, paulakendita@gmail.com

Submitted: 11 March 2025 Revised: 28 October 2025 Accepted: 2 January 2026

**Abstract**

This study examined the impact of collaborative learning on students' mathematics achievement, with a focus on the mediating role of mathematics motivation. Grounded in social constructivist theory, the research employed a descriptive survey design anchored on the quantitative research approach within the positivist paradigm. Conducted between July and December 2024, the study sampled 261 second-year students from a Senior High School. Participants were selected using a simple random sampling technique to ensure representation. Data were collected using a validated structured questionnaire measuring collaborative learning practices, mathematics motivation, and academic performance. A Structural Equation Modeling approach was used to test four hypotheses. The findings revealed that collaborative learning significantly enhanced students' mathematics achievement and positively influenced their mathematics motivation. Additionally, mathematics motivation significantly predicted academic achievement and partially mediated the relationship between collaborative learning and achievement. These results highlight the critical role of motivation in maximizing the benefits of collaborative learning in mathematics education. The study contributes to the literature by demonstrating that collaborative learning not only improves academic performance but also strengthens student motivation. It is recommended that educators incorporate collaborative strategies and motivation-enhancing techniques in mathematics instruction to further boost student outcomes.

**Keywords:** Academic achievement; Collaborative learning; Mathematics motivation; Social constructivism; Structural equation modeling

## 1. Introduction

Mathematics education plays an important role in fostering students' problem-solving skills and cognitive development, and these factors are positively associated with mathematics achievement. In this sense, mathematics learning supports not only academic performance but also the development of capacities that are valuable in complex learning contexts (Bimbim et al., 2026; Asiedu Menlah & Boateng, 2025).

Despite the recognized importance of mathematics, students' achievement in this subject in Ghanaian SHS remains a significant concern for educators, policymakers, and parents alike (Donkoh et al., 2021). In its 2024 assessment of the Ghana's Education Sector, the Ministry of Education of Ghana revealed that between 2020 and 2023, the percentage of students who obtained F9 rose from 13.40 % in 2021 to 20.11% in 2022, then dropped from 20.11% to 10.48 % in 2022, and then dropped again from 10.48 percent to 8.90% in 2023 (Enoch, 2023). According to the report, students' performance in core mathematics is still high when compared with other core subjects like English Language, Integrated Science and Social Studies (Enoch, 2023). Across various educational systems, many students struggle with mathematics, leading to widespread underachievement and a growing disinterest in the subject. This underperformance in mathematics has prompted a global search for more effective teaching methods that can engage students and improve their learning outcomes.

One pedagogical approach that has gained considerable attention is collaborative learning. Rooted in social constructivist theories, collaborative learning posits that students learn more effectively when they engage in-group activities that require them to interact, discuss, and solve problems together (Qureshi et al., 2023). Unlike traditional teaching methods that often emphasize individual work and competition, collaborative learning fosters a learning environment where students work towards common goals, share knowledge, and support each other's learning processes. The premise is that through social interaction, students can construct knowledge more meaningfully and develop a deeper understanding of mathematical concepts (Iwanaga et al., 2021). In light of this, that the Ghana Education Service and the Ministry of Education through the National Council for Curriculum and Assessment [NaCCA] has adopted a new curriculum called the Standard Based Curriculum, which focuses on building in the learners the 21$^{st}$ century skills and core competencies through innovative teaching strategies like the collaborative learning strategy etc., needed to be able to fit in a fast changing world. These core competencies include, Critical Thinking and Problem Solving [CP], Creative and Innovation [CI], Communication and Collaboration [CC], Cultural Identity and Global Citizenship [CG], Personal Development and Leadership [PL] and Digital Literacy (NaCCA, 2019).

Despite the widespread implementation of collaborative learning in mathematics education, its effectiveness varies significantly across different contexts and student populations. This variability raises important questions about the factors that influence the success of collaborative learning (Alam & Mohanty, 2023). While previous research has documented the benefits of collaborative learning, such as improved academic performance and enhanced problem-solving skills (Warsah et al., 2021), there is limited understanding of the underlying mechanisms that drive these outcomes (Pires et al., 2020).

One potential factor that could explain the variability in the effectiveness of collaborative learning is mathematics motivation (Filippou et al., 2022). Motivation is a key determinant of students' engagement and success in learning. Students who are motivated are more likely to invest time and effort in their studies, seek out challenging tasks, and persist in the face of difficulties (Filippou et al., 2022). Conversely, students who lack motivation may disengage from the learning process, leading to lower academic achievement. The relationship between collaborative learning and mathematics achievement may therefore be contingent on the level of student motivation. If students are not motivated, they may not fully participate in collaborative learning activities, limiting the potential benefits of this approach. Conversely, motivated students are more likely to engage actively in group work, contribute to discussions, and benefit from the collective knowledge and skills of their peers (Acosta-Gonzaga & Ramirez-Arellano, 2022).

Despite the theoretical importance of motivation in collaborative learning, there is a paucity of research examining its role as a mediator in the relationship between collaborative learning and academic achievement. This gap in the literature represents a critical challenge for educators seeking to design effective instructional strategies. Without a clear understanding of the role of motivation, it is difficult to predict when and under what conditions collaborative learning will be most effective.

### 1.1. The Ghanaian Context

Mathematical problem-solving constitutes an important area of mathematics instruction. Collaborative learning is embedded in the Ghanaian culture because it encourages sharing of knowledge. CL as a kind of learning situation in which students are expected to work as a team collaboratively in a relatively small group while they share ideas and experiences in the processes. In the Ghanaian settings communal engagement is mostly practiced in homes and this can be translated into learning and teaching of mathematics. Students can explain mathematical concepts to their peers, this practice reinforces their understanding. CL in the Ghanaian settings cultivate deeper understanding and retention of subject matter. Peers have the opportunity to explain mathematical concepts to their peers using their dialect and using examples that relate to their environment. This benefit becomes more apparent where the teacher does not speak the local language of the majority of the students.

Enhancing students' mathematics performance in Ghana through collaborative learning is a promising approach.CL fosters a positive view about the instructional experience than competitive or individualistic techniques. Naturally, this positive trait of non-competitiveness is interwoven in the Ghanaian society. This makes it an easy approach for teachers to employ as a teaching method. However, mathematics motivation is a crucial factor that cannot be overlooked. By fostering a motivated atmosphere and utilizing collaborative strategies, mathematics teachers can significantly improve mathematics outcomes for students in Ghana. This approach of teaching mathematics in our mathematics classroom has not received a lot of attention. This study seeks to address this research gap by investigating the mediating role of mathematics motivation in the relationship between collaborative learning and mathematics achievement. By doing so, it aims to provide a more nuanced understanding of the factors that contribute to the success of collaborative learning and to offer practical recommendations for educators seeking to enhance students' mathematics achievement.

Based on the purpose of the study, four hypotheses were formulated to guide the study. This study contributes to the field of practice by offering actionable insights for mathematics teachers on how to integrate motivational elements into collaborative learning frameworks to improve student performance. It also adds to the profession by informing teacher training and curriculum development on evidence-based instructional strategies. Furthermore, the study enriches the body of knowledge and literature by providing empirical evidence on the mediating role of mathematics motivation in the collaborative learning-achievement nexus, particularly in the Ghanaian secondary school context an area that has been underexplored.

## 2. Literature Review

### 2.1. Theoretical Framework of the Study

The theoretical foundation of collaborative learning is deeply rooted in the principles of social constructivism, which posits that knowledge is constructed through social interaction and shared experiences (Hsu & Liu, 2023). Pioneered by Lev Vygotsky, social constructivism emphasizes the importance of social contexts in learning and development. Vygotsky introduced the concept of the "Zone of Proximal Development" (ZPD), which refers to the range of tasks that a learner can perform with the guidance and support of others, but cannot yet perform independently. Within this framework, collaborative learning is seen as a pedagogical approach that facilitates the co-construction of knowledge as students interact, share perspectives, and work together to solve problems (Cañabate et al., 2021).

