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The Influence of Teachers' Digital Pedagogical Content Knowledge on Perceived Student Learning Outcomes in Mathematics: The Mediating Role of Instructional Quality

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Abstract: The purpose of this study was to investigate how mathematics teachers' digital pedagogical content knowledge influences students' perceived learning outcomes. The instructional quality of teachers is interpreted as the link between their digital pedagogical content knowledge (DPACK) and students' learning outcomes**.** The study employed a predictive correlational cross-sectional survey design involving 355 pre-tertiary mathematics teachers selected from a population of 2,450. The findings of the study reveal that teachers' digital pedagogical content knowledge has a significant direct influence on students' learning outcomes. Furthermore, instructional quality was found to influence students' learning outcomes and partially mediate the nexus between teachers' digital pedagogical content knowledge (DPACK) and students' learning outcomes. The study advances the existing body of knowledge by providing a more comprehensive understanding of how teachers' digital pedagogical content knowledge (DPACK) influences perceived student learning outcomes through the mediating role of instructional quality in the context of pre-tertiary education in Ghana.

Keywords: digital pedagogical content knowledge; instructional quality; perceived student learning outcomes; pre-tertiary mathematics education
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Introduction

The introduction of digital technologies into pre-tertiary mathematics classrooms has transformed expectations for effective teaching and learning (Asare & Boateng, 2025). In recent years, teachers are not only expected to demonstrate strong content and pedagogical knowledge but also to know how to integrate digital tools in a diverse way to teach to enhance students' conceptual understanding and classroom interactions (Blömeke et al., 2022; Karataş & Ataç, 2025; Sanfo & Malgoubri, 2023; Yang & Kaiser, 2022). It has been noted that, in an environment enriched with technologies, instructional quality largely depends on the teacher's ability to align mathematical content, pedagogy, and digital resources to support a meaningful learning experience (Davor et al., 2026). Consequently, recent research has increasingly focused on how teachers' pedagogical, technological, and content-related competencies influence the quality of mathematics instruction and students' learning experiences in digitally mediated classrooms (Aderinoye-Rabiu et al., 2025; Gess-Newsome et al., 2019).

Given the increasing demand for high-quality mathematics instruction in digitally mediated classrooms, researchers have sought to identify the specific forms of teacher knowledge required to integrate digital technologies meaningfully into teaching and learning processes. One framework that has gained attention in this regard is Digital Pedagogical Content Knowledge (DPACK). Digital Pedagogical Content Knowledge (DPACK) is an extension of Technological Pedagogical Content Knowledge, with a focus on teachers' understanding of how technology can be purposefully utilized to teach content effectively (Karataş & Ataç, 2025). The framework moves beyond basic technology use by emphasizing the integration of digital tools with pedagogical strategies and subject-specific instructional practices in mathematics education. This implies that it is a move beyond technology skills, with a focus on effective technology use in sound pedagogical strategies.

Research shows that teachers who have good digital pedagogical content knowledge can develop mathematics lessons that are concept-based, engaging, and encourage student interactivity (Davor & Boateng, 2026; Liu & Aziku, 2025). The quality of teaching in mathematics education is a fundamental aspect that is revealed in the teachers' capacity to convert their knowledge into practice. According to Blömeke et al. (2022) and Pohle et al. (2022), quality teaching in mathematics entails good explanations, representation, mathematically demanding content, and opportunities for student discussion. Instruction can be improved with technology, but only with effective pedagogy (Gyamfi et al., 2025). Although previous studies have examined technology integration, teacher competence, and student learning outcomes in mathematics education (Meroño et al., 2021; Scherer et al., 2018), limited research has explored how teachers' Digital Pedagogical Content Knowledge (DPACK) relates to mathematics instructional quality and perceived student learning outcomes within pre-tertiary educational settings, particularly in developing countries where digital instructional integration is still evolving.

Problem Statement

The integration of digital technologies such as GeoGebra, interactive mathematics applications, virtual simulations, graphing software, learning management systems, and online instructional platforms into pre-tertiary mathematics education has increasingly become part of contemporary classroom instruction (Joshi et al., 2025; Lotey et al., 2025). These technologies are expected to improve students' conceptual understanding, mathematical visualization, classroom interaction, and problem-solving abilities. However, despite the growing availability and promotion of digital instructional technologies within mathematics education, evidence from previous studies suggests that effective integration of these tools into classroom instruction remains a major challenge, particularly within developing educational contexts (Davor et al., 2026; Kemethofer et al., 2025).

Many mathematics teachers hold positive views on making use of digital technologies for their teaching. However, putting these views into practice is another matter (Agyei et al., 2022). In most cases, teachers use digital technologies to distribute content instead of to promote students' construction of meaning, mathematical reasoning, interaction, and to design learning activities that trigger higher-order thinking. The use of digital learning environments in the classroom can promote student engagement and access to learning resources. However, the degree to which digital technologies can deliver instructional benefits depends on teachers' ability to meaningfully integrate the technologies into their teaching (Kemethofer et al., 2025; Li & Ma, 2010). Therefore, having access to and using digital technologies does not automatically enhance the quality of teaching mathematics and students' academic results.

Research on teacher preparation and professional development has further revealed concerns regarding teachers' competencies for effective digital instructional integration in mathematics classrooms (Lotey et al., 2025; Salifu et al., 2023). Most studies on teachers' preparedness for teaching in digital learning environments focus on their level of preparedness, their confidence, and their technology acceptance. However, there is a lack of studies focusing on teachers' Digital Pedagogical Content Knowledge (DPACK) and how it affects their mathematics instructional quality and students' learning outcomes. Research has shown that the quality of teaching is the strongest predictor of student learning outcomes (Blömeke et al., 2022; Yang & Kaiser, 2022). However, research on how teachers' DPACK can be used to improve their teaching in technology-rich mathematics classrooms in pre-tertiary education settings in Africa is scarce.

Another important concern is that previous studies have often examined teacher competence, technology integration, instructional quality, and student learning outcomes as separate constructs rather than investigating the mechanisms through which these constructs interact within mathematics classrooms. Consequently, there remains limited empirical understanding of whether teachers' Digital Pedagogical Content Knowledge enhances perceived student learning outcomes directly or indirectly through improved mathematics instructional quality. This creates an important gap in mathematics education research because instructional quality may represent the key mechanism through which teachers' digital pedagogical competencies influence students' mathematics learning experiences.

Therefore, this study was conducted to investigate the relationship between teachers' Digital Pedagogical Content Knowledge (DPACK), mathematics instructional quality, and perceived student learning outcomes within pre-tertiary mathematics education. Specifically, the study examines whether mathematics instructional quality mediates the relationship between teachers' DPACK and perceived student learning outcomes in technology-supported mathematics classrooms.

Research Question

1. What is the relationship between teachers' Digital Pedagogical Content Knowledge (DPACK) and mathematics instructional quality at the pre-tertiary level?
2. To what extent does teachers' Digital Pedagogical Content Knowledge predict perceived student learning outcomes in pre-tertiary mathematics classrooms?
3. What is the relationship between mathematics instructional quality and perceived student learning outcomes as reported by pre-tertiary mathematics teachers?
4. Does mathematics instructional quality mediate the relationship between teachers' Digital Pedagogical Content Knowledge and perceived student learning outcomes at the pre-tertiary level?

