

# Junior High School Science Teachers' Perception of Their Technological Pedagogical Content Knowledge (TPACK)

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The integration of technology into education has become indispensable in fostering effective teaching and learning, particularly in the sciences. However, the ability of teachers to blend technological tools with pedagogical strategies and content knowledge is captured in a framework known as Technological Pedagogical Content Knowledge (TPACK). Despite the growing emphasis on technology in education, limited research exists on the TPACK competencies of science teachers in Ghana. Understanding these competencies is vital for informing professional development programs and enhancing the quality of science education in Junior High Schools (JHS). This study explored three main questions: (1) How do JHS science teachers perceive their understanding of TPACK constructs? (2) What are the correlations between these constructs, their collective impact on TPACK, and (3) what construct is the strongest predictor of TPACK? A descriptive survey design utilizing questionnaires to collect primary data from 145 JHS science teachers was employed. Data were analyzed using frequency distributions, means, standard deviations, and multiple regression. The findings revealed that science teachers demonstrate a high perceived understanding of the TPACK constructs. There were strong positive correlations between TPACK and its six constituent constructs. Notably, Technological Content Knowledge (TCK) emerged as the most significant predictor of overall TPACK competency. These results underscore the robust self-perceptions of TPACK competencies among JHS science teachers in the study area, suggesting a strong foundation for technology integration in science education. The study's findings provide valuable insights for policymakers, educational administrators, and teacher educators in Ghana. The study recommends the development of targeted professional development programs in technology to strengthen teachers' TPACK capacity to improve science education outcomes in Ghanaian junior high schools. Furthermore, the identification of TCK as a key predictor highlights the importance of focusing on the intersection of technology and content knowledge in teacher training initiatives.

Keywords: Technological Pedagogical Content Knowledge (TPACK), Science Education, Teacher Competencies, Science Teachers, Professional Development

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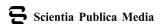


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#### 1. INTRODUCTION

The integration of technology into education is essential for developing global citizens who can thrive in a rapidly changing world. Over the past two decades, technology's role in education has been a key focus globally, significantly impacting teaching and learning. Technology not only benefits teachers but also provides students with access to vast information, aiding their learning process (Gilakjani & Ahmadi, 2017).

Universities and educational institutions worldwide are increasingly incorporating technology into their instructional methods (Shehzadi et al., 2020). Effective use of technology is crucial for educational



reform and societal development (Fu, 2013), as it supports problem-solving and offers solutions in various fields (Sarkar, 2012). Without the necessary computer skills, individuals struggle to function efficiently in modern society (Dunmire, 2010).

Technology integration has revolutionized traditional teaching methods, creating new, beneficial instructional practices for both students and teachers (Tezci, 2011; Reddy & Bubonia, 2020). This integration can motivate learners, providing them with essential skills and access to information, thus fostering independent learning (Bingimlas, 2009; Azmi, 2017). The enriched learning environment helps students understand complex issues, encourages flexible knowledge construction, and accommodates individual differences (Sang, Valcke, Braak, Tondeur & Zhu, 2011). Globally, stakeholders advocate for ICT in education to enhance teaching and learning (Tilya, 2008). Investments in technologies like computers and mobile devices aim to improve instruction (Agyei & Voogt, 2012). While developed countries lead in ICT integration, developing countries like Rwanda, South Africa, Seychelles, and Tunisia are also adopting these practices due to their educational benefits (Ejemeyovwi et al., 2020; Okoli & Tewari, 2020; Oloruntoba et al., 2020).

The government of Ghana has recognized the benefits of technology in classrooms and has implemented policies like the 2008 national ICT in education policy to enhance ICT skills among graduates (Adarkwah, 2021). This includes providing laptops, computer labs, and internet facilities to educational institutions at all levels (Adarkwah, 2021). Teachers, as primary facilitators of curriculum implementation, must possess comprehensive ICT knowledge to utilize these tools effectively (Bingimlas, 2009; Lai & Pratt, 2008). The government aims to equip students with ICT competencies, such as information retrieval, communication, collaboration, and critical thinking (Gastelu, Kiss & Dominguez, 2015). The new science curriculum also emphasizes developing curiosity, creativity, innovation, and critical thinking skills (National Council for Curriculum and Assessment [NaCCA], 2020).

However, simply introducing ICT tools is insufficient (Fischer, Lundin & Lindberg, 2019); technology must be carefully integrated into classroom activities to meet learners' needs (Kereluik, Mishra, & Koehler, 2011). Successful integration requires teachers to have Technological Pedagogical Content Knowledge (TPACK), which combines technology, pedagogy, and content (Koehler & Mishra, 2009). Studies indicate that ineffective technology integration in Ghanaian schools is due to teachers' lack of specific knowledge and skills (Agyei & Voogt, 2012). Research on TPACK in developed countries shows variations in knowledge levels based on gender and experience (Bulut, 2012; Erdogan & Sahin, 2010). In Ghana, studies have explored TPACK among teachers of various subjects but often overlook JHS science teachers (Appiah & Mfum-Appiah, 2019; Agyei & Voogt, 2012). This study aimed to address gaps in understanding JHS science teachers' TPACK and the influence of teaching experience on TPACK constructs, potentially informing teacher training programs and contributing to the broader discourse on TPACK in education. Thus, the research questions that guided the study were: (1) What is the perceived understanding of Junior High School science teachers regarding the various constructs of the TPACK framework? (2) What are the correlations between these constructs, their collective impact on TPACK, and (3) which construct serves as the strongest predictor of TPACK?

