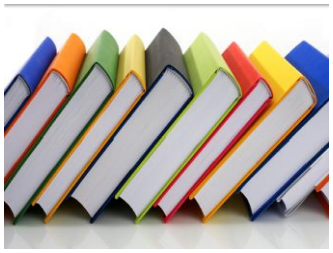

Teachers' TPACK and Pedagogic Knowledge as Predictor of Acquisition of Science Process Skills in Biology among Senior Secondary School Students in Adamawa State, Nigeria

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Received April, 2024, Accepted May, 2024 Published June, 2024

Abstract

The study explored teachers' Technological Pedagogical Content Knowledge **(**TPACK) and Pedagogical Knowledge (PK) as predictors of the acquisition of basic science process skills in Biology among senior secondary school students in Adamawa State, Nigeria. The study is comprised of two objectives and two each of research questions and null hypotheses. A predictive correlational research design was used for the study. The study was conducted in Adamawa State, Nigeria. The population of the study comprised all senior secondary school II students offering Biology and Biology teachers in public secondary schools in Adamawa State. The multi-stage sampling procedure was used for the study which involved simple random, purposive and proportionate sampling techniques. The sample comprise of 470 participants, including 80 Biology teachers and 390 Senior Secondary School II students offering Biology in Adamawa State. Data were collected using a TPACK Biology Self-Assessment Questionnaire" (TPACKBSAQ) adapted from Schmidt, Baran, Thompson, Mishra, Koehler and Shin (2009) to gauge Biology teachers' TPACK and a Science Process Skills Inventory (SPSI) was adopted from Arnold and Bourdeau (2009) for students. Rigorous validation procedures were applied to ensure the face and content validity of these instruments. The reliability of the instruments was established using Cronbach Alpha, yielding a reliability coefficient of 0.94 for TPACK and 0.83 for SPSI. Mean and standard deviation were used to answer the research questions, while the hypotheses were tested at a significance level of 0.05 using linear regression. The findings from the study showed that the level of teachers' TPACK significantly predicted science process skills in Biology among senior secondary school students in Adamawa State ($F = 82.913$, df 1, 79; $R = 0.718$; $p = 0.00 < 0.05$). Similarly, teachers' pedagogical knowledge significantly predicted science process skills in Biology among senior secondary school students in Adamawa State ($F = 105.179$, df 1, 79; $R = 0.758$; $p = 0.00 < 0.05$). It was recommended among others that schools should provide access to relevant technologic tools and resources to facilitate TPACK integration in the classroom.

Keywords: Teachers, TPACK, Pedagogic Knowledge (PK), Science Process Skills, Biology

Introduction

Education acts as a catalyst for igniting curiosity and encouraging inquiry as it is a powerful force that shapes individuals understanding of the world, cultivates critical thinking abilities, and

equips them with essential skills such as information literacy, adaptability, creativity, decision-making and science process skills. Among these skills, the acquisition of science process skills is of paramount importance. The term Science Process Skills (SPSs) was rooted in the concept of Science-A Process Approach (SAPA) initiated by the American Association for Advancement of Science (AAAS) in 1967. The SAPA was developed from the concept coined by Gagne in 1965 concerning science as a process.

Science process skills encompass a range of abilities such as observing, experimenting, measuring, inferring, and critical thinking, which are integral to scientific inquiry (Ibe & Nwosu, 2017). Science process skills begin to take root when students are encouraged to question the world around them. Through well-designed curricula and engaging classroom environments, educators can stimulate students' natural curiosity, prompting them to explore phenomena and seek answers through observing, experimenting and investigation. Science process skills help the learners to develop formal thinking ability and thus appreciate the relevance of science in everyday life (Ihejiamazu, Neji & Ashiwere, 2020). Ihejiamuzu et al. (2020) further opined that science process skills are like the premium motor spirit that powers scientific investigations in science education.