Literature Review

Teachers' DPACK and Mathematics Instructional Quality

Digital Pedagogical Content Knowledge refers to teachers' integrated knowledge of how to teach mathematics content using digital tools (Joshi et al., 2025; Meroño et al., 2021). It is an extension of the Technological Pedagogical Content Knowledge model, where teachers' knowledge of content, teaching methods, and technology is viewed as an integrated whole, rather than as separate entities (Thyssen et al., 2023). This is particularly important in mathematics education because, as stated, effective mathematics teaching often involves the strategic use of representations, dynamic images, and technology. Literature has consistently shown that teachers' competence is a critical factor in teaching quality. In mathematics education, quality teaching has been shown to include clear explanations, appropriate use of representation, cognitively challenging activities, and rich opportunities for student reasoning (Blömeke et al., 2022; Yang & Kaiser, 2022).

While the integration of digital tools in teaching improves some aspects of teaching quality, the essential aspects are not the tools available, but how the tools can be used for the achievement of teaching goals. Existing research consistently demonstrates that teachers' digital and professional competencies significantly influence the quality of mathematics instruction. Studies on technology integration in mathematics education indicate that teachers who are confident and pedagogically competent in using digital tools are more likely to deliver engaging and conceptually meaningful instruction (Agyei et al., 2022; Lotey et al., 2025). Similarly, research grounded in teacher competence frameworks emphasizes that instructional quality is strongly shaped by teachers' professional knowledge and pedagogical decision-making processes (Blömeke et al., 2022; Yang & Kaiser, 2022). Collectively, these studies suggest that teachers' ability to integrate digital technologies meaningfully into mathematics instruction is essential for delivering high-quality instructional experiences.

Collectively, these studies indicate that teachers' ability to integrate digital technologies pedagogically is a critical factor in delivering high-quality mathematics instruction. Recent evidence by Davor et al. (2026) further demonstrated that teachers' Digital Pedagogical Content Knowledge significantly predicts instructional quality and students' mathematics achievement, reinforcing the importance of digitally informed pedagogical competence in mathematics classrooms. Teachers with strong DPACK are better positioned to select appropriate digital tools, design coherent learning activities, and facilitate meaningful mathematical discourse. In contrast, limited DPACK may result in superficial or procedural uses of technology that do not enhance instructional quality. Based on this body of literature, it is reasonable to expect a positive relationship between teachers' Digital Pedagogical Content Knowledge and mathematics instructional quality.

H1: Teachers' Digital Pedagogical Content Knowledge significantly influences mathematics instructional quality at the pre-tertiary level.

Teachers' DPACK and Perceived Student Learning Outcomes

However, the way in which a teacher perceives the progress of students, which we call perceived learning outcomes, can be described as the teacher's perceptions of how engaged the students are, how well the students understand the concepts, how well the students solve the problems, and how the students are progressing under a given teaching practice. When the source of the data for the classroom is the teacher, the perceptions of the students' progress become a good indication of how well the teaching practice works and how the process of teaching and learning in the classroom works. Research has shown a very close relationship between the perceptions of the students' progress and the actual observations of the teaching practices (Hattie, 2008). An important factor in the classroom in the use of technology in teaching mathematics is the Teachers' Digital Pedagogical Content Knowledge (DPACK), which enables the teacher to use technology in teaching mathematics in a way that enables the teacher to present the concepts of mathematics in a very coherent way.

There is also some empirical support for the relationship between digital pedagogical competence and learning-related outcomes. Previous studies indicate that teachers' digital pedagogical competencies contribute positively to student engagement, participation, and learning experiences in mathematics classrooms. Research on technology-supported mathematics instruction suggests that when teachers effectively integrate digital tools pedagogically, students are more likely to experience improved conceptual understanding, interaction, and engagement during instruction (Agyei et al., 2022; Lotey et al., 2025). These findings suggest that DPACK may play an important role in shaping students' perceived learning experiences within digitally mediated mathematics classrooms. Collectively, previous studies indicate that teachers' digital pedagogical competencies play an important role in creating instructional conditions that support student engagement, conceptual understanding, and mathematical reasoning (Agyei et al., 2022; Blömeke et al., 2022; Yang & Kaiser, 2022). These findings suggest that within digitally mediated mathematics classrooms, DPACK represents a critical dimension of teacher competence that may contribute positively to students' perceived learning experiences and outcomes. This argument is further supported by Boadu et al. (2026), who found that students' interest in mathematics is shaped by both instructional and psychological factors, including self-efficacy, mathematics anxiety, and perceptions of the relevance of mathematics, highlighting the importance of learning environments that foster positive student experiences. If a teacher possesses a low level of DPACK, he or she may not effectively utilize digital tools to create a learning environment, resulting in a less favorable learning outcome. As a result of the literature, the following hypothesis can be proposed:

H2: Teachers' Digital Pedagogical Content Knowledge positively predicts perceived student learning outcomes at the pre-tertiary level.

Mathematics Instructional Quality and Perceived Student Learning Outcomes

Mathematics scholars emphasize that good teaching is characterized by clear explanations, meaningful representations, cognitively challenging tasks, opportunities for mathematical reasoning, and productive teacher–student interaction. When high-quality instruction is provided, students can understand math, are motivated, and develop good problem-solving skills. On the contrary, poor instructional practices may limit conceptual understanding and meaningful engagement in mathematics learning. A large body of research links how instruction is provided to how well students learn. Blömeke et al. (2022) considered instructional quality as a significant factor that links teacher competence to student learning, showing that good instruction mediates the relationship between teacher knowledge and student learning. In another study, Yang and Kaiser (2022) found that instructional quality was a reliable forecast of student learning outcomes in mathematics concepts and achievement in various learning environments.

Related previous education levels studies also revealed this link between instructional quality and learning outcomes. Pohle et al. (2022) noted that improved instructional quality in early mathematics courses was associated with improved growth in the mathematical competence of the students. Sanfo and Malgoubri (2023) also demonstrated that effective instructional quality improved learning outcomes and reduced the achievement gap between students from different socioeconomic backgrounds. While the data used in most of the studies were at the student level, they effectively supported the link between instructional quality and learning outcomes. When the data used were from teacher perceptions on student learning outcomes, the perceptions are more likely to reflect the actual learning conditions and instructional methods used in the classroom (Hattie, 2008). Effective and well-organized mathematics instructional methods, such as interactive and concept-based learning, are associated with teacher perceptions of improved learning outcomes for the students, while ineffective and incoherent instructional methods are associated with poor learning outcomes (Appiah et al., 2023). Thus, from the literature, the following hypothesis can be formulated: High-quality mathematics instructional methods are associated with improved learning outcomes, as they encourage the engagement, comprehension, and problem-solving skills of the students, while ineffective instructional methods limit the learning potential of the students.

H3: Mathematics instructional quality positively predicts perceived student learning outcomes at the pre-tertiary level.

From hypotheses 1, 2, and 3, it was realized that teachers' Digital Pedagogical Content Knowledge significantly influences mathematics instructional quality; teachers' Digital Pedagogical Content Knowledge significantly influences perceived student learning outcomes; and mathematics instructional quality significantly influences perceived student learning outcomes. Based on these hypotheses, we subsequently hypothesize that (see Figure 1):

H4: Mathematics instructional quality mediates the relationship between teachers' Digital Pedagogical Content Knowledge and perceived student learning outcomes at the pre-tertiary level.

From the reviewed literature, previous research has primarily examined teachers' technological preparedness, digital competence, or professional knowledge in relation to instructional practices and learning outcomes, as well as the direct effect of instructional quality on student learning. In contrast, the present study explicitly examines mathematics instructional quality as a mediating mechanism through which teachers' Digital Pedagogical Content Knowledge translates into perceived student learning outcomes in pre-tertiary mathematics classrooms.