#### 1.1. Literature Review

The Technological Pedagogical Content Knowledge (TPACK) framework serves as both a tool for assessing and a guide for facilitating technology integration in education (Fabian, Lachner, & Backfisch, 2020). Possessing TPACK is essential for teachers to effectively embed technological tools into their instructional practices (Assadi & Hibi, 2020). Originally introduced as "TPCK," the term was revised to TPACK in 2008 to enhance clarity and ease of pronunciation (Jang, 2010). This framework extends Shulman's (1986) concept of Pedagogical Content Knowledge (PCK) by explicitly incorporating technological knowledge (Koehler, Mishra, & Cain, 2013).

The model encompasses three core domains of knowledge: Technological Knowledge (TK), Pedagogical Knowledge (PK), and Content Knowledge (CK). Their intersections produce four additional domains—Technological Pedagogical Knowledge (TPK), Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Content Knowledge (TPCK).

Together, these seven components capture the integrated expertise required to teach content effectively through the use of suitable pedagogical strategies and technological tools.

As a comprehensive framework, TPACK provides educators with a structured understanding of the competencies necessary for integrating technology into classroom practice, as well as pathways for developing these competencies (Sintawati & Abdurrahman, 2020). Mishra and Koehler (2006) demonstrated its applicability to both preservice and in-service teachers, underscoring its significance in preparing educators for the demands of 21st-century teaching and learning (Rets, Rienties, & Lewis, 2020).

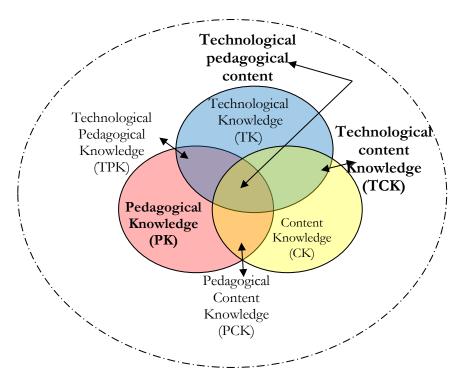


Figure 1. TPACK Framework adapted (Koehler & Mishra, 2009)

Researchers have employed various methods to measure TPACK constructs, including open-ended questionnaires, interviews, performance assessments, and self-report rating scales (Chai, Koh & Tsai, 2016; Su & Foulger, 2019; Willermark, 2018). However, findings from these methods are often contradictory. Studies in Ghana, Tanzania, Greece, and Taiwan have shown varying levels of TPACK constructs among teachers, with some reporting high levels of CK and PK but lower levels of TK (Appiah, 2016; Yalley, 2016; Mtebe & Raphael, 2018; Roussinos & Jimoyiannis, 2019). Pamuk et al. (2015) found significant correlations among TPACK constructs, with TPK and TCK contributing most to TPCK variance. Similarly, studies in Malaysia (Mai & Hamzah, 2017) and online surveys (Archambault & Crippen, 2009) revealed strong correlations between various TPACK constructs. Other studies, such as those by Acikgul and Aslaner (2020), found no significant correlations between certain TPACK constructs. Basaran (2020) concluded that TCK and PCK-21 significantly influence TPACK-21, suggesting a gradual model integrating CK and PCK-21 for professional development programs to enhance 21st-century teaching competencies.

The enhancement of teachers' TPACK development is crucial for various research populations, including science teacher education. The integration of ICT in instruction has been widely recommended as a means to improve science teaching and learning. Numerous studies have explored the implementation of the TPACK framework in science education, examining variables such as self-efficacy (Lee & Tsai, 2010), integration skills (Guzey & Roehrig, 2009; Jang, 2010), and gender influence on TPACK (Lin et al., 2013; Jang, 2010). Helppolainen and Aksela (2015) found that chemistry teachers' ICT integration aligned with that of other science teachers. Studies by Allan et al. (2010), Guzey & Roehrig (2009), and others highlighted positive correlations between science teachers' TPACK and its constructs. Brantley-Dias and Ertmer (2013) and Jimonyiannis (2010) emphasized the need to adapt TPACK for specific subjects, leading to the

development of the Technological Pedagogical Science Knowledge (TPASK) model. The TPACK framework includes eight dimensions for effective ICT integration in science teaching (Yet et al., 2014). Understanding the limitations of relying solely on the internet, Lee and Tsai (2010) introduced Technological Pedagogical Content Knowledge-Web (TPACK-W). Wang, Tsai, and Wei (2015) found positive relationships between knowledge, attitudes towards internet-based instruction, and constructivist teaching conceptions. Despite the abundance of technological frameworks, effective integration in science teaching remains a challenge (Wu, 2013).