The interplay between science process skills and academic performance in Biology is evident in assessment outcomes. Students who possess robust science process skills tend to perform better in practical assessments, where they may demonstrate their ability to apply theoretical knowledge to real-world situations (United Nations Educational, Scientific and Cultural Organization, 2018). Additionally, these skills enhance their performance in examinations that require critical thinking and problem-solving, leading to a comprehensive grasp of biological concepts.

Pedagogical Knowledge (PK) is the understanding of how to teach, including knowledge of teaching methods and strategies, curriculum design, and assessment techniques (Hattie, Fisher & Fraser, 2018). A lot of experimental studies have shown that teachers' use of methodology enhances students' acquisition of science process skills.

Technological pedagogical content knowledge (TPACK) is defined as the interactions between content, pedagogy and technology knowledge. TPACK is the foundation of effective teaching with technology, necessitating an understanding of the representation of concepts using technologies; pedagogical techniques that use technologies in constructive ways to teach content; knowledge of what makes concepts difficult or easy to learn and how technology can help redress some of the problems that students face (Mishra & Koehler 2017).

However, a lack of proficiency in TPACK can hinder educators' ability to create engaging and interactive learning environments that foster the development of these critical skills. This study therefore aimed to investigate TPACK and PK as predictors of science process skills in Biology among senior secondary school students' in Adamawa State, Nigeria.

Theoretical Review

AAAS classified science process skills into 15 activities, such as: observing, measuring, classifying, communicating, predicting, inferring, using numbers, using space/time relationship, questioning, controlling variables, hypothesizing, defining operationally, formulating models, designing experiments, and interpreting data. The SPSs can be divided and categorized as basic SPSs and integrated SPSs (AAAS, 1993). According to Padilla (1990), the basic SPSs are consisted of observing, classifying, predicting, inferring, measuring, and communicating. Meanwhile, the advance SPSs are consisted of controlling variables, defining operationally, formulating hypotheses, interpreting data, experimenting and formulating models. Over the years, many researchers have attempted to modify the SPSs formulation however, the formulation by AAAS is still being recognized as the most comprehensive in terms of skill coverage (Akani, 2015).

Science processes encompass systematic approaches to investigating and understanding nature, involving not only the acquisition of knowledge but also the utilization of scientific procedures akin to those employed by scientists. Through these processes, students engage in knowledge reconstruction and employ scientific methods to explore and comprehend the workings of the natural world, (Wahyuni, Indrawati, Sudarti & Suana, 2017). Science process skills constitute a collection of abilities utilized during scientific endeavours. Science process skills are skills that

students must internalize, practice and possess. It forms the basis for scientific inquiry and is essential for intellectual growth, providing the necessary foundation to comprehend scientific concepts (Duran, Mihladiz & Ozdemir (2011) as cited by Wahyuni et al., 2017). Developing science process skills allows students to cultivate problem-solving abilities, engage in critical thinking, make informed decisions, actively seek answers, enhance logical thinking, pose reasoned questions and effectively tackle the problem-solving challenges they encounter in their daily lives. When the learning stage is thoughtfully designed, students are afforded opportunities to actively participate in the learning process (Safaah, Muslim & Liliawati, 2017). Each scientific process skill is a versatile skill that can be applied in various situations throughout our lives, extending beyond the realm of science itself (Durnham, Knight & Couch, 2017). The researchers further asserted that mastering process skills and "doing" science is more important than just learning scientific facts, ideas, and theories. The scarcity of experimental activities in the classroom for scientific learning has resulted in a deficiency of process skill development. This dearth has contributed to numerous misconceptions among students, ultimately leading to subpar science learning outcomes (Widyaningsih, 2020).