Theoretical and Conceptual Framework

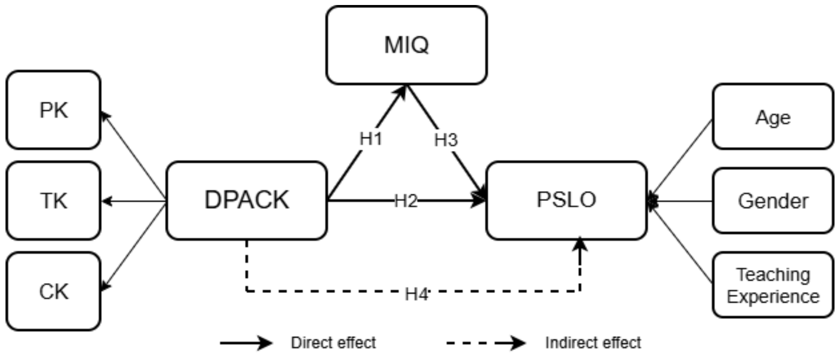
The theoretical framework of this study is grounded in the Digitality-related Pedagogical and Content Knowledge (DPACK) model proposed by Thyssen et al. (2023). The DPACK framework extends the earlier Technological Pedagogical Content Knowledge (TPACK) model by emphasizing that effective teaching in digitally transformed contexts requires more than technological knowledge, pedagogical knowledge, and content knowledge. It also requires teachers to understand how digital transformation shapes communication, learning practices, social interaction, and subject-specific teaching in STEM education. In mathematics education, this implies that teachers' digital pedagogical content knowledge involves not only selecting and using digital tools, but also aligning such tools with mathematical content, instructional strategies, student reasoning, representation, and classroom interaction.

Mathematics instructional quality refers to the extent to which teachers' practices are effective (Blömeke et al., 2022; König et al., 2021). This includes the extent to which teachers' practices can be explained and represented. It also refers to the cognitive load and the level of engagement that teachers can offer their students. Perceived student learning outcomes refer to teachers' perceptions regarding students' engagement, conceptual understanding, participation, and learning progress observed during mathematics instruction. The framework indicates that teachers with high DPACK have a greater likelihood of delivering high-quality practices that can lead to positive learning outcomes.

Figure 1 illustrates the conceptual framework that guided the research. The figure indicates that the research has three constructs. These are teachers' digital pedagogical content knowledge (DPACK), mathematics instructional quality (MIQ), and perceived student learning outcomes (PSLO). DPACK represents the independent variable. MIQ represents the mediator variable. PSLO represents the dependent variable. According to the framework, DPACK has a direct effect on both MIQ and PSLO. MIQ also has a direct effect on PSLO. MIQ mediates the relationship between DPACK and PSLO.

Figure 1

Conceptual Framework (Source: Authors' Creation, 2026)



Methodology

Research Design

This study adopted a quantitative research approach using a predictive correlational cross-sectional survey design. The design enabled the examination of predictive relationships among the study constructs within a defined population at a specific point in time (Sterner et al., 2024).

Population, Sample Size, and Sampling Technique

The research was conducted among pre-tertiary mathematics teachers who are currently working in public senior high schools in the Ashanti region of Ghana. This was because the study aimed to examine teachers' Digital Pedagogical Content Knowledge, mathematics instructional quality, and teachers' perceptions of students' learning experiences in mathematics classrooms. To find out how many participants are enough for the research, the Krejcie and Morgan (1970) sample size table was used to determine the sample size that would be significant enough to represent the population of interest. From the estimation of the population of 2,450 mathematics teachers in the selected schools, it was determined that 355 would be enough.

After the sample size had been determined, convenience sampling was used to select participating teachers from accessible public senior high schools in the Ashanti Region. This technique was appropriate because the study depended on teachers who were available and reachable during the data collection period. Although participation was voluntary, willingness to participate was treated as an ethical requirement rather than the basis for defining convenience sampling. This was chosen because of the nature of the research, whereby the teachers' willingness to participate would be significant in determining the sample size (Wolf et al., 2013). To ensure that the sample was large enough, a questionnaire was used as the main tool for collecting data from the sample of interest. Each questionnaire was accompanied by a cover letter that explained the purpose of the research, the requirements of the participants, and their promise of confidentiality, and was sent to mathematics teachers in selected schools of interest through school administrators. In some cases, the questionnaires were picked up from the schools by field assistants.

Data collection was done over a period of seven weeks from September 15, 2025, to November 4, 2025, after which 355 fully completed questionnaires had been returned, meeting the requirements of the research. Table 1 depicts demographic information about the study.

Table 1

Demographics of teachers

Teachers Background	Frequency (N)	Percentages (%)
Gender	**355**	**100**
Male	195	54.9
Female	160	45.1
Age	**355**	**100**
22-30 years	91	25.6
31-35 years	143	40.3
36-Above	121	34.1
Years of teaching experience	**355**	**100**
1-5years	78	22.0
6-10 years	165	46.5
11-Above	112	31.5

Questionnaire Development

The questionnaire for the study consisted of four sections. The first section, A, consisted of the teacher's demographics, including gender, years of experience, academic qualifications, and the type of school where the teacher was teaching. The second section, B, consisted of items used to measure the teacher's Digital Pedagogical Content Knowledge (DPACK), which is conceptualized as a second higher-order construct with technological knowledge items adapted from the work of Koehler et al. (2014), pedagogical knowledge items adapted from the work of Scherer et al. (2018), and finally, content knowledge items were also adapted from the work of Aderinoye-Rabiu et al. (2025). The third section, C, consisted of items used to measure the instructional quality of the teacher, adapted from the studies of Asare et al. (2024) and Pohle et al. (2022). There were five items used to assess the instructional practices, explanations, representations, and engagement of the teacher. In this study, mathematics instructional quality was not treated as a broad construct covering all possible dimensions of instructional quality. Rather, the study focused specifically on instructional clarity, mathematical representation, cognitively engaging tasks, digital tool integration, and classroom interaction. These dimensions were selected because they align with the study's focus on how teachers' digital pedagogical content knowledge is translated into observable instructional practices in mathematics classrooms. The fourth section, D, consisted of items used to measure the learning outcomes of the students, and there were 5 items used to assess the teacher's perceptions of the engagement, understanding, and learning of the students. All the items used in the study, including the ones used in the four constructs, used a five-point Likert scale ranging from 1, strongly agree, to 5, strongly disagree.

Results

Exploratory Factor Analysis (EFA), KMO, and Bartlett's Test

An Exploratory Factor Analysis (EFA) was performed using SPSS version 27 to examine the underlying structure of the measurement items and reduce them into a smaller number of underlying factors that are meaningful. According to Marsh et al. (2020), the factor loadings were interpreted based on a threshold of 0.50, meaning that the variance between the observed measure and the underlying factor was at least 25%. The EFA results, together with the Kaiser-Meyer-Olkin (KMO) measure and Bartlett's Test of Sphericity, are presented in Table 2. As shown in Table 2, four items loaded on Content Knowledge (CK1-CK4), four on Technological Knowledge (TK1, TK2, TK4, TK5), four on Pedagogical Knowledge (PK1, PK2, PK3, PK5), five on Mathematics Instructional Quality (MIQ1-MIQ5), and five on Perceived Student Learning Outcomes (PSLO1, PSLO2, PSLO3, PSLO4, PSLO6). All these items included in the analysis have factor loadings of more than 0.50. This shows that there is a strong correlation between all these items and their factors. Again, Total Variance Explained was 67.367%, implying that most of the variance is explained by these factors. The Kaiser-Meyer-Olkin value was 0.902, implying that the sampling adequacy is excellent. Bartlett's Test of Sphericity is highly significant, with a χ^2 of 3630.814, a df of 231, and a $p < 0.001$, implying a significant correlation between the variables. In addition, the determinant value of 2.291E-5 suggests that multicollinearity was not a serious concern. Collectively, these results confirm the adequacy of the data and the suitability of the measurement items for subsequent confirmatory and structural analyses.

