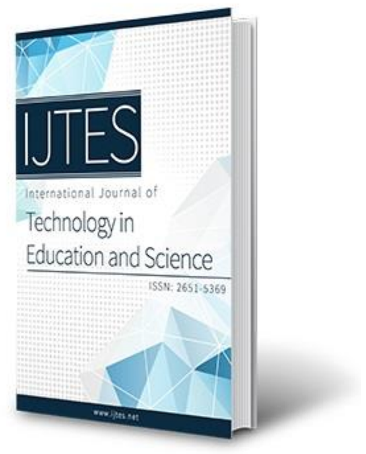

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Mapping TPACK Competency among Life Sciences Teachers in Rural and Marginalised Secondary Schools: A Descriptive Analysis

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To cite this article:

Shambare, B. & Simuja, C. (2024). Mapping TPACK competency among life sciences teachers in rural and marginalised secondary schools: A descriptive analysis. *International Journal of Technology in Education and Science (IJTES), 8*(4), 522-541. https://doi.org/10.46328/ijtes.573

International Journal of Technology in Education and Science
2024, Vol. 8, No. 4, 522-541 https://doi.org/10.46328/ijtes.573

Mapping TPACK Competency among Life Sciences Teachers in Rural and Marginalised Secondary Schools: A Descriptive Analysis

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Article Info

Article History

Received:
20 April 2024
Accepted:
10 September 2024

Keywords

TPACK
Life sciences teachers
rural schools
Technology
Science education

Abstract

This descriptive study assessed technological, pedagogical and content knowledge (TPACK) competency among life sciences teachers in rural and marginalized schools. The study was guided by Koehler and Mishra's (2006) TPACK framework as its theoretical lens. Data gathered through questionnaires from 235 teachers in the Eastern Cape province, South Africa, was analysed using descriptive statistical analysis. The results unveiled a prevalent low level of TPACK competency among respondents. Moreover, an examination of individual TPACK domains, a significant mastery in non-technology-related areas such as content knowledge (CK), pedagogical knowledge (PK), and pedagogical content knowledge (PCK) surfaces, underscoring the pivotal role of teaching experience in fostering foundational knowledge. Despite competency in these traditional domains, a distinct gap emerges in technology-related TPACK domains, including technological knowledge (TK), technological pedagogical knowledge (TPK), and overall TPACK competency. This research addresses a critical gap in educational literature by spotlighting the often-overlooked population of rural school teachers. It recommends tailored professional development initiatives to enhance teachers' overall TPACK competency and enable them to effectively utilise technology in their teaching, thereby facilitating enhanced learning experiences.

Introduction

The universal integration of technology into everyday life has transformed numerous facets of modern society, with education being no exception. This phenomenon is particularly salient in some rural schools in developing countries such as South Africa, where geographical isolation and resource constraints historically pose formidable challenges to educational equity and quality (UNICEF, 2021). However, rapid advancements in digital technologies have provided a glimmer of hope, offering potential solutions to bridge the gap between rural and urban education contexts. From the ubiquity of mobile phones to the proliferation of access to Internet services, individuals, including learners and teachers in some rural communities, are increasingly immersed in a digitally interconnected world (Welsh, 2024). Despite these advancements, many secondary school science teachers in rural South African schools now face technologically adept learners within technology-rich classrooms (Shambare et al., 2022), a stark contrast to the pre-service training and schooling they received. Consequently, teachers serving rural areas are compelled to adapt to this paradigm shift, leveraging technology to enhance pedagogical practices and learning outcomes. This adaptation requires re-examining knowledge that constitutes teacher competence in the modern educational context, as suggested by Koehler and Mishra(2009).

Historically, teacher competence was assessed primarily based on mastery of subject content (content knowledge) and effective pedagogical techniques (pedagogical knowledge) (Shulman, 1986). However, Shulman (1987) argued that competency in these areas alone could not fully capture the essence of effective teaching. To address this gap, he proposed the concept of pedagogical content knowledge (PCK), integrating pedagogical knowledge (PK) and content knowledge (CK) to inform teaching practices. While Shulman's framework remains relevant (Shulman, 1987, 2015), contemporary education discourse has evolved with the widespread integration of innovative technologies into teaching-learning environments, including in rural secondary schools.