Technological pedagogical content knowledge (TPACK) emerges from interactions between content, pedagogy and technology knowledge (Mishra & Koehler, 2017). Mishra and Koehler further opined that TPACK is true, meaningful and deeply skilled teaching with technology from knowledge of all three concepts separately. Separating the three components (content, pedagogy and technology) is an analytical act that is difficult to accomplish in practice (Mishra & Koehler 2017). Santos and Rowell (2021) emphasized that TPACK plays a crucial role in guiding the teaching process and achieving learning goals through effective instructional strategies. Various studies have used the TPACK framework to explore the knowledge required for effective teaching in the digital era. Guggemos and Seufert (2021) revealed that the TPACK framework demonstrated soundness as a measuring instrument and provided support for the conceptual framework. Saengbanchong, Wiratchai and Bowarnkitiwong (2014) validated the Technological Pedagogical

Content Knowledge-Student (TPACK-S) model, an extension of Mishra and Koehler's TPACK framework. The researchers revealed that the TPACK-S measuring model had a good fit with the empirical data, and the individual factors demonstrated strong internal consistency. The study suggests that teachers equipped with TPACK-S have the potential to enhance students' acquisition of science process skills by effectively utilizing technology.

The increasing presence of technology in educational environments has opened up new possibilities for teaching and learning, offering alternatives to traditional face-to-face education. However, many teachers struggle to effectively incorporate these technologies into their teaching practices. This challenge highlights the importance of providing adequate training to teachers to effectively teach in online or blended formats. Research over the years has shown that successful technology integration in the classroom depends on several connected factors relating to teachers' characteristics, schools and educational systems (Joo, Lim, & Kim, 2016; Petko, Prasse, & Cantieni, 2018; Taimalu & Luik, 2019). Therefore, it is crucial for educators to continually develop their competencies to adapt to technology-prolific environments and meet the evolving needs of their students.

Teachers' pedagogical skills enable classroom educators to gain a comprehensive understanding of the subjects they teach and to recognize how the knowledge they have accumulated over time in their respective subject areas can be generated, structured and interconnected with other fields of knowledge (Yusuf & Amali, 2013). Additionally, pedagogical skills empower teachers to acknowledge the preconceptions and prior knowledge that students typically bring to each subject. They are also equipped with strategies and instructional materials that can assist, along with an understanding of how to address and resolve potential challenges that might arise in the classroom.

Akturk and Ozturk (2019) examined the relationship among teachers' TPACK levels, students' self-efficacy and the academic achievement in Turkey. The study adopted singular survey model and relational survey model. The study was conducted in 3 secondary schools in Konya and Ankara in the first semester of 2014-2015 academic year. A total of 78 teachers working in Science

and Technology, Mathematics, Turkish, Social Studies and English branches and 1597 (792 females and 805 male) students attending these courses from teachers participated in the study. Self-Efficacy Questionnaire for Children (SEQ-C), Technological Pedagogical and Content Knowledge (TPACK) and proforma for Grade Point Average (GPA) of Science, Mathematics, Turkish, English and Social Studies courses of the students were used for data collection. Descriptive statistics, correlation analysis, independent sample t-test were used to determine the differences between the two groups, one-way ANOVA test analysis was also used to determine the differences between more than two groups and multiple linear regression analysis were used. The results of the analysis indicated that the students' academic, social, and emotional self-efficacy with teachers' TPACK levels explain 12% of the academic achievement of students. Academic self-efficacy is the most important variable that influences students' general academic achievement. In addition, the impact of teachers' TPACK levels on academic achievement is higher than students' social and emotional self-efficacy. It was recommended among others that Instructors in education faculties who train teacher candidates should also use TPACK-based practices in the curriculum so that they can become role models for teacher candidates.

Yanti, Riandi and Suhandi (2019) investigated how teacher's TPACK affect students' activity when implementing the TPACK strategy on global warming content in Indonesia. The study utilized a qualitative approach with descriptive methods. Participants in this study were science teachers at junior high school level in Sidrap district, South Sulawesi. The selection of participants was done using the convenience sampling method. The convenience sampling method was carried out because the study used one school and only three teachers were willing to be studied. Student activity observation sheets were used to obtain information in the form of student activities throughout the learning. The TPACK questionnaire was used to see the teacher's perception of their TPACK abilities. The trick is to provide answers to each item based on the attitude rating given. The instrument used is a standard instrument from Schmidt consisting of 54 question items. Data generated were analyzed using descriptive statistics of simple percentages. The