Collaborative learning environments are designed to leverage the diverse experiences and knowledge of students. The interaction within these groups enables students to engage in discussions, challenge each other's thinking, and arrive at a deeper understanding of mathematical concepts. This approach contrasts with traditional instruction, where the teacher is the primary source of knowledge and students are passive recipients (Paulsen et al., 2024). Instead, collaborative learning encourages active participation, critical thinking, and the development of higher-order cognitive skills. By working together, students can scaffold each other's learning, which aligns with Vygotsky's emphasis on the social nature of cognitive development (Paulsen et al., 2024).

Research has highlighted numerous cognitive and social benefits of collaborative learning (Nungu et al., 2023). Cognitively, students in collaborative settings are often required to explain their reasoning, justify their answers, and consider alternative viewpoints. This process promotes metacognitive awareness, as students must monitor and regulate their own thinking as well as their contributions to the group's understanding. Additionally, the need to articulate and defend one's ideas can lead to greater conceptual clarity and deeper comprehension (Janssen & Kirschner, 2020).

Socially, collaborative learning fosters the development of communication skills, teamwork, and a sense of responsibility for one's own learning and that of others (Yaacob et al., 2020). Students learn to negotiate meaning, manage conflicts, and work towards a common goal. These social skills are essential not only for academic success but also for future professional and personal interactions. The positive interdependence created in collaborative learning groups can also enhance motivation, as students recognize that their success is linked to the success of their peers (Petre, 2020).

### 2.2. Collaborative Learning and Students' Mathematics Achievement

Numerous empirical studies have demonstrated the effectiveness of collaborative learning in enhancing students' mathematics achievement (Maharani et al., 2020; Olanrewaju & Suleiman, 2019; Talan, 2021). For instance, a study by conducted by Maharani et al. (2020) on the effects of collaborative learning models on mathematics achievement in relation to students' multiple intelligences. The findings revealed that there were statistically significant differences in math achievement based on the collaborative learning models and students' multiple Intelligences. In the context of mathematics education, specific studies have shown that collaborative learning can improve problem-solving skills, mathematical reasoning, and conceptual understanding (Agani, 2021; Klang et al., 2021; Maharani et al., 2020). For example, Agani (2021) found that collaborative learning significantly improves students' educational performance in math compared to conventional teaching methods. The study involved 195 educators and 80 eighth-grade students, divided into experimental and control groups. The experimental group, which used collaborative learning techniques, outperformed the control group that followed traditional learning methods. Similarly, a study by Siller and Ahmad (2024) on analyzing the impact of collaborative learning approach on grade six students' mathematics achievement and attitude towards mathematics found that collaborative learning significantly improved mathematics achievement in sixth-grade students compared to traditional teaching methods. Both groups had similar pre-test scores, indicating no initial differences in mathematics knowledge. After a 12-week intervention, the experimental group showed notable gains in mathematics achievement. Positive changes in attitudes towards mathematics were observed in the experimental group, with some improvement also noted in the control group. The study therefore hypothesized that:

**$H_1$:** Collaborative learning significantly influences students' mathematics achievement.

### 2.3. Collaborative Learning and Students' Mathematics Motivation

Collaborative learning is an educational approach that involves groups of students working together to solve problems, complete tasks, or understand concepts. Within of mathematics education, collaborative learning has been shown to influence students' motivation significantly (İlhan, 2021; Järvenoja et al., 2020). Motivation in mathematics is crucial as it affects students' engagement, persistence, and achievement in the subject. Increased Engagement and Interest numerous studies have demonstrated that collaborative learning environments foster greater student engagement in mathematics (Sinha et al., 2015). A Meta-Analysis study by Xu et al. (2023) on the effectiveness of collaborative problem solving in promoting students' critical thinking indicates that when students work collaboratively, they are more likely to participate actively in discussions and problem-solving activities. This increased engagement often translates into higher levels of interest in mathematics and critical thinking. Collaborative learning provides opportunities for peer support, which can enhance motivation. A study by Järvenoja et al. (2020) found that students who participated in collaborative learning reported feeling more supported by their peers compared to those who learned individually. This sense of community can reduce anxiety associated with mathematics and encourage a positive attitude toward the subject. Collaborative tasks helps students develop essential social skills such as communication, teamwork, and conflict resolution. These skills are not only vital for academic success but also contribute to a positive self-concept regarding mathematical abilities (İlhan, 2021). Similar study by In'am and Sutrisno (2020) highlighted that students who engaged in cooperative learning showed improvements not only in their mathematical understanding but also in their confidence levels. Collaborative learning encourages diverse perspectives on problem-solving strategies. The study therefore hypothesized that:

**$H_2$:** Collaborative learning significantly influences students' mathematics motivation.

### 2.4. Mathematics Motivation and Students Mathematics Achievement

Motivation in mathematics learning is a multifaceted construct that encompasses students' beliefs, attitudes, and goals related to mathematics (Wong & Wong, 2021). According to self-determination theory, motivation can be intrinsic or extrinsic. Intrinsic motivation refers to engaging in a task for the inherent satisfaction and interest it provides, while extrinsic motivation involves performing a task to achieve external rewards or avoid punishment (Hendijani et al., 2016). Mathematics education, intrinsic motivation is particularly important, as students who find joy and interest in solving mathematical problems are more likely to persist in the face of challenges and achieve higher levels of success (Garon-Carrier et al., 2016). Studies have consistently shown that motivation is a key determinant of students' engagement, effort, and achievement in mathematics (Asanre, 2024; Cleary & Kitsantas, 2017; Järvenoja et al., 2020) . For instance, a study by Rodríguez et al. (2021) found that students who were intrinsically motivated in mathematics displayed greater persistence, higher levels of cognitive engagement, and better problem-solving skills. The study therefore hypothesized that:

**$H_3$:** Students Mathematics motivation significantly predicts students’ academic achievement.

### 2.5. Collaborative Learning, Mathematics Motivation and Students’ Mathematics Achievement

In the context of collaborative learning, motivation plays a critical role in determining the effectiveness of the learning experience. Motivated students are more likely to engage actively in group discussions, contribute their ideas, and work collaboratively towards a common goal (Le et al., 2018). Moreover, motivated students are more likely to take on challenging tasks, persist through difficulties, and support their peers in the learning process. This positive engagement can lead to a more productive and effective collaborative learning experience (Zepeda et al., 2020). Several studies have explored the relationship between motivation and collaborative learning outcomes (Bächtold et al., 2023; Nakata et al., 2022). A study by Muawanah (2023) on the Impact of Cooperative Learning Method on Learning Motivation and Academic Achievement of Elementary School Students found that, the Cooperative Learning Method significantly enhances learning motivation among elementary school students. The study also revealed a substantial positive correlation between the Cooperative Learning Method and academic achievement. Motivation also has the potentiality to facilitate the relationship between collaborative learning and academic achievement (Muawanah, 2023).

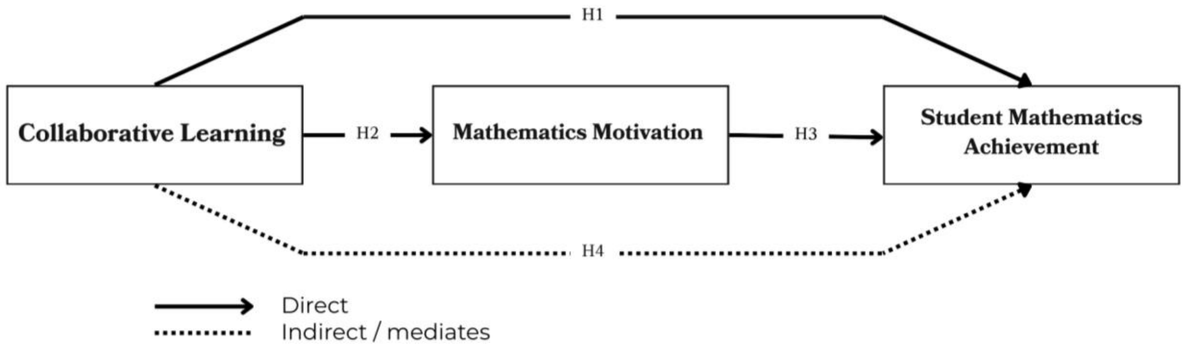
Despite the wealth of research on collaborative learning and motivation, there are still several gaps that need to be addressed. First, while many studies have examined the impact of collaborative learning on academic achievement, fewer have explored the specific mechanisms through which this impact occurs. In particular, the role of mathematics motivation as a mediator in the relationship between collaborative learning and mathematics achievement remains underexplored. Understanding this mediation is crucial for identifying the conditions under which collaborative learning is most effective. Second, most studies on collaborative learning have focused on general education settings, with limited attention to mathematics-specific contexts. Given the unique challenges and demands of mathematics education, it is important to investigate how collaborative learning can be tailored to support students in this subject area. The study therefore hypothesized that;

**$H_4$:** Mathematics motivation (MM) mediates the relationship between collaborative learning (CL) and students' mathematics achievement (SMA).