Reliability and Convergent Validity

The questionnaire went through the content validity phase, where three experts from the field of mathematics education and educational technology reviewed the questionnaire. The purpose of this stage was to identify any ambiguities in the questionnaire, ensure that all items were relevant to the research aims, and ensure that all statements were clear and easy for respondents to understand (Podsakoff et al., 2012). To assess the potential influence of common method bias resulting from the use of self-reported questionnaire data, Harman's single-factor test was conducted. The analysis revealed that the first unrotated factor accounted for less than 50% of the total variance, indicating that common method bias was not a serious concern in the study (Podsakoff et al., 2012). After reviewing all the information from the experts, some minor adjustments were made to enhance their clarity and relevance. Following the content validity phase, the questionnaire went through the convergent validity phase, where the Average Variance Extracted (AVE) values of the retained items were used to check the convergent validity. Convergent validity is said to exist if the Average Variance Extracted is at least 0.50 (Marsh et al., 2020). Based on the Average Variance Extracted values, as presented in Table 2, all the constructs had Average Variance Extracted values that exceeded the minimum, thus ensuring that convergent validity had been achieved. Reliability analysis was carried out using SPSS version 27, where Cronbach's alpha values were used to check the internal consistency of the data collected.

Table 2

Exploratory Factor Analysis (EFA)and KMO and Bartlett's Test

Rotated Component Matrix					
Measurement Items	**Component**				
	1	**2**	**3**	**4**	**5**
CK1	.759				
CK2	.707				
CK3	.802				
CK4	.776				
TK1		.765			
TK2		.765			
TK4		.754			
TK5		.775			
PK1			.753		
PK2			.809		
PK3			.775		
PK5			.773		
MIQ1				.764	
MIQ2				.775	
MIQ3				.759	
MIQ4				.830	
MIQ5				.738	
PSLO1					.800
PSLO2					.758
PSLO3					.808
PSLO4					.821
PSLO6					.774
KMO and Bartlett's Test					
Total Variance Explained				67.367	

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.902
Bartlett's Test of Sphericity	Approx. Chi-Square	3630.814
	df	231
	Sig.	.000
Determinant		2.291E-5

Table 2 presents the convergent validity and reliability values obtained for the three constructs that were used in the study, namely, Digital Pedagogical Content Knowledge (DPACK), Mathematics Instructional Quality (MIQ), and Perceived Student Learning Outcomes (PSLO). All the Cronbach's alpha values exceeded the minimum, indicating that the data collected was reliable.

Discriminant Validity Analysis

In terms of discriminant validity, the square root of the Average Variance Extracted values and the correlations between the constructs are considered. The method used here follows the recommendations of the studies of Asare et al. (2024), Boadu and Boateng (2024), and Davor et al. (2025). The square root of each construct's Average Variance Extracted is greater than the correlations with other constructs. In other words, this means that each construct represents something unique compared to other constructs in the set. In this study, the lowest square root of an AVE was 0.737, which was for the construct of Digital Pedagogical Content Knowledge, and the highest inter-construct correlation was 0.512. Since 0.737 is higher than 0.512, then discriminant validity is achieved. This shows that the study's constructs are unique from each other (Fornell & Larcker, 1981). Table 3 below summarizes our findings regarding discriminant validity.

Table 3

Discriminant validity

Variables	CR	AVE	MIQ	PSLO	DPACK
MIQ	0.868	0.569	***0.754***		
PSLO	0.884	0.603	0.512***	***0.777***	
DPACK	0.781	0.543	0.437***	0.432***	***0.737***

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

Confirmatory Factor Analysis (CFA)

A Confirmatory Factor Analysis (CFA) was performed using AMOS 23 software after completing the EFA. Only the indicators that loaded on their respective constructs in the EFA were selected to confirm the measurement model. All selected indicators had standardized factor loadings of 0.50 or above, as suggested by (Hair et al., 2019) Model fit measures and construct validity were evaluated based on Hair et al. (2012) guidelines. The results of the CFA are presented in Table 4, showing that all the standardized factor loadings are significant at the 0.001 level, implying that all the observed indicators are strongly associated with their respective constructs. Table 4 shows that the loading of content knowledge ranged from 0.692 to 0.803 (CR = 0.901; AVE = 0.694). The range of technological knowledge was between 0.725 and 0.750 (CR = 0.872; AVE = 0.633), while that of pedagogical knowledge ranged from 0.711 to 0.784 (CR = 0.868; AVE = 0.623). Mathematics instructional quality had loadings ranging from 0.708 to 0.783 (CR = 0.868; AVE = 0.569), and perceived student learning outcomes had loadings of 0.735 to 0.804 (CR = 0.884; AVE = 0.603).

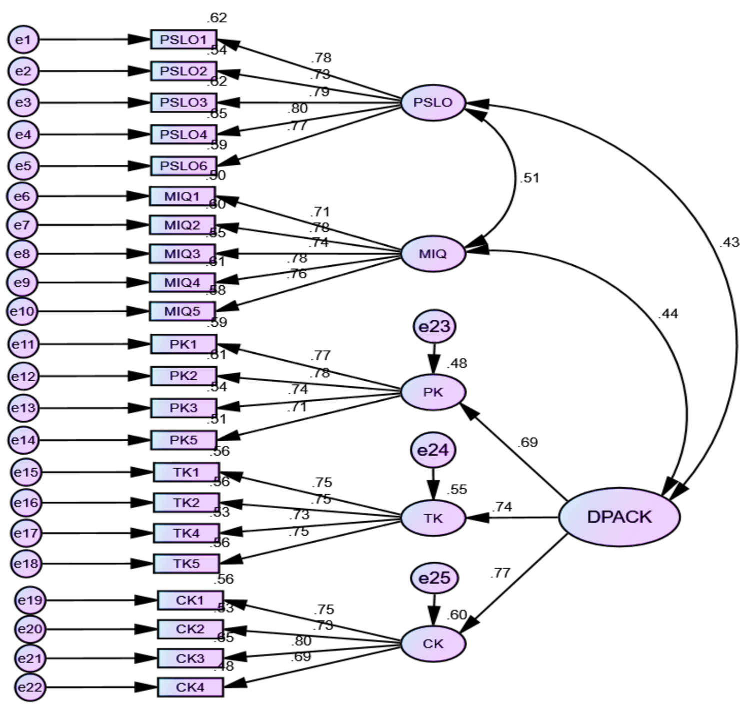


Figure 1: Confirmatory Factor Analysis (Source: Authors' Creation, 2025)

Table 4

Confirmatory Factor Analysis (CFA)

Measurement items	Loadings
Content Knowledge (CK); ***CR = .901; AVE = .694***	
CK1: I have a deep understanding of the mathematics concepts I teach at the pre-tertiary level.	.750
CK2: I can explain mathematical ideas using multiple representations (symbols, diagrams, examples).	.729
CK3: I am confident in identifying students' misconceptions in mathematics.	.803
CK4: I can connect mathematical topics across different content areas.	.692
Technological Knowledge (TK); ***CR = .872; AVE = .633***	