Recognizing the permanence of these technological shifts, scholars like Leahy and Mishra (2023) advocate for teachers to possess technological pedagogical content knowledge (TPACK) to teach effectively with the technologies. Niess and Gillow-Wiles (2017, p.24) posit that "TPACK is attained when a teacher knows how technological tools transform pedagogical strategies and content representations for teaching particular content and how technology tools impact a learner's understanding of the content." However, it must be noted that most teachers in developing countries such as South Africa have not undergone formal training in technology integration, resulting in a notable gap in their technological knowledge. Intriguingly, despite the absence of formal training, our observations and experiences as science teacher educators at a university in South Africa indicate that most science teachers in rural secondary schools in the Joe Gqabi district in the Eastern Cape province of South Africa somehow integrate technologies into their classrooms to meet their learners' learning needs, potentially developing TPACK unknowingly. This discrepancy highlights a significant research gap in understanding how secondary school science teachers in rural schools develop technological pedagogical content knowledge, particularly in South Africa. Thus, the interest of this descriptive study is to quantitatively analyze the nature of science teachers' TPACK in rural secondary schools. Most of these teachers were not formally technologically trained during their pre-service teacher training.

Given the global reach and increasing scholarly interest in TPACK discourse, it becomes imperative to draw attention to a notable imbalance in the representation of studies about TPACK among science teachers from developing countries (Bwalya & Rutegwa, 2023). While most research on TPACK focuses more on developed countries in the Global North (Handayani et al., 2023), with numerous studies exploring its nuances and applications among science teachers, there remains a significant dearth of similar studies in rural secondary schools in developing countries such as South Africa. This discrepancy not only limits the understanding of how TPACK operates in diverse cultural and socio-economic contexts but also hinders efforts to address the unique challenges science teachers face in developing countries. In support, scholars such as Bwalya and Rutegwa (2023) assert that technology research has given little insight into understanding rural teachers' TPACK. Similarly, in South Africa, the few available studies on teachers' TPACK include those by Bernardesa and de Andrade Neto (2020), Tunjera and Chigona (2020), and Ramnarain et al. (2021), and Olayinka et al (2024). All these studies have focussed on pre-service teachers' TPACK assessment and none on in-service teachers, particularly science teachers in rural secondary schools.

Further, the few studies conducted on in-service teachers' TPACK in South Africa (Mutanga et al., 2018; Spangenberg & De Freitas, 2019; Ndlovu & Meyer, 2023) have mainly focussed on mathematics teachers at the primary school level and none on rural science teachers in the secondary schooling contexts. Yet, Cox and Graham (2009 p.47) underscored the nuanced nature of TPACK, characterizing it as "unique, temporary, situated, idiosyncratic, adaptive, and influenced by different contexts". This emphasis underscores the imperative of embracing descriptive perspectives, particularly those from rural schools in developing countries to grasp the multifaceted dynamics of TPACK assessment comprehensively.

This study addresses the question: What are the TPACK competencies among rural school life sciences teachers regarding the integration of technology into teaching? A notable contribution of this research lies in its investigation of rural secondary school teachers' TPACK, an area that remains relatively unexplored in South Africa. Explicitly focusing on science teachers in rural schools, a demographic often sidelined in global educational research discourse, this paper aims to provide an understanding of TPACK dynamics. Additionally, the study offers a detailed and descriptive analysis of individual TPACK components among rural school science teachers, highlighting both strengths and areas requiring improvement to facilitate effective technology integration. To achieve the objective above the paper begins with a comprehensive review of prior studies, followed by an exploration of the theoretical foundations of the research. This lays the groundwork for the methodology outlined in the next section. Afterwards, the results are presented and discussed. The paper concludes with sections on the implications, limitations, and potential directions for future research.