#### 2. METHODOLOGY

# 2.1. Research Design

The study employed a cross-sectional survey design, chosen for its ability to collect substantial data from respondents and generalize findings effectively. This design facilitated the gathering of diverse responses, providing meaningful insights into respondents' opinions and behaviours at a specific point in time. It also enabled the production of statistical results that can be compared with previous studies (Ozudogru & Ozudogru, 2019). The design produced data that was quickly analysed, less time-consuming, and allowed for quantitative analysis using descriptive and inferential statistics (De Leeuw, 2005; Mugenda & Mugenda, 2012). In this approach, the researchers maintained control over the process, ensuring representative findings at a lower cost than collecting data from the entire population (Edmondson & McManus, 2007; Ghauri, Grønhaug & Strange, 2020). Despite its inability to probe deeper into issues and the necessity for a large sample size, the survey's strengths outweigh its weaknesses. Consequently, the design was deemed suitable for examining JHS science teachers' perceived understanding of TPACK and its constructs.

# 2.2. Sampling Procedure

The study targeted Junior High School (JHS) teachers in the KEEA municipality and Cape Coast Metropolis of the Central Region. The focus was on public JHS within these areas, chosen through random selection from the 22 districts, municipalities, and metropolises in the Central Region of Ghana. Respondents were selected using a simple random sampling through a computer-based random number generator, ensuring an unbiased and high-quality sample (Codling, Plank & Benhamou, 2008). Simple random sampling was chosen for its ease of use, fairness, and ability to provide representative findings (Groves et al., 2011). The methodology aimed to generalize results to the entire population of JHS science teachers in the KEEA municipality, Cape Coast Metropolis, and Ghana. Given the large population size, this method was appropriate, as it allows for selecting a manageable sample size without restrictions (Salganik & Heckathorn, 2004). One hundred and forty-five respondents, of whom 58% were male and 42% were female, were used in this study.

#### 2.3. Instruments

The study utilized a questionnaire to gather information from respondents. The questionnaire used was from Owusu, Conner, and Astall (2015). It comprised fifty-five items, divided into sections based on the research objectives. Section "A" captured demographic information. Sections "B" through "H" focused on different aspects of TPACK: TK, CK, PK, PCK, TPK, TCK, and overall TPACK. A five-point Likert scale was used for all items, as it is straightforward for respondents (Lam & Kolic, 2008). The questionnaire ensured standardization, enabling data collection from a large sample efficiently and cost-effectively.

Although the questionnaire had appropriate reliability coefficients, since it was being used in a different context, reliability analyses were conducted again to ensure it is fit for purpose in the Ghanaian context. Cronbach's Alpha was used to gauge internal consistency, with all constructs exceeding the recommended minimum of 0.7, indicating high reliability (Creswell & Creswell, 2017). The coefficients were: TK (0.748), PK (0.894), CK (0.794), PCK (0.777), TCK (0.831), TPK (0.887), and TPACK (0.873).

### 2.4. Data Collection and Analysis Procedure

The first researcher and two assistants personally administered the questionnaires after obtaining permission and assuring respondents of confidentiality. After collecting the questionnaires, the data were entered into SPSS (version 22.0) and underwent editing, coding, classifying, and tabulating for accuracy and completeness. Mean and standard deviation were used to measure central tendencies and dispersion. Pearson's Product-Moment Correlation examined relationships among variables, and a standard multiple regression identified which TPACK constructs predict TPCK. Respondents rated their TPACK constructs on a five-point Likert scale, with means above 3.5 indicating high knowledge and below 3.0 indicating low knowledge. This methodology ensured rigorous data analysis to address the study's research questions.

# 3. RESULTS

The results of this study are presented in line with the stated research objectives. The first research question focused on evaluating teachers' understanding of the TPACK framework. To investigate this, a five-point Likert scale (ranging from strongly disagree to strongly agree) was employed to capture respondents' perceptions of the TPACK constructs. Participants indicated their level of agreement on the scale, after which the mean and standard deviation were computed for each construct. A summary of these findings is provided in Table 1.

Table 1. Science Teachers' Mean Scores for TPACK Constructs

TPACK Constructs	M	SD
PK	4.44	0.72
CK	4.24	0.56
PCK	4.19	0.54
TPK	4.12	0.99
TPCK	4.05	0.59
TCK	3.97	0.80
TK	3.51	0.84
(NI-14F)		

(N=145)

The mean scores for teachers' understanding of the TPACK constructs were generally high, with the lowest being the TK construct (3.51), as shown in Table 2. The PK construct had the highest mean (M = 4.44, SD = 0.72), indicating that science teachers possess relatively high knowledge of TPACK. Only the TK and TCK constructs had mean scores below four, but both scores were still above the midpoint of 3, signifying a high level of agreement.

Given the multidimensional nature of the TPACK framework, each construct was analysed to understand teachers' perceptions better. Specific items within each construct were scrutinized to identify areas needing special attention for potential professional development programs. The mean scores for each item under the various constructs were computed, with the responses for TK items detailed in Table 3.