### 2.6. Conceptual Framework of the Study

This study examines how *collaborative learning* impacts *students' mathematics achievement*, with *mathematics motivation* as a mediating factor. The model proposes that collaborative learning directly enhances students' mathematics achievement (H1) and boosts mathematics motivation (H2). Additionally, mathematics motivation positively influences students' mathematics achievement (H3) and mediates the collaborative learning - students' mathematics achievement relationship (H4), suggesting that collaborative learning improves achievement indirectly through increased motivation. Figure 1 summarizes the conceptual framework of the study.

Figure 1
*Conceptual Framework of the Study*




## 3. Methodology

### 3.1. Research Design

This study adopted the descriptive survey design which is anchored on the quantitative research approach of the positivisms paradigm to collect data on collaborative learning, mathematics motivation, and mathematics achievement. A descriptive survey design was used because it enables the collection of quantifiable data from a large population to describe existing conditions and relationships without manipulating variables. This design was appropriate for examining the natural associations between collaborative learning, motivation, and mathematics achievement, making it suitable for mediation analysis using Structural Equation Modeling (Kumatongo & Muzata, 2021).

### 3.2. Participants

The study participants consisted of second year students from a Senior High School within the Atwima Nwabiagya Municipality of the Ashanti Region which estimated to be seven hundred and fifty-one (751) students in the school.

The study employed a simple random sampling technique to ensure that every student had an equal chance of being selected. Total of 261 senior high school students were randomly chosen to participate in the study. This method was used to enhance the representativeness of the sample and minimize selection bias, providing a robust foundation for generalizing the results to the broader student population.

Table 1
*Demographic Characteristics of the Respondents (N = 261)*

| *Demographics Characteristics* | *Frequency (N)* | *Percent (%)* |
|---|---|---|
| Gender | | |
| Male | 114 | 43.7 |
| Female | 147 | 56.3 |
| Age | | |
| 15 to 16 years | 17 | 6.5 |
| 17 to 18 years | 190 | 72.8 |
| 19 to 20 years | 52 | 19.9 |
| 21 and above | 2 | .8 |

Table 1 presents the demographics characteristics of the respondents. 114(43.7%) represents male while 147(56.3%) represents female. This indicates that majority of the respondents were females. For the age aspect of the respondents, 17(6.5%) were between the ages of 15 to 16 years, 190 (72.8%) were between the ages of 17 to 18 years, 52(19.9%) were between the ages of 19 to 20 years and 2(.8%) were 21 years and above. This indicates that the majority of the respondents were between the ages of 17 to 18 years. This is in consistent with the Ghana Education Service age stipulation. By age 15 the student might have finished the Basic Education and would be in the Senior High School.

### 3.3. Data Collection Instrument

The study utilized a structured questionnaire to gather the data. The questionnaire consisted of four sections, each targeting specific aspects related to the research objectives. Section A gathered demographic details; Section B measured collaborative learning: A set of items measuring students' perceptions of collaborative learning practices in their mathematics classes; Section C focused on mathematics motivation: A validated scale assessing students' motivation towards mathematics, including subscales for intrinsic motivation, self-efficacy, and the perceived value of mathematics; and Section D assessed mathematics achievement: A validated scale assessing students' mathematics, achievement. The instrument for mathematics achievement and motivation were adapted from the works of Arthur and Kwaku (2022), and the collaborative learning was also adapted from the works of Ku et al. (2013) with adjustments made following expert reviews on the field of mathematics education and a pilot study to ensure content, face validity and reliability (Cronbach's alpha of all the constructs were above 0.7). Each construct consisted of ten items (10).

### 3.4. Data Analysis

Data analysis was conducted using Structural Equation Modeling [SEM] in IBM SPSS AMOS Version 23 to assess the direct and indirect effects of collaborative learning on mathematics achievement. SEM was chosen for its robustness and capacity to simultaneously model complex relationships among multiple variables and test for mediation effects with greater precision (Lowry & Gaskin, 2014). The analysis followed a two-step approach: first, the measurement model was tested to confirm the validity of the constructs; second, the structural model was also tested to examine the hypothesized relationships and mediation effects.

## 4. Results

### 4.1. Exploratory Factor Analysis [EFA]

Exploratory Factor Analysis is a widely used statistical technique to identify the underlying structure of a set of variables and reduce data dimensionality while preserving its essential information (Plonsky, 2015) . This study conducted an EFA to examine the factor structure of the measurement items related to collaborative learning, mathematics motivation, and students' mathematics achievement. The analysis aimed to validate the grouping of items into their respective constructs and assess the adequacy of the measurement model before proceeding with further statistical tests. The following presents the key findings from the rotated component matrix and associated tests.

The results of the EFA, using the principal component matrix, revealed the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was .892, indicating that the sample was adequate for factor analysis. Bartlett's Test of Sphericity was significant ( $\chi^2$ = 3693.578, df = 120, $p$ < .001), confirming the suitability of the data for EFA (Arthur & Kwaku, 2022). The total variance explained by the three components was 78.099%, which indicates that the factors account for a substantial portion of the variance in the data. The determinant value of 4.792E-7 was also recorded (Dogbe et al., 2024). To decide whether to keep or remove the items, their significance and applicability were assessed. Items loaded at different components and those with low factor loadings were eliminated iteratively, and each time an item was removed, the fit indices were checked (Xia et al. 2016). It was identified that the number of observed variables in their right definiteness for students' mathematics achievement was five (5), Collaborative Learning was six (6), and students' mathematics motivation was five (5). Table 2 shows factor loadings for each component that were all greater than 0.5. These results demonstrate the robustness of the measurement model, supporting the validity of the constructs measured in this study.

Table 2
*Exploratory Factor Analysis*

| *Rotated Component Matrix* | | | |
|---|---|---|---|
| *Measurement Items* | *Component* 1 | 2 | 3 |
| CL3 | | | .827 |
| CL4 | | | .821 |
| CL5 | | | .861 |
| CL8 | | | .863 |
| CL9 | | | .830 |
| CL10 | | | .841 |
| MM1 | .871 | | |
| MM4 | .861 | | |
| MM5 | .876 | | |
| MM6 | .869 | | |
| MM8 | .876 | | |
| SMA1 | | .898 | |
| SMA2 | | .933 | |
| SMA4 | | .915 | |
| SMA5 | | .768 | |
| SMA10 | | .895 | |

| *KMO and Bartlett's Test* | | |
|---|---|---|
| Total Variance Explained | | 78.099% |
| Kaiser-Meyer-Olkin Measure of Sampling Adequacy | | .892 |
| Bartlett's Test of Sphericity | Approx. Chi-Square | 3693.578 |
| | df | 120 |
| | Sig. | <.001 |
| Determinant | | 4.792E-7 |

*Note.* CL: Collaborative learning; MM: Mathematics motivation; SMA: Students' Mathematics Achievement.