Evaluating Science Teachers' TPACK

Understanding teachers' TPACK has become progressively complex due to its situation-specific nature. Moreover, discrepancies and discussions surrounding the nature of TPACK, and its elements have been recorded in the literature (Cox & Graham, 2009; Niess & Gillow-Wiles, 2017), prompting varied methods for evaluating teachers' TPACK. These approaches include lesson observations (Choi & Paik, 2021), self-evaluation questionnaires (Kartal & Çınar, 2022), lesson plan assessments (Bingimlas, 2018), as well as diverse instruments such as preliminary and subsequent interviews and video recordings of teaching (Durdu & Dag, 2017). Among these numerous evaluation techniques, self-reported instruments, which might not accurately portray teachers' methods, persist as the primary data gathering tool. The ensuing studies provide perspectives into the assessment of TPACK.

Jang and Tsai (2013) conducted a descriptive study in Taiwan focusing on science teachers' TPACK using the TPACK framework. Data generated through questionnaires from 1292 science teachers was analyzed employing independent samples t-tests and ANOVA. Findings suggested that experienced teachers perceived their CK and PCK notably higher than their novice counterparts. Conversely, less experienced teachers rated their TK and TCK significantly higher than those with more significant experience. Similary, Irmak and Yilmaz Tüzün (2019) assessed the perceived levels of TPACK among 1530 pre-service teachers (PSTs) in Turkey, focusing on genetics. Data were collected via a questionnaire encompassing eight sub-dimensions of perceived TPACK. Statistical analysis such as descriptive analysis, multiple linear regression, and MANOVA were used to dissect the data. Results indicated that the average perceived TPACK score was 4.15 out of 6, with PSTs feeling most confident in PK and the slightest in TK. Additionally, perceived TPACK dimensions related to content significantly bolstered the PSTs' knowledge. In the study by Kaplon-Schilis and Lyublinskaya (2020), quantitative research was conducted in Malaysia to measure science teachers' confidence in technology integration using the TPACK framework. Data collected from questionnaires distributed among 408 teachers from 59 secondary schools was analyzed using descriptive and inferential statistics. Results unveiled high levels of CK, PK, TK, and PCK, contrasted with moderate levels of TCK, TPK, and TPACK. Additionally, teachers with more teaching experience demonstrated greater confidence in CK, PK, and PCK, whereas novice teachers exhibited slightly higher confidence in TK.

In another study, Sastria (2023) conducted a descriptive survey in Indonesia that evaluated TPACK levels among 211 pre-service and in-service science teachers, exploring various influencing factors such as gender, status, and age. Results showed dominance in understanding and applying non-technological dimensions among both groups. However, a greater need for TK was observed, suggesting lower levels of TK among the teachers. Analysis revealed significant differences concerning status and age, although no significant differences were found regarding age alone. In contrast, Amidi et al. (2024) conducted a recent study in Central Java in Indonesia assessing mathematics PSTs' TPACK. Employing a descriptive approach and questionnaires distributed among 100 respondents, findings indicated an adequate understanding of TPK and TCK in mathematics education. Overall, respondents demonstrated a satisfactory grasp of TPACK in mathematics teaching.

Ning et al. (2024) revisited the relationship between technology, pedagogy, and content in the context of artificial intelligence (AI) in Chinese school teachers. The scholars developed a scale for assessing teachers' AI-TPACK, administered to 400 teachers. This framework comprised seven components, including PK, CK, AI-Technological Knowledge (AI-TK), PCK, AI-Technological Pedagogical Knowledge (AI-TCK), AI-Technological Pedagogical Knowledge (AI-TPK), and AI-TPACK. Utilizing structural equation modelling (SEM) through exploratory factor analysis (EFA) and confirmatory factor analysis (CFA), the study revealed that all six knowledge elements served as predictive factors for AI-TPACK. Notably, core knowledge elements indirectly influenced AI-TPACK, mediated by composite knowledge elements, with technology-related elements playing a more significant role. Additionally, CK diminished the explanatory power of TPK and AI-Technological Pedagogical Knowledge.

The critical point of reflection from most of these past studies is a predominant focus on PSTs was observed in the existing research on TPACK. Notably, Setiawan et al.'s (2019) review spanning the years 2011 to 2017 underscored this trend, revealing that most studies (66%) centred on PSTs, with only one-third (31%) examining in-service teachers. This discrepancy highlights a notable absence of understanding regarding the development of TPACK among in-service teachers, particularly in comparison to their pre-service counterparts. Therefore, this study seeks to fill this void by investigating the TPACK development of in-service teachers, particularly within the domain of life sciences. Moreover, there exists a disparity in the literature concerning teachers' TPACK levels. For instance, Irmak and Yilmaz Tüzün (2019) discovered that PSTs expressed the highest confidence in PK but the lowest in TK. Conversely, these outcomes contrast with the findings of Kaplon-Schilis and Lyublinskaya

(2020), who observed that experienced teachers exhibited heightened confidence in CK, PK, and PCK, while novice teachers demonstrated elevated confidence levels in TK.