Table 1. Science Teachers' Mean Scores for TK Items

TK Items	M	SD
I abreast myself with modern technologies	3.83	1.01
I am aware of a lot of different technologies	3.74	1.03
I can install on my device new programs that I want to use	3.52	1.30
I possess Technological knowledge on how to use modern technology.	3.51	1.20
I know how to overcome challenges associated with the use of technology.	3.49	1.13
On my own I can learn new software with ease.	3.43	1.27
I have used different technologies to work severally	3.05	1.30
(NI-14E)		

(N=145)

Table 3 reveals that science teachers only scored a mean above 3.5 on two items of the TK construct: "I keep up with important new technologies" (M=3.83, SD=1.01) and "I know about a lot of different technologies" (M=3.74, SD=1.03). This suggests that teachers agree on these two items, but are uncertain about the others; hence, they neither agree nor disagree. In contrast, responses regarding Content Knowledge (CK) show that science teachers have a high perception of their CK, with mean scores of 4.0 and above for all CK items, as shown in Table 4.

4.14

4.08

0.77

0.82

**CK** Items M SD The science I teacher I have adequate knowledge about it. 4.39 0.77 I have varied methods of improving upon my understanding of the subject I teach 4.31 0.93 In my class, the concepts that need to be taught I can plan the scope and sequence 4.30 0.78 The lessons I taught I know how to relate them to real world situations. 4.25 0.77 I can reason scientifically. 4.25 0.70 I understand the nature of science better 4.20 0.83

Table 2. Science Teachers' Mean Scores for Content Knowledge Items

(N = 145)

I am abreast with developmental updates of my subject area

I am good about the subject matter of the subject I teach

The high mean score for teachers' confidence and comfort in developing their understanding of their subject (M = 4.39, SD = 0.77) indicates a strong agreement among the teachers. They also expressed that their understanding of the subject matter is both deep and wide (M = 4.3, SD = 0.77). The lowest-scoring item on the CK construct was 'I can use scientific way of thinking,' with a mean score of 4.08 (SD = 0.82).

Regarding pedagogical knowledge (PK), eight items were used to assess science teachers' levels. Teachers demonstrated high levels of PK, with mean scores of 4.0 and above for all items, as shown in Table 5. This suggests that teachers are well-equipped with the necessary pedagogical strategies to enhance students' understanding.

**Table 3.** Science Teachers' Mean Score for the Items Under PK

PK Items	M	SD
I am good at students' performance assessment	4.60	.606
I take into account the current understanding of my student when teaching	4.54	.717
I tried as much as possible to deal with individual differences when teaching.	4.47	.590
In my classroom setting I use different teaching approaches	4.40	.606
I am able to better assessment techniques in my classroom.	4.35	.682
I can better manage and control my classroom.	4.32	.674
I can apply suitable strategy for my lesson delivery	4.29	.645
I can prepare lesson plan for the various topics I teach.	4.28	.752

(N = 145)

The teachers demonstrated strong confidence in selecting appropriate methods for lesson delivery, as well as in assessment tools, classroom management, and addressing individual learner needs.

Similarly, teachers rated themselves highly on all eight PCK items, with mean scores of 4.0 and above for each item, as shown in Table 6. This reflects a strong grasp of pedagogical content knowledge among the science teachers surveyed.

Table 4. Mean Scores for the Items Under PCK

	SD
9	0.68
5	0.65
2	0.89
1	0.69
1	0.79
1	0.77
3	0.97
1	0.80
03	03

(N=145)

Science teachers indicated a strong ability to deliver lesson plans that enhance understanding of their subjects (M = 4.39, SD = 0.68). The lowest mean score in PCK was 4.01 for "When I am teaching, I can set clear targets for my learners," which still represents agreement. This reflects teachers' capability to predict and address students' misconceptions.

For Technological Pedagogical Knowledge (TPK), six items were assessed. Teachers agreed with most TPK items, all scoring 4.0 and above, except "I am able to manage effectively a technological-rich classroom" (M = 3.96). This suggests some uncertainty in managing tech-rich classrooms. The detailed mean scores for TPK items are presented in Table 7.

Table 5. Teachers' Mean Scores for the Items Under TPK

TPK Items	M	SD
Am able to choose technologies that influence teaching approaches for lesson delivery.	4.14	0.86
Improving students' learning through the appropriate technologies is not a problem for me.	4.10	0.82
Am able to choose best technologies to fit my teaching	4.08	0.95
Am able to cater for individual teaching activity with different technologies	4.06	0.91
I can effectively assess students' learning using technology	4.04	0.87
Am able to manage a technology-rich classroom effectively	3.96	0.87
(N= 145)		

The teachers' scores for items on the Technological Pedagogical Knowledge (TPK) construct were high, indicating that science teachers are positively aware of the technologies needed for effective teaching. The highest scoring item was "I can help learners use technology to assess learning" (M=4.14), with a low standard deviation suggesting homogeneous responses.

The Technological Content Knowledge (TCK) construct is critical for identifying appropriate technology for specific content. Data from seven items revealed that teachers scored 4.0 and above on two items, with the highest mean being "I can use technological representation to demonstrate specific concepts in my subject matter" (M=4.10, SD=0.86). The remaining five items scored below 4.0. Table 8 summarizes the mean scores for TCK items.