TK1: I am confident in using digital tools relevant to mathematics instruction.	.749
TK2: I can learn new educational technologies without difficulty.	.747
TK4: I can troubleshoot basic technical problems during mathematics lessons.	.725
TK5: I can select appropriate digital tools to support mathematics teaching.	.750
Pedagogical Knowledge (PK)*: CR =.868; AVE = .623*	
PK1: I use a variety of teaching strategies to support students' understanding of mathematics.	.771
PK2: I design mathematics lessons that actively engage students in learning.	.784
PK3: I adapt my teaching methods to suit students' learning needs.	.736
PK5: I use questioning techniques to promote students' mathematical reasoning.	.711
Mathematics Instructional Quality (MIQ)*: CR =.868; AVE = .569*	
MIQ1: My mathematics lessons are well-structured and clearly explained.	.708
MIQ2: I encourage students to explain their mathematical thinking during lessons.	.775
MIQ3: I use instructional tasks that promote deep understanding rather than memorization.	.740
MIQ4: I integrate digital tools to enhance students' understanding of mathematics concepts.	.783
MIQ5: My instructional practices support student interaction and discussion in mathematics lessons.	.763
Perceived Student Learning Outcomes (PSLO)*: CR =.884; AVE = .603*	
PSLO1: My students demonstrate improved understanding of mathematics concepts.	.785
PSLO2: Students actively participate during mathematics lessons.	.735
PSLO3: Students can apply mathematical knowledge to solve problems.	.789
PSLO4: Students show increased confidence in learning mathematics.	.804
PSLO6: Overall, my students' mathematics learning outcomes have improved.	.769

Model Fit Measures

Model fit was assessed using multiple goodness-of-fit indices to evaluate how well the proposed model represented the observed data as presented in Table 5. The chi-square statistic (CMIN), which assesses discrepancies between the observed and model-implied covariance matrices, was interpreted alongside degrees of freedom using the CMIN/DF ratio due to its sensitivity to sample size. The results indicate that there is a good fit for the proposed model. CMIN/DF is 1.318, and it is between 1 and 3. Other fit statistics also support the results. CFI is 0.988, and TLI is 0.967. Both are higher than 0.95. SRMR is 0.025, and RMSEA is 0.018. Both are below 0.08. PClose is 0.748 and is higher than 0.05. This also supports that there is a close fit. All these statistics indicate that the structural model fits well with the data (Figure 2).

Path Results

Covariance-Based Structural Equation Modeling (CB-SEM) analysis was conducted using the AMOS 23 software to investigate the relationships among the proposed constructs. CB-SEM is an ideal technique for theory-driven studies, which allows for the simultaneous testing of relationships among variables. Parameters for estimating relationships were computed via a bias-corrected percentile bootstrapping procedure with 5,000 samples and a 95% confidence interval. Table 6 presents the hypothesized relationships. In the structural model, teaching experience, age, and gender were used as control variables to control for their potential influence on perceived student learning outcomes. Age, gender, and teaching experience were included as control variables because previous educational research suggests that demographic characteristics may influence instructional practices and perceptions of student learning outcomes (Blömeke et al., 2022; König et al., 2021). Controlling for these variables helped isolate the specific effects of DPACK and instructional quality on perceived student learning outcomes. The findings revealed that teaching experience has a positive, although statistically non-significant, influence on perceived student learning outcomes ($\beta = 0.091$, $p = 0.060$). Age, on the other hand, had a negative, although non-significant, relationship with perceived student learning outcomes ($\beta = -0.024$, $p = 0.647$). Likewise, gender had a positive, although non-significant, influence on perceived student learning outcomes ($\beta = 0.033$, $p = 0.561$). These findings, in general, revealed that teachers' demographic factors do not influence perceived student learning outcomes.

Table 5

The Model Fit Indices

Measures	Estimates	Standard	Interpretation	Source
CMIN	267.554	The smaller the better	--------	--------
DF	203	The smaller the better	--------	--------
CMIN/DF	1.318	Between 1 and 3	Excellent	Xia and Yang (2019)
TLI	.967	> 0.95	Excellent	Asare et al. (2024)
CFI	.988	> 0.95	Excellent	Hu and Bentler (1999)
NFI	.931	> 0.90	Good fit	Davor et al. (2026)
GFI	.940	> 0.90	Good fit	Marsh et al. (2020)
RMSEA	.018	< 0.08	Excellent	Hair et al. (2012)
PClose	.748	> 0.05	Excellent	Marsh et al. (2020)
SRMR	.025	< 0.08	Good fit	Hair et al. (2019)

Table 6

Path Summary of the Study

Direct Effect	Std. Est.	S.E.	C.R.	p-value
Teaching Experience → PSLO	.091	.048	1.896	.060
Age→ PSLO	-.024	.088	-.273	.647
Gender→ PSLO	.033	.060	.550	.561

DPACK→ MIQ	.442	.099	4.444	***
DPACK→ PSLO	.253	.107	2.364	***
MIQ→ PSLO	.401	.080	5.013	***
Indirect Effect	**Std. Est.**	**L. B**	**U. B**	**p-value**
DPACK→MIQ→PSLO	.026	.005	.066	.010

*Note: ***p=0.1% significant value of p (0.001).*

H1: Teachers' Digital Pedagogical Content Knowledge positively affects mathematics instructional quality.

Research hypothesis one (H1) posits that teachers' Digital Pedagogical Content Knowledge (DPACK) has a positive relationship with mathematics instructional quality (MIQ). This implies that teachers with higher levels of integrated digital pedagogical competence are more likely to deliver higher-quality mathematics instruction. As shown in Table 6, DPACK exerted a significant positive relationship on mathematics instructional quality, with a p-value less than 0.001 (β = 0.442; C.R. = 4.444). This finding provides empirical support for H1, indicating that teachers' DPACK is positively associated with mathematics instructional quality.

H2: Teachers' Digital Pedagogical Content Knowledge positively affects perceived student learning outcomes

Research hypothesis two (H2) states that teachers' Digital Pedagogical Content Knowledge has a positive influence on perceived student learning outcomes (PSLO). This suggests that teachers who are more competent in integrating digital technologies pedagogically are more likely to perceive improved student engagement, understanding, and learning progress. The results presented in Table 6 indicate that DPACK had a statistically significant positive effect on perceived student learning outcomes, with a p-value below the 0.001 threshold (β = 0.253; C.R. = 2.364). Consequently, hypothesis H2 was supported, confirming that teachers' DPACK positively influences perceived student learning outcomes.

H3: Mathematics instructional quality positively influences perceived student learning outcomes

H3 stated that the impact of the instructional quality of mathematics on the perceived learning outcomes is positive. To verify this, the structural model is analyzed, and from Table 6, the direct impact is evident, where the instructional quality of mathematics is related to the perceived learning outcomes of the students. The standardized path coefficient is 0.401, the critical ratio is 5.013, and the p-value is 0.000, proving the hypothesis to be true. The instructional quality of mathematics is directly related to the perceived learning outcomes of the students, thereby proving Hypothesis 3 to be true (see Figure 3).

H4: Mathematics instructional quality mediates the relationship between teachers' Digital Pedagogical Content Knowledge and perceived student learning outcomes at the pre-tertiary level.

H4 posits that mathematics instructional quality is a partial mediator between DPACK and perceived student learning outcomes. The indirect impact of DPACK on PSLO mediated by MIQ is statistically significant, β = 0.026, 95% CI [0.005, 0.066], p = 0.010. This result confirms that mathematics instructional quality serves as a mechanism through which teachers' Digital Pedagogical Content Knowledge influences perceived student learning outcomes.

The standardized path coefficients also provide evidence of effect size. The relationship between DPACK and mathematics instructional quality was moderate (β = .442), while the relationship between mathematics instructional quality and perceived student learning outcomes was also moderate (β = .401). The direct relationship between DPACK and perceived student learning outcomes was weaker but still meaningful (β = .253). These results suggest that DPACK contributes more strongly to instructional quality than directly to perceived student learning outcomes, supporting the mediating role of instructional quality.