The literature further suggests a geographical imbalance in the distribution of TPACK research. For instance, Handayani et al.'s (2023) bibliometric analysis of TPACK research trends revealed that the United States of America led in the number of studies conducted, followed by Türkiye, Australia, Singapore, and South Korea. This observation suggests a significant research gap, wherein a limited number of studies have been conducted on TPACK in developed countries as opposed to the developing countries in Africa. Although some research has explored teachers' TPACK in developing countries, the emphasis has been on PSTs. For example, Ramnarain et al.' s (2021) study in South Africa investigated 103 third- and fourth-year PST levels regarding their practical knowledge of technological pedagogical content knowledge (TPACK-P) using a 17-item questionnaire. Rasch analysis was employed to analyze the data. The findings showed that the majority of PSTs have a competency level of 3 for their knowledge of TPACK-P.

Technological Pedagogical Content Knowledge (TPACK) Framework

The TPACK framework offers a valuable approach to identifying the core knowledge required by teachers to effectively incorporate technologies into their teaching (Koehler & Mishra, 2006). This framework builds upon Shulman's (1987) seminal work, which introduced the concept of PCK as the intersection of PK, CK and TK. By examining how pedagogy, content, and technology intersect, TPACK provides a lens to understand the complex dynamics of technology integration in education. Scholars such as Leahy and Mishra (2023) have highlighted the importance of the TPACK framework in elucidating how the integration of technology influences the interaction between content, pedagogy, and technology. Within this context, Koehler and Mishra (2006) have emphasized that TPACK directs attention towards the concept that:

> New technological resources reshape pedagogical knowledge, content knowledge, and pedagogical content knowledge. Furthermore, effective teaching with technology is context-dependent, and it necessitates a profound understanding of how technology interacts with pedagogy and content. (p. 13)

Drawing from this interpretation, Koehler and Mishra (2006) conceptualized TPACK as the intricate and interdependent relationship among CK, PK, and TK. Mishra (2019) further underscored this perspective by stating:

> Good teaching is not simply adding technology to the existing teaching and content domain. Instead, the introduction of technology causes the representation of new concepts. It requires developing a sensitivity to the dynamic, transactional relationship between all three components suggested by the TP[A]CK framework. (p. 87)

Recently, Mishra et al. (2022) underscored that the TPACK model (see Figure 1 and Table 1) "involves asking how technology can enhance and broaden effective teaching and learning within a particular discipline. This process also entails adapting to the changes in content and pedagogy that technology inherently introduces" (p. 2198).

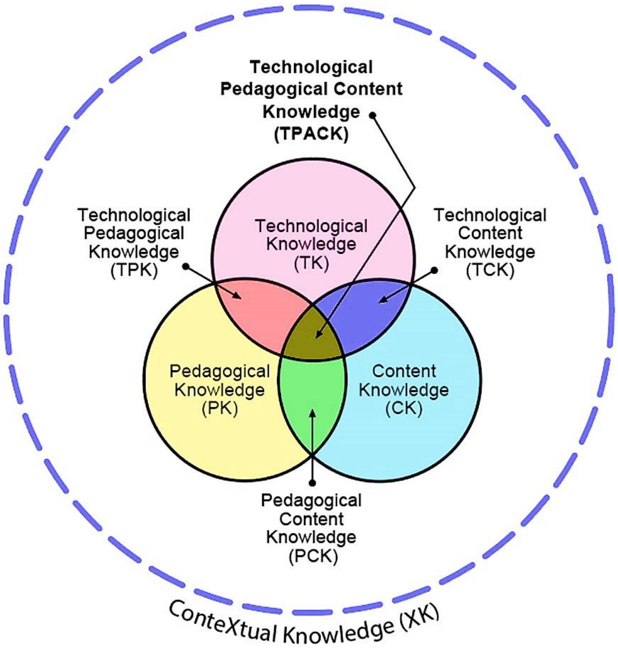

Figure 1. Updated TPACK Diagram (Mishra, 2019, p. 2)

The study adopted the TPACK framework because of its ability to provide perspectives for comprehending the types of knowledge we aimed to investigate. This framework not only shaped our research methodology but also enabled us to explore the connections between rural science teachers' self-reported CK, PK, and TK as they navigate the integration of technology in their classrooms.