Table 6. Science Teachers' Mean Scores on the Items Under TCK

TCK Items	M	SD
I know about technologies that I can use for teaching specific concepts in my subject matter	4.10	0.86
I know how technology can be used to present my subject matter	4.02	0.75
Am able to enhance students' understanding of specific concepts through the use of technologies in my subject matter	3.99	0.77
Am able to demonstrate specific concepts by the use of technological representation.	3.98	0.83
Am able to deliver my content in my subject area with different technologies.	3.95	0.89
Am able to make students observe phenomenon in my subject matter through the use of technology easily.	3.90	0.88
Am able to create and manipulate scientific models through the use of technology (e.g. animations, modelling, etc)	3.61	1.01
(N= 145)		

The item under the TCK construct with the lowest mean score (3.61) was "creating and manipulating models of scientific phenomena such as animations." The wide standard deviation indicates that teachers' responses were heterogeneous. This suggests that science teachers find it challenging to use animations and modeling to help students understand scientific concepts that are difficult or impossible to observe in real-life situations.

Effective teaching in the knowledge economy requires blending content, pedagogy, and technology, known as Technological Pedagogical Content Knowledge (TPCK). This involves selecting and using technology effectively to enhance student understanding. Eight items were used to assess teachers' TPCK. The data showed that science teachers have a high understanding of TPCK, with mean scores above 4.0 for most items, except for "applying technology to enhance scientific inquiry" (M=3.94) and "effective representation of content that departs from textbook approaches" (M=3.99). The detailed results are presented in Table 9.

Science teachers expressed high confidence in the significant influence of technology selection on student learning during teaching processes. They agreed that online materials could effectively demonstrate specific scientific concepts, enhancing student understanding. Additionally, teachers recognized the importance of choosing appropriate technologies to facilitate content comprehension in lessons.

Table 7. Science Teachers' Mean Scores on the Items Under the TPCK Construct

TPCK Items	M	SD
I am able to employ subject matter, technologies and teaching methods to deliver my lessons.	4.12	0.80
I am able to apply technologies to enhance what I teach, how I teach and what students learn.	4.12	0.77
I am able to combine content, teaching approaches and technologies in my classroom.	4.10	0.74
I am able to help my counterpart science teachers to apply technology, content and teaching methods at my school	4.06	0.69
I am able to choose better technologies for the understanding of my learner.	4.03	0.76
I can find and use online resources for effective demonstration of specific scientific concept.	4.01	0.74
I can apply ICT to enhance science classroom activities.	3.94	0.82
I can manipulate ICT to achieve effective content representation that may be very different from textbook approaches.	3.99	0.83

(N = 145)

To answer the second research question, which sought to examine the relationship among the variables (TPACK framework constructs), Pearson's Product-Moment Correlation was used to analyse the data gathered for the study. This statistical tool was employed after the normality test had been conducted (see Figures 4 and 5). The result of the Product-Moment Correlation is depicted in Table 10.

Table 8. Correlation Result among TPACK Construct

	TK	CK	PK	PCK	TPK	TCK	TPCK
TK	-	.359**	101	.142	376**	.347**	.525**
CK		-	.427**	.539**	.264**	.272**	.443**
PK			_	.410**	.288**	.233**	.336**
PCK				-	.381**	.340**	.412**
TPK					-	.371**	.445**
TCK						-	.599**
TPCK							-

\*\* indicates significant correlation

The results in Table 10 show that there were positive weak to moderate significant relationships between most of the constructs. The only constructs without any correlation were TK and PK, and TK and PCK. The strongest correlation comparatively was seen between TCK and TPCK (r=.599, p< 0.05), while the weakest correlation was between PK and TCK (r=.233, p< 0.05). TPCK correlated significantly with all the TPACK framework constructs. TCK also correlated significantly with all the TPACK framework constructs. TK correlated significantly with all the technological components of the TPACK Framework (i.e., TPK, TCK, and TPCK). All the basic constructs (i.e., PK, CK, and TK) correlated significantly with TPCK.

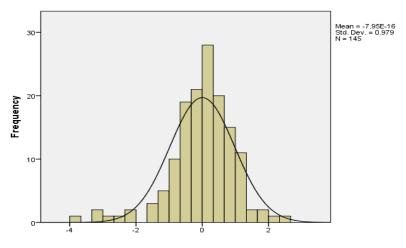


Figure 2. Regression Standardized Residual

To address the third research question, which aimed to identify which TPACK constructs predict TPCK, a standard multiple regression was conducted. TPCK was the dependent variable, while TK, PK, CK, PCK, TPK, and TCK were the independent variables. This analysis helps educators determine which constructs to emphasize in professional training programs for technology integration in teaching. SPSS version 22 was used, and classical regression assumptions were checked. The correlations between dependent and independent variables were acceptable, with values above 0.3 (Pallant, 2010; Tabachnick, 2007). The correlations among independent variables were not excessively high (r > 0.9) (Field & Golubitsky, 2009). Additional assumptions, such as normality, multicollinearity, and autocorrelation, were verified to ensure they were not violated. The normality of the dataset was confirmed using a histogram, which showed that the data did not violate the regression analysis assumptions (see Figure 2).

The normal probability plot was also employed in the study to examine the normality of the data, and the corresponding results are presented in Figure 3.