### 4.2. Descriptive and Discriminant Validity Analysis

Descriptive statistics provide an initial understanding of the data by summarizing the central tendencies and dispersion of the variables under study. In this research, the key variables include students' mathematics achievement, collaborative learning, and mathematics motivation. The following table presents the means and standard deviations of these variables, offering insights into the overall trends and variability within the dataset before further analysis. Discriminant validity is a key aspect of construct validity, ensuring that each construct is distinct from others in the model (Fornell & larcker, 1981). To assess discriminant validity, this study compares the square root of the Average Variance Extracted [AVE] for each construct with the inter-construct correlations. Additionally, Composite Reliability [CR] and AVE were calculated to verify internal consistency and convergent validity. The following table summarizes these results, with bolded and underlined values representing the square root of AVE, ensuring that each construct meets the necessary criteria for discriminant validity. In Table 3, the descriptive statistics are displayed.

Table 3
*Descriptive and Discriminant Validity Analysis*

| *Variables* | *Mean* | *SD* | *CR* | *AVE* | *SMA* | *CL* | *MM* |
|---|---|---|---|---|---|---|---|
| SMA | 4.15 | 0.73 | 0.944 | 0.774 | <u>0.880</u> | | |
| CL | 4.21 | 0.71 | 0.926 | 0.677 | 0.340*** | <u>0.823</u> | |
| MM | 4.22 | 0.74 | 0.933 | 0.736 | 0.290*** | 0.322*** | <u>0.858</u> |

*Note*. ****p*-value significant at 0.1% (.001), with √AVE underlined.

Students Mathematics Interest received the mean score of 4.15 from the analysis; collaborative learning had a mean score of 4.21 while students' mathematics motivation had mean score of 4.22.

The study employed A five-point Likert scale, from 1 (Strongly Disagree) to 5 (Strongly Agree), to measure the responses and a mean score greater 3 means Agree. Discriminant validity was assessed to ensure that the constructs are distinct from each other, following Fornell and Larcker's (1981) criterion. Composite Reliability values ranged from 0.926 to 0.944, all above the recommended threshold of 0.7, indicating internal consistency reliability (Hair el al., 2010). The Average Variance Extracted values ranged from 0.677 to 0.774, exceeding the 0.5 threshold, confirming convergent validity. The square roots of the AVE (bolded and underlined in the table) are higher than the inter-construct correlations, indicating good discriminant validity. Significant correlations between the constructs are reported at the 0.1% level ($p < .001$).

### 4.3. Validity and Reliability Analysis

The validity and reliability of measurement instruments are critical to ensuring the integrity and robustness of research findings (Jongbo, 2014). This study conducted comprehensive analyses to evaluate both aspects for the constructs of Students' Mathematics Achievement, Collaborative Learning, and Mathematics Motivation. This study employed Cronbach's Alpha to measure the internal consistency of the scales associated with the constructs of Students' Mathematics Achievement, Collaborative Learning, and Mathematics Motivation. Table 4 presents the number of items for each variable alongside their respective Cronbach's Alpha values, providing insights into the reliability of the measurement instruments utilized in this research.

Table 4
*Reliability Analysis*

| *Variables* | *Number of Items* | *Cronbach's Alpha Value* |
|---|---|---|
| SMA | 5 | .943 |
| CL | 6 | .883 |
| MM | 5 | .933 |

The measurements instruments were given to experts in the field of mathematics to judge if what the items purports to measure has the potentiality to measure thereby face validity was achieved Reliability analysis is essential for evaluating the consistency of measurement instruments used in research. In this study, Cronbach's Alpha was computed for each variable to assess internal consistency. The results indicate that Students' Mathematics Achievement demonstrated a high reliability with a Cronbach's Alpha of 0.943, while Collaborative Learning showed acceptable reliability at 0.883. Mathematics Motivation also exhibited high reliability with a value of 0.933. These findings suggest that the instruments used to measure these constructs are reliable and suitable for further analysis (Taber, 2020).

### 4.4. Results of Confirmatory Factor Analysis [CFA]

Confirmatory Factor Analysis is a statistical technique used to test the hypothesis that a relationship exists between observed variables and their underlying latent constructs. This methodology is particularly beneficial in validating measurement models, as it allows researchers to confirm whether the data fit a specified factor structure (Sujati et al., 2020). In this study, CFA was employed using AMOS to assess the dimensionality of the constructs related to Students' Mathematics Achievement, Collaborative Learning, and Mathematics Motivation. Table 5 provides an overview of the CFA outcomes.

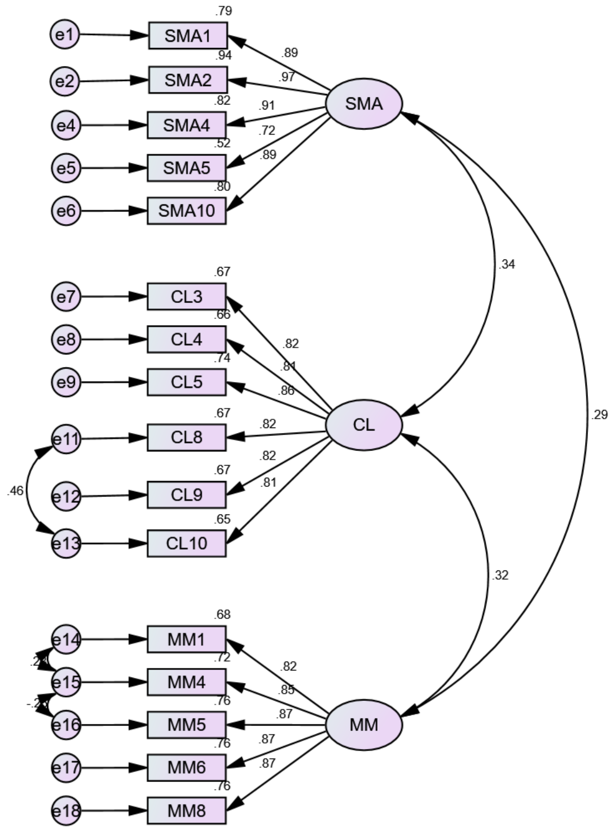
The assessment of model fit indices is crucial for determining the adequacy of a structural equation model. The present analysis yielded a Chi-square value [CMIN] of 170.630 with 98 degrees of freedom [df], resulting in a CMIN/DF ratio of 1.741 (Akendita et al., 2024). This value is well below the acceptable threshold of 3.0, suggesting a good fit to the data. Additionally, the Tucker-Lewis Index [TLI] and Comparative Fit Index [CFI] were found to be 0.976 and 0.980, respectively, both exceeding the recommended threshold of 0.95, indicating an excellent model fit (Arthur et al., 2022). The Root Mean Square Error of Approximation [RMSEA] was calculated at 0.053, which is also below the threshold of 0.06, confirming a close fit. Moreover, the PClose value

Table 5
*Confirmatory Factor Analysis*

| Model Fit indices: CMIN= 170.630; DF = 98; CMIN/DF = 1.741; TLI= .976; CFI = .980; RMR = .018; RMSEA = .053; PClose = .325 | | *Sd. Factor Loadings* |
|---|---|---|
| *Students Mathematics Achievement (SMA): CA = .933; CR = .944; AVE = .774;* | | |
| SMA1 | I understand the mathematics concepts taught in my class. | .891 |
| SMA2 | I perform well on mathematics assignments and homework. | .969 |
| SMA4 | I am confident in my mathematics skills. | .907 |
| SMA5 | I score well in mathematics exams and quizzes | .718 |
| SMA10 | I consistently achieve high scores in mathematics tests. | .894 |
| *Collaborative Learning(CL): CA = .883; CR = .926; AVE = .677;* | | |
| CL3 | I am comfortable sharing my ideas during collaborative tasks in mathematics. | .821 |
| CL4 | My peers support my learning in mathematics during group activities. | .813 |
| CL5 | Working in groups makes learning mathematics more enjoyable for me. | .859 |
| CL8 | Collaborative learning helps me retain mathematics concepts better. | .816 |
| CL9 | My classmates and I help each other understand mathematics concepts. | .821 |
| CL10 | I feel motivated to participate in mathematics when working with others. | .806 |
| *Mathematics Motivation (MM): CA =.933; CR = .933; AVE = .736;* | | |
| MM1 | I enjoy tackling challenging mathematics problems. | .823 |
| MM4 | Solving mathematics problems gives me a sense of accomplishment. | .847 |
| MM5 | I am confident that I can excel in mathematics. | .874 |
| MM6 | I believe I am capable of solving complex mathematics problems. | .872 |
| MM8 | I am confident that I can understand even the most difficult mathematics topics. | .873 |

of 0.325 suggests that the model is acceptable, further validating the robustness of the proposed model. The findings suggest that the measurement model is robust, with high reliability and validity across all constructs.