Table 1. The Eight TPACK Framework Constructs (Mishra2019 p. 9)

Construct	Abbreviation	Definition
Content knowledge	CK	Knowledge of the subject matter
Technological knowledge	TK	Knowledge of many technologies
Pedagogical knowledge	PK	Knowledge of teaching methods
Technological content knowledge	TCK	Knowledge of delivering subject matter through the application of technology
Technological pedagogical knowledge	TPK	Knowledge of incorporating technology to implement diverse teaching strategies
Pedagogical content knowledge	PCK	Knowledge of teaching methods tailored for different types of content
Technological pedagogical content knowledge	TPACK	Knowledge of utilizing technology to execute teaching methodologies across diverse subject content

Methodology

This study adopted a quantitative method and a descriptive survey design. A descriptive study is "one that is designed to describe the distribution of one or more variables, without regard to any causal or other hypotheses" (Aggarwal & Ranganathan, 2019, p. 34). Prominent scholars like Jang and Tsai (2013), Sastria (2023), and Ning et al. (2024) have applied this methodology in their investigations, finding it suitable for elucidating phenomena without manipulation. Our methodology is organized into sections: respondents, questionnaire design, data generation and data analysis techniques.

Respondents

This research comprised 235 respondents selected from the cohort of rural secondary school life science teachers in the Eastern Cape province, South Africa. Eligible respondents had to be qualified life sciences teachers employed in rural schools with access to and use technologies such as computers, laptops, mobile technologies, and the Internet in their teaching. The teachers were sourced through science teachers' quarterly meetings at the provincial office. Table 2 presents the respondents' demographic information, including gender, age, years of teaching experience, and educational levels.

Table 2. Demographics of the Respondents

Gender	**N**	**%**
Female	150	64
Male	85	36
Age (years)	**N**	**%**
24–30	57	24
31–40	76	32
41–50	64	27
51–60	26	11
> 61	4	2
Teaching experience (years)	**N**	**%**
0–4	37	16
5–10	81	34
11–15	45	19
16–20	40	17
21–25	23	10
> 26	9	4
Educational level	**N**	**%**
Bachelors' degree	187	80
Post-graduate certificate	41	17
Master's degree	1	0
Doctoral degree	0	0
Other	6	3

The demographic profile of the respondents reveals a significant gender disparity, with a higher representation of female teachers (n = 150; 64%) compared to male teachers (n = 85; 36%). The average age of the respondents was 33 years, with 21.5% within this age range. Most respondents (n = 140; 60%) were distributed across the 31

- 40 years and 41 - 50 years age brackets. Regarding teaching experience, the largest segment (n = 81; 34.5%) reported having 5 - 10 years of experience. In terms of educational qualifications, a substantial proportion of respondents (n = 187; 80%) indicated holding a Bachelor of Education degree.

Questionnaire Design

This study utilized a measurement scale adapted from the classical scale proposed by Schmidt et al. (2009), employing a 5-point Likert scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). The questionnaire consisted of two main sections: The first section aimed to gather demographic information (7 items), while the second section collected responses regarding the TPACK constructs (TK = 6 items, PK = 8 items, PCK = 2 items, CK = 6 items, TPK = 6 items, and TPACK = 3 items). It is important to note that, except for minor wording changes tailored to the specific words in this examination, no changes were made to the user acceptance scale. The questionnaire administered in the study comprised a total of 38 items.