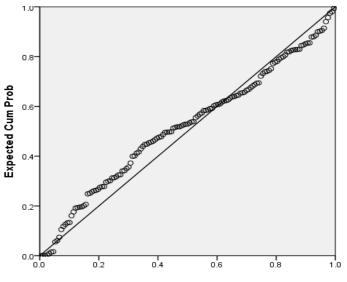


Figure 3. Observed Cum Prob

The results of the normal probability plot indicated that the data were normally distributed. The graph demonstrated that the points were dispersed along the diagonal line, aligned with its direction, and did not deviate significantly from it. Hence, the data can be considered normally distributed.

To assess multicollinearity among the variables in the regression model, the variance inflation factor (VIF) was employed. The findings showed that tolerance values exceeded 0.1 and the VIF values were below 10, indicating the absence of multicollinearity issues (Pallant, 2010). The outcomes of the multicollinearity test are presented in Table 11.

Variables	Tolerance	VIF
TK	.712	1.405
CK	.577	1.732
PK	.744	1.344
PCK	.589	1.697
TPK	.704	1.420
TCK	.761	1.314

Table 9. Multicolinearity Test

Mahalanobis distances were employed to identify outliers in the data. Although 9 cases exhibited distances higher than the critical value, their Cook's distances were all below 1. As a result, these cases were retained in the analysis, as outliers can be acceptable with a reasonably sized data file (Pallant, 2010). Table 12 presents the Mahalanobis residual statistics.

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	26.8842	45.3786	32.1448	2.39294	145
			0=		
Std. Predicted Value	-2.198	5.530	.000	1.000	145
Standard Error of Predicted	200	2 202	0.07	20.4	4.45
Value	.398	3.293	.807	.394	145
Adjusted Predicted Value	25.5245	50.2003	32.1458	2.64024	145
Residual	-10.71002	14.11455	.00000	4.00121	145
Std. Residual	-2.620	3.453	.000	.979	145
Stud. Residual	-2.672	3.731	.000	1.017	145
Deleted Residual	-12.20034	16.47546	00098	4.34390	145
Stud. Deleted Residual	-2.734	3.920	.000	1.030	145
Mahal. Distance	.376	92.486	5.959	10.446	145
Cook's Distance	.000	.503	.013	.052	145
Cantered Leverage Value	.003	.642	.041	.073	145

Table 10. Mahalanobis Residuals Statistics<sup>a</sup>

The Durbin–Watson statistic was employed to test for potential autocorrelation, yielding a value of 1.842, which indicates the absence of such a problem. A Durbin–Watson value within the range of 1.5 to 2.5 is generally regarded as acceptable and free from autocorrelation issues (Alabdullah, 2018). Since no violations of statistical assumptions were detected, multiple regression analysis was conducted to examine which TPACK constructs significantly contributed to the overall TPACK framework. Six independent predictors—CK, PK, TK, PCK, TCK, and TPK—were included in the analysis to identify the primary predictor of TPCK, the dependent variable. The results of this regression analysis are displayed in Table 13.

Table 11. Model Summary For The Multiple Regression

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
	.739a	.547	.527	3.23630	1.842

The analysis demonstrated a strong positive relationship (R = .739) between the dependent variable (TPCK) and the independent variables (CK, PK, TK, PCK, TCK, and TPK). The coefficient of determination (R²) was 0.547, while the Adjusted R² was 0.527. These findings suggest that the model accounts for 52.7% of the variance in science teachers' TPACK, thereby serving as a valuable tool for predicting outcomes within the TPACK framework. The remaining 47.3% of the variance is attributable to other factors not captured in the model.

Table 12. ANOVA<sup>a</sup>

M	odel	Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1742.772	6	290.462	27.733	.001b
	Residual	1445.366	138	10.474		
	Total	3188.138	144			

Table 13. Coefficient Table

Model	Unstandardized Coefficients		Standardized Coefficients		Sic
	В	Std. Error	Beta	ι	Sig.
1 (Constant)	5.224	2.534		2.061	.041
TK	.236	.055	.294	4.325	.000
CK	.116	.079	.111	1.471	.143
PK	.082	.054	.100	1.512	.133
PCK	.116	.082	.106	1.417	.159
TPK	.078	.054	.098	1.440	.152
TCK	.313	.055	.371	5.645	.000

a. Dependent Variable: Technological Pedagogical Content Knowledge

Table 14 tests the overall fitness of the regression model and it shows that the fitted regression model is significant as the p-value of F statistics < 0.001, which is less than the significance level of 0.05. The Coefficient table was run to help in the determination of the regression equation. The results of the coefficient table were presented in Table 15.

The Unstandardized Coefficients column and its sub-column 'B' give the regression coefficients. The first value is constant, which is also known as the y-intercept, and the second one is the regression coefficient of the dependent variable (TPCK) on independent variables (CK, PK, TK, PCK, TPK, TCK). Hence, the regression equation for the above model is:  $y = 5.224 + 0.236x_1 + 0.313x_2$ , where  $x_1 = TK$ , and  $x_2 = TCK$ .

From the coefficient table, it can be seen that TK and TCK were the only constructs of TPACK that made significant contributions to TPCK among the study participants. Thus, one from the primary constructs (TK) and one from the secondary constructs (TCK) of the TPACK framework statistically significantly predict the TPCK at the five percent significance level. In terms of the magnitudes of the effects, the standardised coefficient results suggested that TCK contributes 31% to the dependent variable (TPCK), followed by TK (24%).