results of the findings showed that the ability of TPACK teachers who have high to lowest abilities are teachers A, B and C. Likewise with its relation to students as from student learning activities and outcomes. Consecutive activities with the percentage of activity 86%, 80% and 50%. Because the teacher's TPACK ability and its relation to students have the same pattern, that is, the better the TPACK ability of the teacher, the activities of the students being taught are also more active. So it can be concluded that the ability of TPACK teachers has a relationship to student activities. Based on the study's findings. It was recommended among others that the development of advanced program to enhance the ability of teachers to integrate basic knowledge in implementing learning into a full TPACK framework should urgently be carried out. The follow-up program can be in the form of a seminar or training that addresses the importance of TPACK knowledge for teachers.

Adebusuyi, Bamidele and Adebusuyi (2020) examined the level of Teachers' Technological, Pedagogical and Content Knowledge (TPACK), relationship and effects on students' scientific attitude and literacy in Chemistry in Southwestern Nigerian secondary schools. The study was guided by two research questions and two null hypotheses. The cross sectional survey design was employed for the study. The population of the study comprised all Chemistry teachers and students in secondary school in southwest Nigeria. Sample comprised of 75 in-service Chemistry teachers (of which 51% were female and 49% male) and students in their intact classes in which 1518 were randomly selected. The instruments used for data collection were the Teachers' TPACK Classroom Observation Checklists (TTPACKCOC) and Chemistry Students Scientific Attitude Questionnaire (CSSAQ).

Data were analyzed using mean, Pearson Product Moment Correlation (PPMC) and Multivariate Analysis of Variance (MANOVA). The result showed that teachers level of TPACK were limited to content knowledge (CK) and do not translate to high TPK and TPACK. Also, there were correlation between the teachers' individual components of TPACK and students' scientific attitude and literacy. Finally, there was notable significant effect of teachers' TPACK on students' scientific attitude and literacy. The study recommended that professional development programs

should not only focus on helping teachers to increase their repertoire of technologies and pedagogical practices, rather emphasize ways to integrate TPACK.

Subagja, Rubini and Kurniasih (2023) investigated the development of interactive multimedia based on Technological Pedagogical Content Knowledge (TPACK) to enhance students' science process skills on living cell matter in Indonesia. The research method used in this study is the Research and Development (R&D) method with the Analyze, Design, Develop, Implement and Evaluate (ADDIE) model developed by Branch (Branch, 2009). The ADDIE model comprises five stages: analysis, design, development, implementation and evaluation. The population of the study comprised grade VII students in Indonesian schools. The sample for the study consisted of 27 students. The science process skill test, the media validation judgment sheet, the content validation judgment sheet, and the student response sheet following interactive multimedia made up the data collection tools.

A Paired T-test analysis was employed for data analysis. The results of the analysis revealed that interactive multimedia is practicable, as evidenced by the percentage of data collected from the validator and the outcomes of the implementation test to the students. The students' SPS N-Gain analysis results obtained a score of 0.78 in the high category. In other words, a product that has undergone testing and validation may be one that can be used to aid in learning about living cells and can enhance students' science process skills. Based on the findings of this research, it was recommended among other things, that schools should make available the required resources and instructional tools that can assist the teachers in developing their content with TPACK-based pedagogy or strategy to promote the acquisition of science process skills among students.

Sacre and Lallemand (2023) investigated the relationships between perceived instructional quality and teacher knowledge in human-computer interaction utilizing the TPACK model in the Netherlands. The study was guided by two research questions and two null hypotheses. The researchers employed the correlational survey research design. The study's participants were human-computer interaction instructors and the sample comprised 54 participants (9 men, 18

women, 1 non-binary (transgender), 26 others whose gender were not specified). The instrument for data collection was a survey questionnaire on teacher knowledge. Kruskal-Wallis tests and correlations were performed to compare the scores of TPACK components and teaching quality dimensions according to teachers' gender, level of education, age and teaching experience. For the second research question, inter-correlations between TPACK and teaching quality were conducted using the Spearman method. A multiple regression analysis was carried out, with teaching quality as dependent variables and TPACK as independent variables.