Figure 2
*Confirmatory Factor Analysis*



### 4.5. Path Analysis

The data was then subjected to additional analyses by looking at the potential relationship between the endogenous and exogenous variables of the framework used for the study, following the evaluation of the measurement model fit using Amos (v.23), Structural equation modeling. The estimates for the test of direct relationships and the mediating effect of teacher mathematics motivation on the relationship between collaborative learning and students' mathematics achievement. In addition, the control variables were included into the analysis and are presented in Table 6 and graphically depicted in Figure 3. Overall, the model shows a good fit.

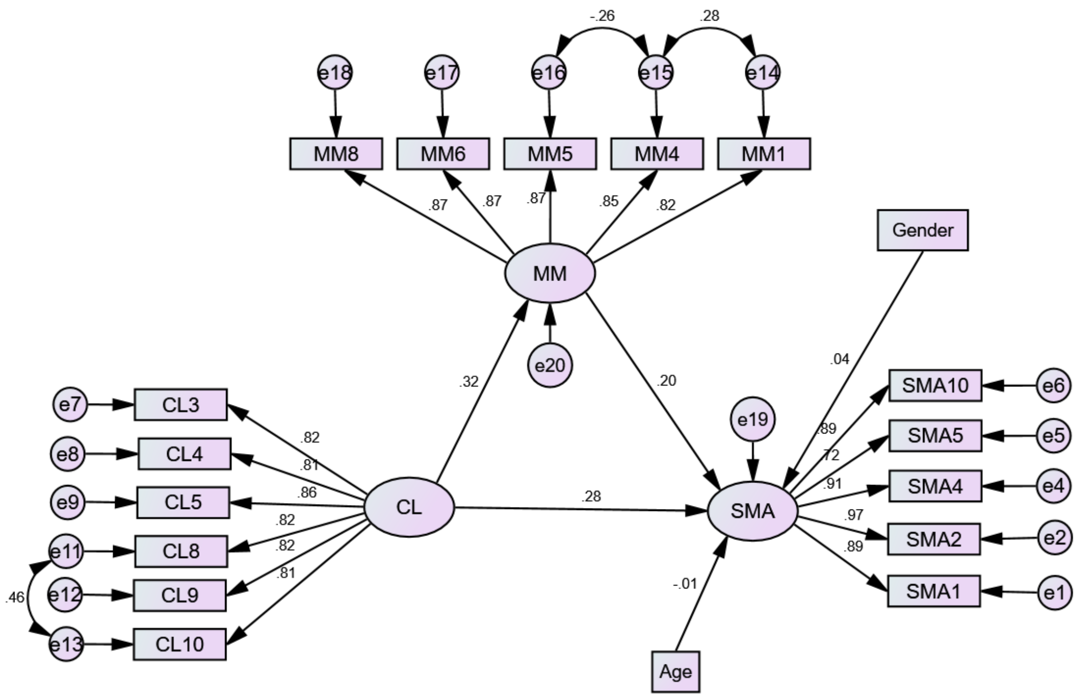
Table 6
*Path Summary*

| Direct Effect | Std. Estimates | SE | C.R | *p*-Value |
|---|---|---|---|---|
| Age → SMA | −.007 | .073 | −.095 | .904 |
| Gender → SMA | .041 | .077 | .532 | .479 |
| CL → SMA | .277 | .074 | 3.743 | *** |
| CL → MM | .324 | .070 | 4.628 | *** |
| MM → SMA | .196 | .069 | 2.840 | .003 |
| **Indirect Effect** | **Std. Estimate** | **Lower Bound** | **Upper Bound** | ***p*-Value** |
| CL → MM→SMA | .063 | .020 | .134 | .003 |

*Note.* ****p* = 0.1% significant value of $p < .001$

From the Table 6, the result showed that, the respondents' gender positively impacted the students' mathematical performance (SMP) but is statistically insignificant with 0.6% positive impact ($\beta$ = 0.006.; *CR* = .068; *p* =.946). Students' mathematics performance was negatively impacted by age but is statistically significant with 18.2% negative impact ($\beta$ = −.182; *CR* = −2.729; *p* = .006). In addition, Students' performance in mathematics was negatively impacted by the respondents' course and statistically insignificant with 2.4% negative impact on Students Mathematics Performance ($\beta$ = −.024; *CR* = −.794; *p* = .427).

Figure 3
*Path Analysis*



*4.5.1. Hypothesis one (Collaborative learning significantly influences students' mathematics achievement)*

Finding out if collaborative learning significantly influences students' mathematics achievement is the goal of this study's hypothesis. Table 6 presents the specific results in detail.

Results on the hypothesized paths, as shown in Table 6, demonstrated that Collaborative learning had a positive effect on students' mathematics achievement and this impact was statistically significant, with a 27.7% positive impact on students' math achievement ($\beta$ = .227; $CR$ = 3.743; $p$ = .001). That is, a 27.7% increase in students' maths achievement can be attributed to Collaborative learning as a teaching strategy in the teaching and learning process of the subject. This suggests that students' achievement in mathematics is positively impacted when they being engaged through collaborative learning strategy in the subject. Thus, $H_1$ was supported.

*4.5.2. Hypothesis two (Collaborative learning significantly influences students' mathematics motivation)*

This hypothesis of the study is intended to determine whether Collaborative learning significantly influences students' mathematics motivation. Table 6 shows the details of the findings.

As indicated in Table 6. The outcomes pertaining to the postulated pathways demonstrated that Collaborative learning significantly influences students' mathematics motivation and statistically significant with 32.4% positive impact on students' mathematics motivation ($\beta$ = .324; $CR$ = 4.628; $p$ = .001). That is, about 32.4% improvement on Students mathematics motivation is attributed to the effectiveness of the Collaborative learning strategy in the instructional process. This indicates that Collaborative learning strategy in the instructional process influences positively, students' mathematics motivation. Based on the results of the study, $H_2$ was supported.

*4.5.3. Hypothesis three (Students' Mathematics motivation significantly predicts students' academic achievement)*

This hypothesis of the study is meant to ascertain whether or not students' mathematics motivation significantly predicts students' academic achievement. Table 6 displays the specifics of the findings.

As indicated in Table 6, Findings on the proposed pathways suggested that Students' Mathematics motivation significantly predicted students' academic achievement and statistically significant with 19.6% positive impact on students' academic achievement ($\beta$ = .196; $CR$ = 2.840; $p$ = .001). In light of the study's findings, $H_3$ was supported.

*4.5.4. Hypothesis four (Mathematics motivation mediates the relationship between collaborative learning and students' mathematics achievement)*

Using a 95% confidence level and a 5,000-bootstrap sample, the Bias-Corrected [BC] percentile method of bootstrapping was applied. The structural model shown in Table 6 satisfied all of the different fit indices as recommended by Hair et al. (2010), just as the CFA did. Additionally, Figure 3 displays the study's diagrammatic representation of the structural model.

The purpose of this hypothesis is to ascertain whether students' mathematics motivation mediates the relationship between collaborative learning and students' mathematics achievement. Table 6 presents the specifics of the findings.