#### 4. DISCUSSION

From the results, science teachers who participated in the study rated their understanding of the TPACK constructs very high, except TK and TCK, as shown in Table 2. The lowest mean was TCK, which fell below the "agreed" point, though still higher than the midpoint. This could be attributed to the fact that most of the respondents received their initial teacher education training program at a time when ICT was not a principal course of study in teacher education programmes, since most respondents have taught for more than 10 years (Edumadze, 2015). Again, most educational institutions are not equipped with ICT tools to allow teachers to use them in their teaching (Buabeng-Andoh, 2012). Even though teachers scored low for TK, all the other technology-related constructs, such as TPK, TPCK, and TCK, they rated their understanding.

The findings of this study are in congruence with those of Luik Taimalu and Laane (2019) and Qui et al. (2022), who found that teachers rated themselves very high in all the TPACK constructs except TK. The results from the study show that teachers indicated that they have in-depth knowledge of PK, CK, and PCK. This means science teachers were more familiar and well-versed with CK, PK, and PCK constructs, which are associated with old methods of teaching before the introduction of emerging technologies in the teaching enterprise. The outcome of the study is in line with that of Mtebe and Raphael (2018), who conducted a study in Tanzania to examine In-service teachers' TPACK and found that teachers' level of CK, PK, and PCK constructs were higher than that of their TK, TCK, TPK, and TPCK. The trend of teachers perceiving their CK, PK, and PCK to be high is not related only to science teachers. For instance, Appiah (2016) and Asare-Danso (2017) found similar traits in Ghanaian Religious and Moral Education teachers and Archambault and Crippen (2009) in the US.

Teachers' assessment of themselves as having high CK and PK could be attributed to the fact that the initial teacher education programmes, which ushered them into their teaching profession, have prepared them well by focusing on equipping the teachers with appropriate content and repertoire of pedagogical skills. This assertion is supported by the fact that most of the teachers in the current study had their initial teacher education training, which is highly concentrated on CK and PK, which prepares them for their teaching profession. However, the finding from the current research is contrary to that of Graham et al. (2009), Luik et al. (2018), and Mai and Hamzah (2016), who found that science teachers who scored high TPCK also scored high on TK. The teachers in the current study rated their TPCK high, though their TK was low.

The results emanated from the correlation analysis on the constructs in the TPACK framework, science teachers' TPCK correlating with all the other constructs, indeed prove the central nature of TPCK. This is because TPCK is an intersection among the three cardinal constructs of TK, PK, and CK. Thus, anyone with TPCK should first have these cardinal constructs. The evidence from this study regarding the correlation between TPCK and all the other constructs of the TPACK framework is consistent with many studies (Archambault & Crippen, 2009; Ekrem & Recep, 2014; Lin et al., 2013; Owusu et al., 2015).

The study found a strong correlation between TCK and TPCK (.599) and a weak relationship between TK and CK (.359). This is consistent with the findings of other researchers (e.g., Archambault & Crippen, 2009; Ekrem & Recep, 2014; Lin et al., 2013). The science teachers seem to indicate that a critical aspect of the TPACK framework is TCK. Thus, an improved TCK is associated with an improved TPCK. On the other hand, the weak correlation between TK and CK is understandable since the knowledge of the subject matter may not be so much linked to technological knowledge. Furthermore, there is no correlation at all between TK and PK; this is understandable because one may not need TK to develop their PK, and vice versa. Again, there is no correlation between TK and PCK; this is also understandable because one does not necessarily need TK to develop their PCK. The results of the study indicate that TCK contributes more to the TPACK framework than all other constructs of the TPACK framework.

The results of the present study show partial alignment with prior research (Chai et al., 2011; Horzum, 2013; Pamuk et al., 2015). Both Horzum (2013) and Pamuk et al. (2015) reported that TCK and TPK exerted the strongest influence on TPCK, although Pamuk et al. (2015) specifically identified TCK as the most significant contributor. In contrast, Horzum (2013) did not clarify which of the two constructs (TCK or TPK) played the dominant role. Structural equation modeling conducted by Chai et al. (2011) demonstrated that TPK had the greatest impact on the TPCK framework; however, TCK could not be incorporated into their model due to construct validation concerns. These findings are consistent with those of Owusu et al. (2015), who concluded that TPK was the strongest predictor of New Zealand science teachers' TPACK. However, they found that TCK also makes a contribution to TPACK after a stepwise regression. The outcomes of Chai et al. (2011) and Owusu et al. (2015) are incongruent with the findings of this study, whereby TCK was the largest contributor to TPCK. Nonetheless, the current study confirmed the significance of the secondary construct (TCK) as a major contributor to TPCK but could not sustain that of TPK.

Rukmana and Handayani (2021) and Liu, Zhang, and Wang (2015) also identified that the secondary constructs (TPK, TCK, PCK) predict TPACK development strongly than the core knowledge basis (TK, PK, CK). All the above studies are in line with the current study, which has also found that TCK is the major contributor to the TPCK, followed by TK. This could be attributed to the fact that one cannot develop their TCK without TK, hence it is the second contributor to the TCK in the prediction of TPCK. Since there were correlations between TCK and all the other constructs, one can conclude that all the other constructs indirectly contribute to TPCK. This is because, in order to develop TCK, one needs TK and CK (Koehler & Mishra, 2008). TK, as the second contributor, is not a surprise; this is because there is a correlation between TK and TCK. This means there is a direct linkage between TK and TCK. Therefore, one needs TK before he/she can develop his/her TCK.