The findings revealed that HCI instructors rated their domain-specific and technological knowledge rather high, while the components of pedagogical knowledge were rated lower. Yet, pedagogical knowledge was related to instructional quality, specifically the degree of cognitive activation provided to students. It was recommended that teachers should be continuously exposed to professional development programs that promote the incorporation of technology into their teaching methods or strategies to enhance students' academic success.

Purpose of the Study

The purpose of the study is to investigate the technological pedagogical content knowledge (TPACK) and Pedagogical Knowledge (PK) as predictor of science process skills in Biology among senior secondary school students' in Adamawa State, Nigeria. Specifically, the study sought to determine:

1. the relationship between teachers TPACK and science process skills in Biology among senior secondary school students' in Adamawa State.
2. the relationship between teachers' pedagogical knowledge and science process skills in Biology among senior secondary school students' in Adamawa State.

Research Questions

The following research questions are raised to guide the study:

1. What is the level of TPACK of secondary school Biology teachers in Adamawa State?
2. What is the level of pedagogical knowledge of secondary school Biology teachers in Adamawa State?

Hypotheses

The following null hypotheses were formulated to guide the study and were tested at a 0.05 level of significance.

Ho_1: There is no significant predictive relationship between teachers' TPACK and students' science process skills in Biology in senior secondary schools in Adamawa State.

Ho_2: There is no significant predictive relationship between teachers' pedagogical knowledge and students' science process skills in Biology in senior secondary schools in Adamawa State.

Methodology

The research adopted quantitative predictive correlational research design. The study was carried out in Adamawa State, Nigeria. The population of the study comprised all 49,253 SS II students and 545 Biology teachers in Adamawa state (Adamawa State Post Primary Schools Management Board, 2022). The sample size for the study was 390 SS II students and 80 Biology teachers from public senior secondary schools in Adamawa State making a total sample of 470. The sample was selected using a multistage sampling procedure. In the first stage, a simple random sampling technique was used to select Yola education zone from the five zones through balloting. In the second stage, a purposive sampling technique was employed to select 12 public secondary schools in Yola education zone that had both ICT facilities and science laboratories. The 12 public secondary schools had 97 Biology teachers combined. In the third stage, a simple random sampling technique was used to sample 80 teachers from among the 97 Biology teachers for the study.

The research advisors table provides sample sizes based on a given population size, a desired margin of error, and a preferred confidence interval. To utilize this information, locate your population size in the left column (choose the next highest value if your exact size is not listed). The corresponding value in the adjacent column represents the required sample size for achieving a Margin of Error of ± 5% applicable to any population proportion. Using the above information, the researcher located the population size for Biology teachers (97) in the left column and chooses the

next highest value since the exact size is not listed and obtained a sample size of 80 for Biology teachers.

In the fourth stage, a proportionate sampling technique was used to determine the proportion of participants per school to ensure equal distribution. In the final stage, a systematic sampling technique was employed to select each proportion from the schools summing up to a total of 470 participants both of teachers and students for the study (Research Advisors, 2006). Two instruments that were used in obtaining the required data for this study are questionnaires titled "TPACK Biology Self-Assessment Questionnaire" (TPACKBSAQ) and Science Process Skills Inventory (SPSI). TPACKBSAQ was adapted from Schmidt, Baran, Thompson, Mishra, Koehler and Shin (2009), while Science Process Skills Inventory (SPSI) was adapted from Arnold and Bourdeau (2009). Both the TPACKBSAQ and SPSI underwent face and content validation to ensure their content validity. For this validation, two experts from the Department of Environmental and Life Sciences Education and one expert from the Department of Physical Sciences Education at Modibbo Adama University, Yola, were involved. The data generated from the respondent were analyzed using linear regression analysis at a 0.05 alpha level.