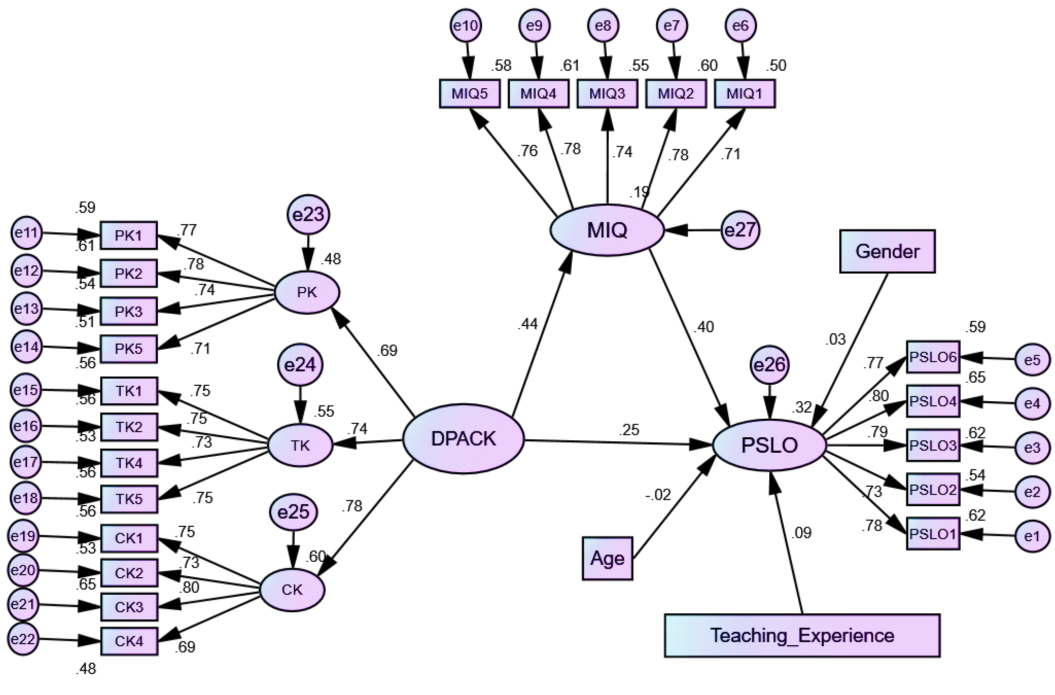


Figure 3: Path Analysis (Source: Authors' Creation, 2026)

Discussions

The study indicates that teachers' DPACK is an important aspect in the quality of mathematics teaching. The findings align with other studies that have shown the importance of integrating teachers' digital, pedagogical, and content-related competencies for effective tech-rich teaching (Thyssen et al., 2023). The DPACK framework emphasizes that effective teaching in digitally transformed mathematics classrooms depends on teachers' ability to integrate digital, pedagogical, and content-related competencies in meaningful and instructionally relevant ways. For example, in a mathematics class, the meaningful integration of digital technologies can support students' conceptual understanding, mathematical visualization, and participation in classroom discourse. This finding aligns with Hill et al. (2008), who found that teachers' professional knowledge significantly influences the effectiveness of classroom instruction. This argument is consistent with Yang and Kaiser's (2022) argument that a teacher's competence is a strong predictor of the quality of teaching, suggesting that DPACK plays a significant role in determining how competent teachers are in tech-rich mathematics teaching.

Moreover, the study established that the Digital Pedagogical Content Knowledge of the teacher positively affects the perceived learning outcomes of the students. Previous studies emphasize the importance of a teacher's ability to use pedagogical technology in facilitating student engagement, learning, and progress (Agyei et al., 2022; Hamenu & Davor, 2026; Scherer et al., 2017). A meta-analysis study by Li and Ma (2010) established that the impact of technology on the learning of mathematics is dependent on the teacher's technology application skills. Furthermore, Hattie (2008) established that the learning outcomes are significantly affected by the teacher's instructional decisions, supporting the significance of the teacher's perceptions on the learning outcomes. This finding is also consistent with Davor et al. (2026), who demonstrated that metacognitive awareness significantly shapes mathematics achievement through self-regulated learning processes, suggesting that instructional practices capable of promoting meaningful engagement and reflective learning are essential for improving students' mathematics learning outcomes.

Furthermore, the study found that the quality of mathematics instruction had a positive impact on students' perceived learning outcomes. These findings align with Blömeke et al. (2022) and Yang and Kaiser (2022), who demonstrated that instructional quality serves as a key mechanism linking teacher competence to student learning outcomes. This implies that high-quality mathematics education ensures that students comprehend and enjoy the subject. Studies by Pohle et al. (2022) and Sanfo & Malgoubri (2023) emphasize the significance of instructional quality in mathematics student outcomes.

From the mediation analysis, it was established that instructional quality in mathematics mediates the relationship between teachers' DPACK and students' perceived learning outcomes. This is in line with other studies that have established instructional quality as a significant mediator of students' learning and achievement across various contexts (Blömeke et al., 2022; Yang & Kaiser, 2022). Although DPACK has a direct influence on students' outcomes, its indirect influence via instructional quality underscores the significance of knowledge being used. This conforms with other studies that have indicated that learning outcomes are most likely to improve when instructional practices are enhanced and not knowledge (Kemethofer et al., 2025). By affirming instructional quality as a mediating factor in student learning and teacher knowledge, the study enhanced the understanding of how teachers' knowledge of digital pedagogical content knowledge impacts student learning and learning outcomes in pre-tertiary mathematics learning settings. In the Ghanaian pre-tertiary context, where access to digital instructional resources and teacher technology preparedness remain uneven across schools, the findings highlight the importance of strengthening teachers' Digital Pedagogical Content Knowledge through targeted professional development. The findings suggest that improving teachers' capacity to integrate digital tools meaningfully into mathematics instruction may enhance instructional quality and ultimately improve students' learning experiences in mathematics classrooms.

Conclusion

This study demonstrated that teachers' Digital Pedagogical Content Knowledge (DPACK) plays a significant role in improving mathematics instructional quality and perceived student learning outcomes at the pre-tertiary level. The findings revealed that teachers with stronger digital pedagogical competencies were more likely to deliver high-quality mathematics instruction and report improved student engagement, understanding, and learning progress. In addition, mathematics instructional quality significantly influenced perceived student learning outcomes and partially mediated the relationship between teachers' DPACK and perceived student learning outcomes. The study contributes to the growing body of literature on technology integration in mathematics education by providing empirical evidence from the pre-tertiary African context, where research on teachers' digital pedagogical competencies and instructional quality remains limited. By conceptualizing DPACK as a higher-order construct and examining the mediating role of instructional quality, the study extends current understanding of how teachers' digital competencies translate into improved learning experiences in mathematics classrooms. The findings further highlight the importance of strengthening teachers' capacity to integrate digital technologies meaningfully into mathematics instruction. Consequently, educational stakeholders, curriculum developers, and teacher training institutions should prioritize professional development programs that enhance teachers' digital pedagogical competencies and instructional practices to improve mathematics teaching and learning outcomes at the pre-tertiary level.

Theoretical Implications

This research contributes to the growing body of literature supporting the Digitality-related Pedagogical and Content Knowledge (DPACK) framework proposed by Thyssen et al. (2023). The findings support the argument that effective teaching in digitally transformed mathematics classrooms depends on teachers' ability to integrate digitality-related pedagogical, technological, and content knowledge in meaningful ways. The results further demonstrate that mathematics instructional quality is strongly associated with teachers' DPACK, suggesting that digitally informed pedagogical competence is essential for delivering high-quality mathematics instruction in technology-rich learning environments. The significant direct effect of mathematics instructional quality on perceived student learning outcomes is consistent with theoretical perspectives that propose that instructional quality mediates the relationship between teacher competence and student learning. In this way, instructional quality acts as a theoretical bridge that connects the teacher's knowledge with the student's learning. The partial mediation effect of mathematics instructional quality on the relationship between Digital Pedagogical Content Knowledge and perceived student learning outcomes represents a new form of theoretical contribution, as this effect sheds new light on the theoretical model that has been proposed by previous research. The results indicate that the effect of DPACK on student learning is most effective when the DPACK is transformed into a form of instructional quality.