The differences between the current study in Ghana and previous studies can be attributed to several factors. These factors individually and collectively influence how teachers perceive and rate their TPACK constructs, leading to variations in study outcomes. For instance, there is a lack of ICT infrastructure in Ghana. The evidence (Buabeng-Andoh, 2012) indicates that many Ghanaian schools lack ICT tools, which affects teachers' ability to develop TK and TCK through practical application. This could explain why teachers in Ghana rated their Technological Knowledge (TK) and Technological Content Knowledge (TCK) lower compared to teachers in other contexts with better-equipped ICT tools in their schools. Again, the differences between the current study and the others in terms of the strongest contributor to TPCK could be due to different teaching contexts. Ghanaian teachers might rely more on TCK because they integrate content knowledge with limited available technology rather than emphasizing technology-based pedagogy, which is facilitated by TPK, as found by other studies. The current study found that science teachers rated their understanding of TPACK constructs as high, except for TK and TCK. This is likely because many teachers received their initial education at a time when ICT was not a major part of teacher training programs. In contrast, previous studies (e.g., Graham et al., 2009; Luik et al., 2018; Mai & Hamzah, 2016) found that teachers who scored high in TPCK also had high TK, possibly due to better ICT integration in their teacher education. The initial teacher education programs in Ghana, particularly for the older generation of teachers, did not emphasize ICT as a principal course of study (Edumadze, 2015). This historical lack of focus on technology in teacher training could account for the lower self-ratings in TK and TCK among Ghanaian teachers.

# 5. CONCLUSION AND RECOMMENDATIONS

Based on the results of this research, it has been seen that there is a high understanding of the perception of JHS science teachers concerning TPACK framework constructs. TPCK has a positive correlation with the other six TPACK framework constructs. The major predictor of TPCK is TCK, followed by TK. This means various TPACK framework constructs have connections among themselves; therefore, the development of the TPACK framework should not be isolated into the various constructs but should be integrated and blended in a holistic manner to achieve unity. The study makes significant contributions by providing new insights into the relative importance of TPACK constructs, particularly emphasizing the role of TCK. Unlike some earlier studies that found TPK as the strongest predictor of TPCK, this study identifies TCK as the dominant contributor. This suggests that teachers who integrate technology into their content knowledge (TCK) are better positioned to develop a comprehensive TPCK, emphasizing the need for stronger TCK development in teacher training. This finding adds to the ongoing debate about the relative importance of different TPACK constructs and provides empirical evidence supporting the critical role of TCK in the development of TPCK.

The study further provides a nuanced understanding of how science teachers perceive their TPACK constructs, particularly highlighting the disparity between their high self-ratings in Pedagogical Knowledge (PK), Content Knowledge (CK), and Pedagogical Content Knowledge (PCK) versus their lower ratings in Technological Knowledge (TK) and Technological Content Knowledge (TCK). Again, the study affirms the centrality of TPCK by demonstrating strong correlations between TPCK and all other constructs. This reinforces the idea that TPCK development is dependent on a solid foundation of CK, PK, and TK, particularly emphasizing the role of TCK.

The results of this study significantly advance our understanding of the TPACK framework, particularly the critical role of TCK in predicting TPCK. The study underscores the central role of Technological Content Knowledge (TCK) in the TPACK framework. These findings underscore the necessity of re-evaluating how technology is incorporated into pre-service training by focusing on understanding how TCK can be developed and integrated into teacher education programs, especially given its strong correlation with TPCK. Educational stakeholders can use these findings to develop more effective digital learning tools that accommodate teachers' varying levels of technological competence. Policies should mandate comprehensive training in TPACK-related competencies, particularly TCK and TK. Governments and educational institutions should invest in ICT infrastructure and continuous professional development programs to ensure that teachers are well-equipped to integrate technology into their teaching. Ongoing professional development programs should be established to help experienced teachers update their skills in TK and TCK. Policy makers and school administrators should prioritize content-specific technology resources over general-purpose ICT tools. They should design professional development programs that build on teachers' strong content and pedagogical knowledge while introducing technological elements. These programs could include workshops, online courses, and peer collaboration opportunities. Again, school administrators can establish mentor programs whereby they will pair technologically confident teachers with those seeking to improve their TCK. Finally, the interdisciplinary potential of the TPACK framework suggests that its principles could be applied in a wide range of fields, making it a valuable tool for enhancing teaching and learning in the digital age.

Given the correlation between technological content knowledge (TCK) and technological pedagogical content knowledge (TPCK), future research should focus on effective strategies to enhance teachers' TCK, thereby improving their overall TPCK. This could involve longitudinal studies tracking the impact of targeted professional development programs aimed at improving technological knowledge. Further investigation can also be conducted into the effectiveness of professional development models that specifically target TCK. Researchers can also explore how institutional and systemic factors influence TPACK development. Studies examining the relationship between teachers' self-perceived TPACK and actual classroom practices can also be conducted.

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