The descriptive statistics in Table 1 indicate that 80 Biology teachers responded to the 10 items on the instrument assessing the level of Technological Pedagogical Content Knowledge (TPACK) among secondary school Biology teachers in Adamawa State. The table shows that 1 item was rated at a very high level, while the remaining 9 items recorded a high level, resulting in a grand mean of 4.02 and a standard deviation of 1.05. This indicates that the TPACK of secondary school Biology teachers in Adamawa State is at a high level.

Results and Discussion

Research Question 1: What is the level of TPACK of secondary school Biology teachers in Adamawa State?

Table 1: Descriptive Statistics of Level of TPACK of Secondary School Biology Teachers in Adamawa State.

S/N	Items	n=80	Mean	SD	Decision
1	Rate your ability to seamlessly integrate technology into your Biology lessons to enhance learning.		3.81	1.406	HL
2	Rate your effectiveness in using technology in teaching.		3.72	1.102	HL
3	Rate your consistency in assessing the impact of technology usage on students learning in your Biology classes.		3.94	1.048	HL
4	Rate your ability to adapt your TPACK based on the evolving abilities of your students.		4.10	.922	HL
5	Rate your ability to collaborate with other Biology teachers to share experiences about TPACK strategies on Biology instruction.		4.09	1.034	HL
6	Rate your commitment to seeking professional development opportunities to enhance your TPACK skills.		4.10	1.121	HL
7	Rate your proficiency in using TPACK to differentiate instruction for diverse groups of Biology students.		3.81	.988	HL
8	Rate your commitment to continuously exploring new ways to integrate technology for Biology teaching.		4.09	.996	HL
9	Rate your confidence in balancing traditional teaching methods with technology.		4.09	.942	HL
10	Rate your effectiveness in encouraging students' creativity through TPACK-infused activities in Biology.		4.48	.900	HL
	Grand mean		4.02	1.05	

Research Question 2: What is the level of pedagogical knowledge of secondary school Biology teachers in Adamawa State?

The descriptive statistics in Table 2 indicate that 80 Biology teachers responded to the 10 items on the instrument assessing the level of pedagogical knowledge among secondary school Biology teachers in Adamawa State. The table reveals that all 10 items were rated at a high level,

with a grand mean of 4.00and a standard deviation of 1.07. This suggests that the technology knowledge of secondary school Biology teachers in Adamawa State is at a high level.

Table 2: Descriptive Statistics of Level of Pedagogical Knowledge of Secondary School Biology Teachers in Adamawa State.

S/N	Items	n=80	Mean	SD	Decision
1	Rate your knowledge of various instructional strategies for teaching Biology.		3.79	1.375	HL
2	Rate your ability to design an interactive Biology lesson.		3.75	1.085	HL
3	Rate your proficiency in managing instructional time.		3.86	1.052	HL
4	Rate your proficiency in scaffolding learning experiences to support students' understanding of complex Biology concepts.		4.13	.960	HL
5	Rate your ability to assess students' prior knowledge.		4.18	1.003	HL
6	Rate your ability to create a positive classroom environment for Biology learning.		4.05	1.135	HL
7	Rate your ability to design effective group projects activities in Biology.		3.85	1.051	HL
8	Rate your proficiency in providing constructive feedback to help students improve their Biology skills.		4.07	1.016	HL
9	Rate your ability to align your teaching goals with relevant Biology standard.		4.03	1.000	HL
10	Rate your ability to reflect on your teaching practices based on student outcomes.		4.35	1.050	HL
	Grand mean		4.00	1.07	

Ho_1: There is no significant predictive relationship between teachers' TPACK and students' science process skills in Biology in senior secondary schools in Adamawa State.

Table 3: ANOVA of Teachers' TPACK as Predictor of Senior Secondary School Students' Science Process Skills in Biology in Adamawa State.

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2274.321	1	2274.321	82.913	.000[b]
	Residual	2139.567	:8	27.430		
	Total	4413.888	79			

a. Dependent Variable: Science Process Skills

b. Predictors: (Constant), TPACK

Tables 3 clearly shows that teachers' TPACK significantly predicted the acquisition of science process skills in Biology among senior secondary school students in Adamawa State $F = 82.913$ (df 1, 79), $p < 0.05$. Since the p-value of 0.00 is less than the 0.05 level of significance, the null hypothesis, which was previously stated as having no significant predicting, is hereby rejected.