As indicated in Table 6, results on the direct impact of Collaborative learning on students' mathematics achievement is positive and is statistically significant with 27.7% positive impact on students' mathematics motivation ($\beta$ = .227; $CR$ = 3.743; $p$ = .001). This implies that 27.7% improvement on Students mathematics achievement is attributed to Collaborative learning strategy in mathematics. This indicates that students who collaborative learning strategy in mathematics influences positively, students mathematics achievement in the subject. Similarly, the effect of students mathematics motivation on the relationship between collaborative learning and students' mathematics achievement was statistically significant ($\beta$ = .063; $LB$ = .020; $UB$ = .134; $p$ = .003). According to the study's findings, $H_4$ was supported. This implies that students' mathematics motivation explains the relationship between collaborative learning and students' mathematics achievement. Since the direct effect of collaborative learning is significant as well as the indirect effect, students mathematics motivation therefore, serves as a partial mediator between the relationship of collaborative learning and students' mathematics achievement.

## 5. Discussion

The purpose of this study was to investigate the role of collaborative learning in enhancing students' mathematics achievement and to examine whether mathematics motivation mediates this relationship. The findings can be discussed in relation to social constructivist perspectives on collaborative mathematical activity and to educational psychology research emphasizing the role of motivation in mathematics learning. In this sense, the results contribute to ongoing discussions of how interaction-rich learning environments and motivational factors may shape students' experiences and outcomes in mathematics education (Gökdeniz Tahiroğlu & Özcan, 2025; Møller & Kaup, 2023).

The first hypothesis, which posited that collaborative learning significantly influences students' mathematics achievement, was supported by the findings. This result aligns well with Vygotsky's social constructivism, which emphasizes that learning is a social process and that knowledge is co-constructed through interaction within social contexts, particularly in collaborative environments. The findings are consistent with previous empirical studies. For example, Agani (2021) found that collaborative learning significantly improves students' educational performance in math compared to conventional teaching methods. Similarly, a study by Siller and Ahmad (2024) on analyzing the impact of collaborative learning approach on grade six students' mathematics achievement and attitude towards mathematics found that collaborative learning significantly improved mathematics achievement in sixth-grade students compared to traditional teaching methods. Both groups had similar pre-test scores, indicating no initial differences in mathematics knowledge. After a 12-week intervention, the experimental group showed notable gains in mathematics achievement. Positive changes in attitudes towards mathematics were observed in the experimental group, with some improvement also noted in the control group.

The second hypothesis, which suggested that collaborative learning significantly influences students' mathematics motivation, was also supported. The findings revealed that collaborative learning had a positive impact on students' motivation to engage with mathematics. This supports the argument that learning in a collaborative setting not only improves academic outcomes but also fosters a greater interest and motivation in the subject (İlhan, 2021; Järvenoja et al., 2020). This is consistent with the Self-Determination Theory, which posits that motivation is enhanced when individuals feel autonomous, competent, and connected to others. Collaborative learning environments inherently promote these feelings as students work together to solve problems, share ideas, and provide peer support. Empirical evidence a study by Järvenoja et al. (2020) found that students who participated in collaborative learning reported feeling more supported by their peers compared to those who learned individually. Similar study by In'am and Sutrisno (2020) highlighted that students who engaged in cooperative learning showed improvements not only in their mathematical understanding but also in their confidence levels. Collaborative learning encourages diverse perspectives on problem-solving strategies

The third hypothesis proposed that students' mathematics motivation significantly predicts their academic achievement, and this was confirmed by the results. A 19.6% improvement in students' mathematics achievement can be attributed to their motivation levels. This is in line with previous studies, such

The third hypothesis proposed that students' mathematics motivation significantly predicts their academic achievement, and this was confirmed by the results. A 19.6% improvement in students' mathematics achievement can be attributed to their motivation levels. This finding is consistent with previous research showing that mathematics motivation is closely related to mathematics achievement. It also aligns with evidence that instructional practices associated with gains in mathematics motivation may coincide with improved mathematics achievement and more positive attitudes toward the subject (Al Umairi, 2024). For instance, a study by Rodríguez et al. (2021) found that students who were intrinsically motivated in mathematics displayed greater persistence, higher levels of cognitive engagement, and better problem-solving skills. This study further validates the role of motivation in enhancing academic performance, particularly in challenging subjects like mathematics. The positive relationship between motivation and achievement highlights the need for instructional strategies that not only focus on cognitive development but also on increasing students’ engagement and interest in the subject (Insorio, 2024).

Moreover, the fourth hypothesis tested whether mathematics motivation mediates the collaborative learning and mathematics achievement relationship of students. From the results, mathematics motivation partially mediated the relationship and motivation explains part of the collaborative learning impact on achievement. The direct relationship between collaborative learning and mathematics achievement as well as the indirect relationship via motivation were both statistically significant. This mediating function of motivation is in line with Self-Determination Theory, which theorizes that students' inherent psychological needs satisfaction increases autonomous motivation, ultimately leading to better academic performance (Ryan & Deci, 2020). Empirical studies indicate that students with higher motivation and stronger interest in mathematics tend to achieve better outcomes in mathematics (Asare et al., 2025; Lv et al., 2019). Additionally, cooperative learning settings have been observed to promote students' motivation and engagement, which result in better mathematics performance (Osei et al., 2026). The partial mediation indicates that cooperative learning is directly related to mathematics achievement but has an even greater impact when motivated students engage intensively with the material.

## 6. Conclusion

This study has demonstrated that collaborative learning is a powerful pedagogical strategy for enhancing students' mathematics achievement, with a positive impact. Additionally, it was found that students’ mathematics motivation plays a significant mediating role, partially explaining the relationship between collaborative learning and mathematics achievement. The findings confirm that collaborative learning not only fosters academic success but also boosts students’ motivation, which in turn further drives achievement. These results highlight the importance of integrating social interaction and motivation into mathematics instruction to create more effective learning environments. The novelty of this study lies in its integration of collaborative learning and motivation theories within the context of mathematics education. While both factors have been studied independently, this research is one of the few to explore how motivation mediates the relationship between collaborative learning and mathematics achievement. The use of rigorous statistical methods, such as bootstrapping, adds robustness to the findings, making them highly relevant for educational practitioners looking to enhance student outcomes in mathematics through innovative teaching methods. Moreover, the study's focus on quantifying the effect sizes of both direct and indirect relationships provides new insights into the relative importance of collaborative learning and motivation in shaping students' academic success. This evidence-based approach supports the design of interventions that not only emphasize collaborative strategies but also actively seek to boost students’ motivation to maximize learning outcomes.

## 7. Recommendation

Teachers should adopt collaborative learning strategies in mathematics classrooms to enhance both academic achievement and motivation. This could involve group-based problem-solving, peer teaching, and discussion activities that allow students to co-construct knowledge.

Schools and educators should develop interventions that specifically aim to boost students’ intrinsic motivation in mathematics. This could include offering more autonomy in tasks, connecting math concepts to real-world applications, and providing positive reinforcement for student participation and effort.

Continuous professional development programs should be organized to train teachers on how to effectively implement collaborative learning strategies and foster motivation in the classroom. This will ensure that teachers have the skills and tools necessary to create engaging and supportive learning environments.

## 8. Limitations and Future Research

The study was conducted with a limited sample size, which may restrict the generalizability of the findings to broader populations. Future studies should consider larger and more diverse samples across different regions and school settings. This study focused on short-term outcomes of collaborative learning. Longitudinal research is needed to examine whether the effects of collaborative learning and motivation on mathematics achievement persist over time.

Future research should explore the long-term impact of collaborative learning on both motivation and achievement to determine whether these benefits are sustained over multiple academic years.

Research should be conducted in various educational settings, including rural and urban schools, to assess whether the effectiveness of collaborative learning and motivation interventions varies across different contexts and student demographics.

**Acknowledgements:** The authors gratefully acknowledge the support of the students who participated in this study and the institution that facilitated the research.

**Author contributions:** All authors were involved in concept, design, collection of data, interpretation, writing, and critically revising the article. All authors approve final version of the article.

**Data availability:** The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

**Declaration of interest:** No conflict of interest is declared by author.

**Ethics statement:** The ethics committee approved this study since it's a study supervised by the Faculty supervisors for publication. No participants' names were mentioned. Informed consent was obtained from all participants involved in the study. Participants were informed of the study's purpose, procedures, and their right to withdraw at any time without any repercussions. Confidentiality and anonymity of the participants were ensured throughout the research process.