Practical Implications

These findings highlight the importance of strengthening teachers' capacity to integrate digital technologies meaningfully into mathematics instruction. Professional development programs should therefore focus not only on teachers' technology skills but also on how digital tools can be integrated with pedagogically sound instructional strategies to improve conceptual understanding, classroom interaction, and student engagement in mathematics learning. The findings further suggest that improving instructional quality through digitally informed pedagogical practices may enhance students' learning experiences and participation in mathematics classrooms. This position is supported by Boateng et al. (2026), who found that innovative teaching approaches supported by artificial intelligence significantly enhanced students' mathematical problem-solving through increased student engagement.

Limitations

Despite the contributions of this study, certain limitations should be acknowledged. First, the study was confined to pre-tertiary mathematics teachers within a single region of Ghana. Although the sample size was adequate for structural equation modeling, limiting the study to one geographical context may restrict the generalizability of the findings to other regions or educational settings. Consequently, caution should be exercised when extending the conclusions beyond the context of the present study. Another limitation of this study is the reliance on self-reported measures, particularly regarding perceived student learning outcomes. Since the data were based on teachers' perceptions rather than objective student achievement measures, there is a possibility of response bias or social desirability bias, which may have influenced the findings.

Suggestions for Further Research

Further, there is a scope to include other mediating or moderating factors that can enhance the overall understanding of the role of teachers' Digital Pedagogical Content Knowledge (DPACK) in influencing learning outcomes. For example, teacher motivation, teacher beliefs, classroom climate, and learners' attitudes towards mathematics could be included to understand the process through which instructional quality impacts learning outcomes. This will help to create a more comprehensive model of the effectiveness of technology-based instruction. Further, longitudinal study designs can also be employed to understand the changes that take place in teachers' digital pedagogical competencies, instructional quality, and perceived learners' outcomes over a period. This will help create a more comprehensive understanding of how these constructs change with time, how teachers can improve their instructional quality with professional development, and how it can impact learners' outcomes. Further, cross-national studies can also be conducted to understand whether regional, cultural, and national variations play a role in influencing the relationships between Digital Pedagogical Content Knowledge (DPACK), instructional quality, and learners' outcomes. Further, there is a scope to employ experimental study designs to understand the role of professional development programs that can enhance teachers' digital pedagogical competencies, instructional quality, and learners' outcomes in mathematics classrooms.

References

Aderinoye-Rabiu, R. A., Bello, A. B., Usman, A. A., Falebita, O. T., & Oloyede, G. O. (2025). Assessing the influence of primary mathematics educators' content knowledge and pedagogical content knowledge on teaching effectiveness. *Pedagogical Research*, *10*(3), em0240. https://doi.org/10.29333/pr/16665

Agyei, E., Darko Agyei, D., & Benning, I. (2022). In-service mathematics teachers' preparedness, knowledge, skills, and self-efficacy beliefs of using technology in lesson delivery. *Cogent Education*, *9*(1). https://doi.org/10.1080/2331186X.2022.2135851

Amemasor, S. K., Oppong, S. O., Ghansah, B., Benuwa, B.-B., & Essel, D. D. (2025). A systematic review on the impact of teacher professional development on digital instructional integration and teaching practices. *Frontiers in Education*, *10*. https://doi.org/10.3389/feduc.2025.1541031

Appiah, J. B., Arthur, Y. D., Boateng, F. O., & Akweittey, E. (2023). Teacher-student relationship and students' mathematics achievement: Mediating roles of students' perception of mathematics, students' self-efficacy, and cooperative learning strategies. *Journal of Mathematics and Science Teacher*, *3*(2), em041. https://doi.org/10.29333/mathsciteacher/13193

Asare, B., & Boateng, F. O. (2025). Self-awareness and self-regulatory learning as mediators between ChatGPT usage and pre-service mathematics teachers' self-efficacy. *Journal of Pedagogical Research*. https://doi.org/10.33902/JPR.202530637

Asare, B., Welcome, N. B., & Arthur, Y. D. (2024). Investigating the impact of classroom management, teacher quality, and mathematics interest on mathematics achievement. *Journal of Pedagogical Sociology and Psychology*. https://doi.org/10.33902/JPSP.202426232

Bannor, G. A., Boadu, S. K., & Arthur, Y. D. (2023). Effects of teaching quality, teaching competence, and mathematics connection on mathematics achievement motivation among senior high school students in Ghana. *Matrix Science Mathematic*, *7*(2), 63–68. https://doi.org/10.26480/msmk.02.2023.63.68

Blömeke, S., Jentsch, A., Ross, N., Kaiser, G., & König, J. (2022). Opening up the black box: Teacher competence, instructional quality, and students' learning progress. *Learning and Instruction*, *79*, 101600. https://doi.org/10.1016/j.learninstruc.2022.101600

Boadu, S. K., & Boateng, F. O. (2024). Enhancing students' achievement in mathematics education in the 21st century through technology integration, collaborative learning, and student motivation: The mediating role of student interest. *Eurasia Journal of Mathematics, Science and Technology Education*, *20*(11). https://doi.org/10.29333/ejmste/15622

Boadu, S. K., Boateng, F. O., & Obeng, B. A. (2026). Modeling students' interest in mathematics: The role of self-efficacy, mathematics anxiety, cultural and societal perceptions, and relevance of mathematics. *Frontiers in Education, 11*, Article 1732581. https://doi.org/10.3389/feduc.2026.1732581

Boateng, F.O., Davor, I., & Appiah Manu, C. (2026). Innovative teaching methods supported by artificial intelligence and students' mathematical problem-solving: The mediating role of student engagement. *EIKI Journal of Effective Teaching Methods, 4*(1). https://doi.org/10.59652/7tsj5730

Davor, I., & Boateng, F.O. (2026). AI-enhanced pedagogical practices and mathematical language proficiency in STEM education. *American Journal of STEM Education, 22*, 237-262. https://doi.org/10.32674/6h0e3376

Davor, I., Asare, C., & Abanamu, A. (2026). Predictors of students' mathematics problem-solving skills: Feedback, beliefs, learning support, and technology. Sustainable and Pedagogical Technologies, 2(2), e43735. https://doi.org/10.33902/SPT.202643735

Davor, I., Boateng, F. O., & Lotey, E. K. (2025). The mediating role of metacognitive thinking in the relationship between attributional beliefs, academic buoyancy, error-management mindset, and mathematics achievement. *European Journal of Mathematics and Science Education*, *6*(4), 239–253. https://doi.org/10.12973/ejmse.6.4.239

Davor, I., Boateng, F. O., & Akweittey, E. (2026). Modeling the impact of teachers' digital pedagogical content knowledge (DPACK) on instructional quality and student mathematics achievement. *Frontiers in Education, 11*, 1807792. https://doi.org/10.3389/feduc.2026.1807792

Davor, I., Boateng, F. O., Osei-Wusu, F., Osei Bosompem, A., Osei-Tutu, P., & Hamenu, J. (2026). The role of metacognitive awareness as mediator and moderator in the nexus between self-regulated learning and mathematics achievement. *Cogent Education, 13*(1). https://doi.org/10.1080/2331186X.2026.2661434

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

Gess-Newsome, J., Taylor, J. A., Carlson, J., Gardner, A. L., Wilson, C. D., & Stuhlsatz, M. A. M. (2019). Teacher pedagogical content knowledge, practice, and student achievement. *International Journal of Science Education*, *41*(7), 944–963. https://doi.org/10.1080/09500693.2016.1265158