Table 4. Model Summary of Teachers' TPACK as Predictor of Senior Secondary School Students' Science Process Skills in Biology in Adamawa State

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.718[a]	.515	.509	5.237

a. Predictors: (Constant), TPACK

The model summary in Table 4 shows the coefficient of determination (Adjusted R-Square value) value of 0.509. This indicates that only 50.9% of the variance in senior secondary school students' acquisition of basic science process skills in Biology in Adamawa State can be accounted for by teachers' TPACK.

Table 5 shows that teachers' TPACK significantly contributes to the acquisition of science process skills in Biology among senior secondary school students in Adamawa State. The coefficient of predicting between teachers' TPACK as the predictor and the outcome variable is significant ($\beta = 0.718$, $t = 9.106$, $p = 0.000 < 0.05$).

Table 5: Coefficient of Beta of Teachers' TPACK as Predictor of Senior Secondary School Students' Acquisition of Science Process Skills in Biology in Adamawa State.

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	9.978	3.291		3.032	.003
	TPACK	.736	.081	.718	9.106	.000

a. Dependent Variable: Science Process Skills

Ho_2: There is no significant predictive relationship between teachers' pedagogical knowledge and students' acquisition of basic science process skills in Biology in senior secondary schools in Adamawa State.

Table 6: ANOVA of Teachers' Pedagogical Knowledge as Predictor of Senior Secondary School Students' Acquisition of Basic Science Process Skills in Biology in Senior Secondary Schools in Adamawa State.

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	2534.400	1	2534.400	105.179	.000[b]
	Residual	1879.487	78	24.096		
	Total	4413.888	79			

a. Dependent Variable: Science_Process_Skills

b. Predictors: (Constant), Pedagogical Knowledge

Tables 6 clearly show that teachers' pedagogical knowledge significantly predicts the acquisition of basic science process skills in Biology among senior secondary school students in Adamawa State $F(1, 79) = 105.179$, $p < 0.05$. Since the p-value of 0.00 is less than the 0.05 level of significance, the null hypothesis, which was previously stated as having no significant predicting, is hereby rejected.

The model summary in Table 7 shows the coefficient of determination (Adjusted R-Square value) as 0.569. This indicates that only 56.9% of the variance in senior secondary school students' acquisition of basic science process skills in Biology in Adamawa State can be accounted for by teachers' pedagogical knowledge.

Table 7: Model Summary of Teachers' Pedagogical Knowledge as Predictor of Senior Secondary School Students' Science Process skills in Biology in Senior Secondary Schools in Adamawa State.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.758[a]	.574	.569	4.909

a. Predictors: (Constant), Pedagogical_Knowledge

Table 8: Coefficient of Teachers' Pedagogical Knowledge as Predictor of Senior Secondary School Students' Process Skills in Biology in Senior Secondary Schools in Adamawa State.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	9.623	2.961		3.250	.002
	Pedagogical_Knowledge	.750	.073	.758	10.256	.000

a. Dependent Variable: Science_Process_Skills

Table 8 shows that teachers' pedagogical knowledge significantly contributes to senior secondary school students' acquisition of basic science process skills in Biology in Adamawa State. The coefficient of predicting between teachers' pedagogical knowledge as the predictor and the outcome variable is significant ($\beta = 0.758$, $t = 10.256$, $p = 0.00 < 0.05$).

Discussion of Findings of the Study

The findings of the study were discussed based on the objectives viz-a-viz research questions and hypotheses of the study.

The first finding of this study indicates that the level of teachers' TPACK in Adamawa State is high. This suggests a generally strong proficiency among teachers in integrating technology with pedagogy and content knowledge. Furthermore, the significant prediction of senior secondary school students' acquisition of basic science process skills in Biology by teachers' TPACK implies that a well-developed TPACK positively influences students' learning outcomes in the subject. There is, therefore, a need for teachers to possess technological competence, pedagogical skills, and content knowledge to enhance students' understanding of science processes in Biology. This finding

aligned with Akturk and Ozturk (2019) who found that students' academic, social, and emotional self-efficacy with teachers' TPACK levels explain 12% of the academic achievement of students.