**Funding:** The authors received no financial support for the research and/or authorship of this article.

## References

Acosta-Gonzaga, E., & Ramirez-Arellano, A. (2022). Scaffolding matters? investigating its role in motivation, engagement and learning achievements in higher education. *Sustainability*, *14*(20). https://doi.org/10.3390/su142013419

Agani, Y. M. A. (2021). The effect of the collaborative learning technique on students' educational performance in math. *Journal for the Mathematics Education and Teaching Practices*, *2*(2), 93–103.

Akendita, P. A., Arthur, Y. D., & Asare, B. (2025). Moderating effect of teacher efficacy on the relationship between students' perception of mathematics and students' mathematics achievement. *International Journal of Didactical Studies, 6*(1), 28932. https://doi.org/10.33902/ijods.202528932

Al Umairi, K. S. (2024). Role of mathematics motivation in the relationship between mathematics self-efficacy and achievement. *Journal of Pedagogical Research, 8*(4), 125–146. https://doi.org/10.33902/JPR.202428560

Alam, A., & Mohanty, A. (2023). Cultural beliefs and equity in educational institutions: exploring the social and philosophical notions of ability groupings in teaching and learning of mathematics. *International Journal of Adolescence and Youth*, *28*(1), 2270662. https://doi.org/10.1080/02673843.2023.2270662

Arthur, Y. D., Simon, C., Dogbe, K., & Asiedu-addo, S. K. (2022). Enhancing performance in mathematics through motivation , peer assisted learning , and teaching quality : the mediating role of student interest. *EURASIA Journal of Mathematics, Science and Technology Education, 18*(2), em2072. https://doi.org/10.29333/ejmste/11509

Arthur, Y., & Kwaku, B. (2022). Effects of peer tutoring, teaching quality and motivation on mathematics achievement in senior high schools. *International Journal of Educational Sciences*, *37*, 35–43. https://doi.org/10.31901/24566322.2022/37.1-3.1221

Asanre, A. A. (2024). Motivational factors as determinant of mathematics achievement of students in senior secondary schools. *Interdisciplinary Journal of Education Research*, *6*, 1–9. https://doi.org/10.38140/ijer-2024.vol6.19

Asare, B., Arthur, Y. D., & Adu Obeng, B. (2025). *Modeling motivation: The effect of peer teaching on mathematics achievement*. *International Journal of Didactical Studies,* *6*(2), 30243. https://doi.org/10.33902/ijods.202530243

Asiedu Menlah, C. K., & Boateng, F. O. (2025). Examining the effect of student cognitive awareness and mathematics interest on mathematics achievement. *International Journal of Didactical Studies, 6*(2), 31438. https://doi.org/10.33902/ijods.202531438

Bächtold, M., Roca, P., & De Checchi, K. (2023). Students' beliefs and attitudes towards cooperative learning, and their relationship to motivation and approach to learning. *Studies in Higher Education*, *48*(1), 100–112. https://doi.org/10.1080/03075079.2022.2112028

Bimbim, E. N., Ampofo, B., & Boateng, F. O. (2026). Exploring the effect of students' willingness on mathematics cognitive achievement: A mediation model of problem-solving skills. *International Journal of Didactical Studies, 7*(1), 29294. https://doi.org/10.33902/ijods.202629294

Cañabate, D., Bubnys, R., Nogué, L., Martínez-Mínguez, L., Nieva, C., & Colomer, J. (2021). Cooperative learning to reduce inequalities: Instructional approaches and dimensions. *Sustainability*, *13*(18), 1–17. https://doi.org/10.3390/su131810234

Cleary, T. J., & Kitsantas, A. (2017). Motivation and self-regulated learning influences on middle school mathematics achievement. *School Psychology Review*, *46*(1), 88–107. https://doi.org/10.1080/02796015.2017.12087607

Dogbe, F., Alhassan, M. D., Adomako, R. B., & Davies, E. (2024). The mediating role of government ICT use on the nexus between ICT access and public sector performance. *Transforming Government: People, Process and Policy*, *18*(3), 434-450. https://doi.org/10.1108/TG-02-2024-0039

Donkoh, R., Wing-On, L., & Donkor, J. (2021). Educational development issues in ghana in light of educational policy and planning. *International Journal of Educational Development in Africa*, *5*, 1–21. https://doi.org/10.25159/2312-3540/9224

Enoch, F. D. (2023). *WAEC releases 2023 WASSCE results.* Graphic Online. https://www.graphic.com.gh

Filippou, D., Buchs, C., Quiamzade, A., & Pulfrey, C. (2022). Understanding motivation for implementing cooperative learning methods: a value-based approach. *Social Psychology of Education*, *25*(1), 169-208. https://doi.org/10.1007/s11218-021-09666-3

Fornell, C., & Larcker, D. (1981). Fornell, C., & Larcker, D. F. (1981). Evaluating structural equation models with unobservable variables and measurement error. *Journal of Marketing Research*, *18*(1), 39–50. https://doi.org/10.1177/002224378101800104

Garon-Carrier, G., Boivin, M., Guay, F., Kovas, Y., Dionne, G., Lemelin, J. P., Séguin, J. R., Vitaro, F., & Tremblay, R. E. (2016). Intrinsic motivation and achievement in mathematics in elementary school: a longitudinal investigation of their association. *Child Development*, *87*(1), 165–175. https://doi.org/10.1111/cdev.12458

Gökdeniz Tahiroğlu, N., & Özcan, Z. Ç. (2025). Impact of worked-out examples via a Web 2.0 tool on fifth graders' achievement, attitudes, and motivation in mathematics. *Journal of Pedagogical Research, 9*(4), 202-224. https://doi.org/10.33902/JPR.202533896

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2010). *Multivariate data analysis: A global perspective*. Pearson Education.

Hendijani, R., Bischak, D. P., Arvai, J., & Dugar, S. (2016). Intrinsic motivation, external reward, and their effect on overall motivation and performance. *Human Performance*, *29*(4), 251–274. https://doi.org/10.1080/08959285.2016.1157595

Hsu, K. C., & Liu, G. Z. (2023). The construction of a theory-based augmented reality-featured context-aware ubiquitous learning facilitation framework for oral communication development. *Journal of Computer Assisted Learning*, *39*(3), 883–898. https://doi.org/10.1111/jcal.12792

Ilhan, A. (2021). The impact of game-based, modeling, and collaborative learning methods on the achievements, motivations, and visual mathematical literacy perceptions. *SAGE Open*, *11*(1). https://doi.org/10.1177/21582440211003567

In'am, A., & Sutrisno, E. S. (2020). Strengthening students' self-efficacy and motivation in learning mathematics through the cooperative learning model. *International Journal of Instruction*, *14*(1), 395–410. https://doi.org/10.29333/IJI.2021.14123A

Insorio, A. O. (2024). Integrating differentiated instruction to improve STEM students' mathematical engagement and academic performance. *International Journal of Didactical Studies, 5*(2), 27678. https://doi.org/10.33902/ijods.202427678

Iwanaga, J., Loukas, M., Dumont, A. S., & Tubbs, R. S. (2021). A review of anatomy education during and after the COVID-19 pandemic: Revisiting traditional and modern methods to achieve future innovation. *Clinical Anatomy*, *34*(1), 108–114. https://doi.org/10.1002/ca.23655

Janssen, J., & Kirschner, P. A. (2020). Applying collaborative cognitive load theory to computer-supported collaborative learning: towards a research agenda. *Educational Technology Research and Development*, *68*(2), 783–805. https://doi.org/10.1007/s11423-019-09729-5

Järvenoja, H., Malmberg, J., Törmänen, T., Mänty, K., Haataja, E., Ahola, S., & Järvelä, S. (2020). A collaborative learning design for promoting and analyzing adaptive motivation and emotion regulation in the science classroom. *Frontiers in Education*, *5*, 111. https://doi.org/10.3389/feduc.2020.00111

Jongbo, O. C. (2014). The role of research design in a purpose driven enquiry. *Review of Public Administration and Management*, *3*(6), 87–94.