Gyamfi, E. K., Ghansah, B., Yidana, I., Oppong, S. O., Ananga, P., Essibu, E. K., & Essibu, W. K. (2025). Preservice teacher trainees' preparedness and implementation of computing curriculum in Ghana. *Discover Education*, *4*(1), 63. https://doi.org/10.1007/s44217-025-00451-4

Hair, J. F., Risher, J. J., Sarstedt, M., & Ringle, C. M. (2019). When to use and how to report the results of PLS-SEM. *European Business Review*, *31*(1), 2–24. https://doi.org/10.1108/EBR-11-2018-0203

Hair, J. F., Sarstedt, M., Ringle, C. M., & Mena, J. A. (2012). An assessment of the use of partial least squares structural equation modeling in marketing research. *Journal of the Academy of Marketing Science*, *40*(3), 414–433. https://doi.org/10.1007/s11747-011-0261-6

Hamenu, J., & Davor, I. (2026). Digital learning platforms and mathematical problem-solving ability: The moderating role of self-regulated learning. *European Journal of Mathematics and Science Education*, *7*(2), 87-99. https://doi.org/10.12973/ejmse.7.2.87

Hattie, J. (2008). *Visible Learning*. Routledge. https://doi.org/10.4324/9780203887332

Hill, H. C., Ball, D. L., & Schilling, S. G. (2008). Unpacking pedagogical content knowledge: conceptualizing and measuring teachers' topic-specific knowledge of students. *Journal for Research in Mathematics Education*, *39*(4), 372–400. https://doi.org/10.5951/jresematheduc.39.4.0372

Hu, L., & Bentler, P. M. (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*(1), 1–55. https://doi.org/10.1080/10705519909540118

Joshi, D. R., Khanal, B., & Adhikari, K. P. (2025). Effects of digital pedagogical skills of mathematics teachers on academic performance. *International Journal of Educational Reform*, *34*(4), 665–688. https://doi.org/10.1177/10567879231164615

Karataş, F., & Ataç, B. A. (2025). When TPACK meets artificial intelligence: Analyzing TPACK and AI-TPACK components through structural equation modelling. *Education and Information Technologies*, *30*(7), 8979–9004. https://doi.org/10.1007/s10639-024-13164-2

Kemethofer, D., Helm, C., & Warwas, J. (2025). Does educational leadership enhance instructional quality and student achievement? The case of Austrian primary school leaders. *International Journal of Leadership in Education*, *28*(3), 461–485. https://doi.org/10.1080/13603124.2021.2021294

König, J., Blömeke, S., Jentsch, A., Schlesinger, L., née Nehls, C. F., Musekamp, F., & Kaiser, G. (2021). The links between pedagogical competence, instructional quality, and mathematics achievement in the lower secondary classroom. *Educational Studies in Mathematics*, *107*(1), 189–212. https://doi.org/10.1007/s10649-020-10021-0

Krejcie, R. V., & Morgan, D. W. (1970). Determining sample size for research activities. *Educational and Psychological Measurement*, *30*(3), 607–610. https://doi.org/10.1177/001316447003000308

Li, Q., & Ma, X. (2010). A meta-analysis of the effects of computer technology on school students' mathematics learning. *Educational Psychology Review*, *22*(3), 215–243. https://doi.org/10.1007/s10648-010-9125-8

Liu, J., & Aziku, M. (2025). Role of adaptive instructional pedagogy in linking STEM digital pedagogical practices and instructional integration: Evidence from PISA 2022. *International Journal of Science and Mathematics Education*, *23*(8), 3231–3254. https://doi.org/10.1007/s10763-025-10589-0

Lotey, E. K., Boateng, F. O., Arthur, Y. D., Adu-Obeng, B., & Gordon, J. F. (2025). Exploring GeoGebra acceptance: an implication for pre-service mathematics teachers' professional development. *Cogent Education*, *12*(1). https://doi.org/10.1080/2331186X.2025.2514980

Marsh, H. W., Guo, J., Dicke, T., Parker, P. D., & Craven, R. G. (2020). Confirmatory factor analysis (CFA), exploratory structural equation modeling (ESEM), and set-ESEM: Optimal balance between goodness of fit and parsimony. *Multivariate Behavioral Research*, *55*(1), 102–119. https://doi.org/10.1080/00273171.2019.1602503

Meroño, L., Calderón, A., & Arias-Estero, J. L. (2021). Digital pedagogy and cooperative learning: Effect on the technological pedagogical content knowledge and academic achievement of pre-service teachers. *Revista de Psicodidáctica (English Ed.)*, *26*(1), 53–61. https://doi.org/10.1016/j.psicoe.2020.10.002

Podsakoff, P. M., MacKenzie, S. B., & Podsakoff, N. P. (2012). Sources of method bias in social science research and recommendations on how to control it. *Annual Review of Psychology*, *63*(1), 539–569. https://doi.org/10.1146/annurev-psych-120710-100452

Pohle, L., Hosoya, G., Pohle, J., & Jenßen, L. (2022). The relationship between early childhood teachers' instructional quality and children's mathematics development. *Learning and Instruction*, *82*, 101636. https://doi.org/10.1016/j.learninstruc.2022.101636

Salifu, I., Chirani, F., Amoah, S. K., & Odame, E. D. (2023). Training teachers by the distance mode: implications for quality teacher performance in pre-tertiary schools. *Sage Open*, *13*(4). https://doi.org/10.1177/21582440231219081

Sanfo, J.-B. M. B., & Malgoubri, I. (2023). Teaching quality and student learning achievements in Ethiopian primary education: How effective is instructional quality in closing socioeconomic learning achievement inequalities? *International Journal of Educational Development*, *99*, 102759. https://doi.org/10.1016/j.ijedudev.2023.102759

Scherer, R., Tondeur, J., Siddiq, F., & Baran, E. (2018). The importance of attitudes toward technology for pre-service teachers' technological, pedagogical, and content knowledge: Comparing structural equation modeling approaches. *Computers in Human Behavior*, *80*, 67–80. https://doi.org/10.1016/j.chb.2017.11.003

Sterner, P., Pargent, F., Deffner, D., & Goretzko, D. (2024). A causal framework for the comparability of latent variables. *Structural Equation Modeling*, *31*(5), 747–758. https://doi.org/10.1080/10705511.2024.2339396

Thyssen, C., Huwer, J., Irion, T., & Schaal, S. (2023). From TPACK to DPACK: The digitality-related pedagogical and content knowledge model in STEM education. Education Sciences, 13(8), 769. https://doi.org/10.3390/educsci13080769

Wawire, B. A., Kiambati, F., Muhia, N., Gathoni, G., & Abuya, B. (2025). Competence-based curriculum implementation in Africa: a scoping review of pedagogical and assessment practices. *Journal of Curriculum Studies*, 1–30. https://doi.org/10.1080/00220272.2025.2523429

Wolf, E. J., Harrington, K. M., Clark, S. L., & Miller, M. W. (2013). Sample size requirements for structural equation models. *Educational and Psychological Measurement*, *73*(6), 913–934. https://doi.org/10.1177/0013164413495237

Xia, Y., & Yang, Y. (2019). RMSEA, CFI, and TLI in structural equation modeling with ordered categorical data: The story they tell depends on the estimation methods. *Behavior Research Methods*, *51*(1), 409–428. https://doi.org/10.3758/s13428-018-1055-2

Yang, X., & Kaiser, G. (2022). The impact of mathematics teachers' professional competence on instructional quality and students' mathematics learning outcomes. *Current Opinion in Behavioral Sciences*, *48*, 101225. https://doi.org/10.1016/j.cobeha.2022.101225

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