Academic self-efficacy is the most important variable that influences students' general academic achievement. In addition, the impact of teachers' TPACK levels on academic achievement is higher than students' social and emotional self-efficacy. Similarly, Yanti, Riandi and Suhandi (2019) found that the ability of TPACK teachers has significantly predicted students learning activities and outcomes. Adebusuyi, Bamidele and Adebusuyi (2020) found notable significant effects of teachers' TPACK on students' scientific attitude and literacy.

The second findings of this study revealed that the level of teachers' pedagogical knowledge in Adamawa State is at a high level. This implies a positive indication of educators possessing strong pedagogical skills, a necessary potential for effective instructional delivery and classroom management techniques. Furthermore, the significant prediction of senior secondary school students' acquisition of basic science process skills in Biology by teachers' pedagogical knowledge underscores the crucial role that effective teaching methods play in shaping students' understanding of science processes. These results indicate that students in Adamawa State are receiving quality instruction through the effective utilization of teaching strategies that foster a deeper understanding of science process skills in Biology.

The results of these findings aligned with Sacre and Lallemand (2023) who found that pedagogical knowledge of teachers correlated with instructional quality, specifically the degree of cognitive activation provided to students. Similarly, Subagja et al., (2023) found that interactive multimedia pedagogy based on TPACK enhances students' science process skills on living cell matter.

There is need therefore, to enhance and further improve pedagogical knowledge among teachers, through implementation of targeted professional development initiatives since teachers' pedagogical knowledge predicted student's acquisition of science process skills. Continuous training programs should focus on updating teachers with the latest research-based teaching methods, incorporating interactive and student-centered approaches into their instructional

practices. Workshops and seminars dedicated to pedagogical enhancement can provide a platform for educators to share best practices, discuss challenges, and collectively explore innovative teaching strategies.

Additionally, mentorship programs pairing experienced teachers with those seeking to enhance their pedagogical skills can facilitate knowledge transfer and skill development as well as collaborative lesson planning and peer observations to create a supportive learning community among teachers.

Conclusion

This study concluded that TPACK and Pedagogical Knowledge significantly predicted students' acquisition of basic science process skills in Biology in Adamawa State.

Recommendations for policy direction

Based on the findings of this study, the following recommendations are made:

1. Educators should encourage the integration of TPACK. This can be achieved through the development of TPACK-focused curriculum and resources, as well as fostering a culture of collaboration and sharing of best practices among teachers.
2. Despite the high level of pedagogical knowledge among teachers, it is essential to maintain and further strengthen this knowledge through continuous professional development opportunities that focus on effective teaching methods and strategies.
3. Schools and educational authorities should organize regular professional development programs focusing on enhancing teachers' TPACK. These programs should include training on integrating technology into science teaching effectively.
4. Schools and concerned authorities should establish collaborative learning communities where teachers can share best practices, resources and experiences related to the integration of technology and pedagogy in science education.

5. Curriculum planners should design the science curriculum to incorporate activities that explicitly develop science process skills. This could include inquiry-based learning, hands-on experiments, and problem-solving tasks that require the application of these skills.
6. Teachers should be provided with access to the latest technological tools and resources. This includes software, hardware, and digital content that can facilitate the teaching of science process skills.
7. School authorities should implement a mentoring system where experienced teachers with strong TPACK mentor less experienced teachers. This support can help build confidence and competence in integrating technology into science teaching.
8. Schools should encourage the conduct of research to evaluate the effectiveness of TPACK-based teaching strategies in improving students' science process skills. Use the findings to continually refine and improve teaching practices.
9. Schools should promote student-centered learning approaches that encourage active participation and engagement in science lessons. Techniques such as flipped classrooms, project-based learning, and collaborative group work can be particularly effective.

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