Klang, N., Karlsson, N., Kilborn, W., Eriksson, P., & Karlberg, M. (2021). Mathematical problem-solving through cooperative learning—the importance of peer acceptance and friendships. *Frontiers in Education*, *6*, 1–10. https://doi.org/10.3389/feduc.2021.710296

Ku, H. Y., Tseng, H. W., & Akarasriworn, C. (2013). Collaboration factors, teamwork satisfaction, and student attitudes toward online collaborative learning. *Computers in Human Behavior*, *29*(3), 922–929. https://doi.org/10.1016/j.chb.2012.12.019

Kumatongo, B., & Muzata, K. K. (2021). Research paradigms and designs with their application in education. *Journal of Lexicography and Terminology*, *5*(1), 16–32.

Le, H., Janssen, J., & Wubbels, T. (2018). Collaborative learning practices: teacher and student perceived obstacles to effective student collaboration. *Cambridge Journal of Education*, *48*(1), 103–122. https://doi.org/10.1080/0305764X.2016.1259389

Lowry, P. B., & Gaskin, J. (2014). Partial least squares (PLS) structural equation modeling (SEM) for building and testing behavioral causal theory: When to choose it and how to use it. *IEEE Transactions on Professional Communication*, *57*(2), 123–146. https://doi.org/10.1109/TPC.2014.2312452

Lv, B., Lv, L., Wang, P., & Luo, L. (2019). A person-centered investigation of math motivation and its correlates to math achievement in elementary students. *Journal of Pacific Rim Psychology*, *13,* 21.https://doi.org/10.1017/prp.2019.21

Maharani, R., Marsigit, M., & Wijaya, A. (2020). Collaborative learning with scientific approach and multiple intelligence: Its impact toward math learning achievement. *Journal of Educational Research*, *113*(4), 303–316. https://doi.org/10.1080/00220671.2020.1806196

Møller, A. K., & Kaup, C. F. (2023). Parents' and children's learning when collaborating on inquiry-based mathematics and computational thinking tasks. *Journal of Pedagogical Research, 7*(2), 108-126. https://doi.org/10.33902/JPR.202319033

Muawanah, U. (2023). The impact of cooperative learning method on learning motivation and academic achievement of elementary school students. *International Journal of Multidisciplinary Research and Analysis*, *6*(12), 5920–5925. https://doi.org/10.47191/ijmra/v6-i12-57

NaCCA, M. (2019). *Mathematics curriculum for primary schools*. Author.

Nakata, Y., Nitta, R., & Tsuda, A. (2022). Understanding motivation and classroom modes of regulation in collaborative learning: an exploratory study. *Innovation in Language Learning and Teaching*, *16*(1), 14–28. https://doi.org/10.1080/17501229.2020.1846040

Nungu, L., Mukama, E., & Nsabayezu, E. (2023). Online collaborative learning and cognitive presence in mathematics and science education. Case study of university of Rwanda, college of education. *Education and Information Technologies*, *28*(9), 10865–10884. https://doi.org/10.1007/s10639-023-11607-w

Olanrewaju, M. K., & Suleiman, Y. (2019). Effects of collaborative learning technique and mathematics anxiety on mathematics learning achievement among secondary school students in Gombe State, Nigeria. *Asian Journal of University Education*, *15*(1), 44–58.

Osei, E. G., Osei-Bona, H. K., & Adu, F. G. (2026). Cooperative learning as a sustainable pedagogical strategy for enhancing mathematics achievement in secondary education. *Sustainable Education and Digital Transformation, 1*(1), e43539. https://doi.org/10.33902/SEDT.202643539

Paulsen, L., Dau, S., & Davidsen, J. (2024). Designing for collaborative learning in immersive virtual reality: a systematic literature review. *Virtual Reality*, *28*(1), 63. https://doi.org/10.1007/s10055-024-00975-4

Petre, G.-E. (2020). Developing students' leadership skills through cooperative learning: An action research case study. *International Forum*, *23*(2), 143–162.

Pires, E. M. S. G., Daniel-Filho, D. A., de Nooijer, J., & Dolmans, D. H. J. M. (2020). Collaborative learning: Elements encouraging and hindering deep approach to learning and use of elaboration strategies. *Medical Teacher*, *42*(11), 1261–1269. https://doi.org/10.1080/0142159X.2020.1801996

Plonsky, L. (2015). *Advancing quantitative methods in second language research.* Routledge. https://doi.org/10.4324/9781315870908

Qureshi, M. A., Khaskheli, A., Qureshi, J. A., Raza, S. A., & Yousufi, S. Q. (2023). Factors affecting students' learning performance through collaborative learning and engagement. *Interactive Learning Environments*, *31*(4), 2371–2391. https://doi.org/10.1080/10494820.2021.1884886

Rodríguez, S., Estévez, I., Piñeiro, I., Valle, A., Vieites, T., & Regueiro, B. (2021). Perceived competence and intrinsic motivation in mathematics: Exploring latent profiles. *Sustainability*, *13*(16), 1–12. https://doi.org/10.3390/su13168707

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology*, *61*, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

Siller, H. S., & Ahmad, S. (2024). Analyzing the impact of collaborative learning approach on grade six students' mathematics achievement and attitude towards mathemat. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(2), 14153. https://doi.org/10.29333/ejmste/14153

Sinha, S., Rogat, T. K., Adams-Wiggins, K. R., & Hmelo-Silver, C. E. (2015). Collaborative group engagement in a computer-supported inquiry learning environment. *International Journal of Computer-Supported Collaborative Learning*, *10*(3), 273–307. https://doi.org/10.1007/s11412-015-9218-y

Sujati, H., Sajidan, Akhyar, M., & Gunarhadi. (2020). Testing the construct validity and reliability of curiosity scale using confirmatory factor analysis. *Journal of Educational and Social Research*, *10*(4), 229–237. https://doi.org/10.36941/JESR-2020-0080

Taber, K. S. (2020). Mediated learning leading development—the social development theory of Lev Vygotsky. In B. Akpan & T. Kennedy (Eds.), *Science education in theory and practice. springer texts in education* (pp. 277–291). Springer. https://doi.org/10.1007/978-3-030-43620-9_19

Talan, T. (2021). The effect of computer-supported collaborative learning on academic achievement: A meta-analysis study. *International Journal of Education in Mathematics, Science and Technology*, *9*(3), 426–448. https://doi.org/10.46328/IJEMST.1243

Warsah, I., Morganna, R., Uyun, M., Hamengkubuwono, H., & Afandi, M. (2021). The impact of collaborative learning on learners' critical thinking skills. *International Journal of Instruction*, *14*(2), 443–460. https://doi.org/10.29333/iji.2021.14225a

Wong, S. L., & Wong, S. L. (2021). Effects of motivational adaptive instruction on student motivation towards mathematics in a technology-enhanced learning classroom. *Contemporary Educational Technology*, *13*(4), 11199. https://doi.org/10.30935/cedtech/11199

Xia, Y., Yung, Y. F., & Zhang, W. (2016). Evaluating the selection of normal-theory weight matrices in the satorra–bentler correction of chi-square and standard errors. *Structural Equation Modeling*, *23*(4), 585–594. https://doi.org/10.1080/10705511.2016.1141354

Xu, E., Wang, W., & Wang, Q. (2023). The effectiveness of collaborative problem solving in promoting students' critical thinking: A meta-analysis based on empirical literature. *Humanities and Social Sciences Communications*, *10*(1), 1–11. https://doi.org/10.1057/s41599-023-01508-1

Yaacob, A., Mohd Asraf, R., Hussain, R. M. R., & Ismail, S. N. (2020). Empowering learners' reflective thinking through collaborative reflective learning. *International Journal of Instruction*, *14*(1), 709–726. https://doi.org/10.29333/IJI.2021.14143A

Zepeda, C. D., Martin, R. S., & Butler, A. C. (2020). Motivational strategies to engage learners in desirable difficulties. *Journal of Applied Research in Memory and Cognition*, *9*(4), 468–474. https://doi.org/10.1016/j.jarmac.2020.08.007