Reliability and Validity of the Questionnaire Instrument

Before this research, several researchers had already assessed the reliability of the instrument employed using the widely recognized Cronbach alpha coefficient test of inter-item consistency reliability (Cronbach, 1951; Cliff, 1984; Hajjar, 2018). Paulsen and BrckaLorenz (2017) emphasized that "utilizing existing, previously validated measures indicates that the data are reliable and can enhance the likelihood that new data are reliable" (p. 53). The Cronbach alpha coefficients derived from the collected data indicated high reliability, with values ranging from 0.75 to 0.94. This aligns with the assertion of Cohen et al. (2017), who stated:

> Cronbach's alpha is a metric used to assess internal consistency, yielding a reliability coefficient ranging from 0 to 1. The interpretation typically considers scores above 0.90 as very highly reliable, 0.80 – 0.90 as highly reliable, 0.70 – 0.79 as reliable, 0.60 – 0.69 as minimally reliable, and scores below 0.60 as unacceptable. (pp. 638–641)

Therefore, with a median alpha of 0.80, the reliability measures of the 31 domain scores indicate that the questionnaire exhibits high reliability, as depicted in Table 3.

Table 3. Questionnaire Reliability Statistics

Construct	No. of variables	Cronbach alpha coefficient	Result
TK	6	0.78	Reliable
CK	6	0.82	Highly reliable
PK	8	0.82	Highly reliable
PCK	2	0.81	Highly reliable
TPK	6	0.83	Highly reliable
TPACK	3	0.75	Reliable
Total scale score	**31**	**0.80**	**Highly reliable**

Data Generation

The first author distributed the questionnaire to 250 life sciences teachers during a quarterly subject meeting at the provincial district office. Respondents had three weeks to complete and return the questionnaire voluntarily. Upon receiving the completed questionnaires, the second author coded and entered the data into a Microsoft Excel spreadsheet. Subsequently, the authors conducted an initial data inspection (data cleaning) to identify any missing values before transferring the data to the Statistical Package for the Social Sciences (SPSS) Version 29 programme for analysis. The SPSS is a comprehensive software widely used for statistical analysis in social science research. The authors found that fifteen questionnaires contained incomplete information, rendering them unsuitable for inclusion in this research. Ultimately, the authors deemed a total of 235 questionnaires usable for subsequent data analysis.

Data Analysis

The authors transferred the data captured on the Excel spreadsheet to SPSS version 29 for analysis. Utilizing descriptive statistical analysis, the study primarily focused on central tendency, frequency distribution, and measures of association and dispersion, which included standard deviation (SD), mean (M), and frequency (N).

Ethics Clearance

The study sought ethical clearance from the ethics committee of our affiliated university. This committee thoroughly reviewed our study to ensure compliance with ethical standards. Before participating in the study, all respondents were provided with comprehensive information about the study's objectives, procedures, potential risks, and benefits. The participants were encouraged to ask questions and seek clarification before giving their consent. Consent was documented through signed consent forms, and verbal consentwas accurately recorded. The study assured respondents of their voluntary participation rights, including the option to withdraw at any stage, and guaranteed privacy and confidentiality.

Findings

To understand the respondents' TPACK levels, the study applied Fisher and Marshall's (2009) classification to interpret the mean scores of the five-point Likert scale. Table 4 illustrates the mean score classification.

Table 4. Classification of Mean Scores

Mean score	**Classification**
1.0–1.79	Very low
1.8–2.59	Low
2.6–3.39	Medium/Neutral
3.4–4.19	High
4.2–5.0	Very high

TPACK Descriptive Statistics

The results presented are derived from descriptive statistical analysis of the questionnaire responses provided by the surveyed teachers. Table 5 displays the descriptive statistics for each TPACK domain.

Table 5. Descriptive Statistics: TPACK Domains

Construct	N	Mean	SD	Min	Max
TK	235	3.4475	0.9732	1.00	5.00
CK	235	4.3014	0.4530	3.00	5.00
PK	235	4.3821	0.5162	3.00	5.00
PCK	235	4.2378	0.3839	3.00	5.00
TPK	235	3.9090	0.7346	1.00	5.00
TPACK	235	3.1137	1.0420	1.00	5.00

Table 5 illustrates the mean, standard deviation, minimum, and maximum values for the six TPACK domains, divided into two categories: three associated with non-technology constructs(list here the constructs) and three associated with technology constructs(list here the constructs). The non-technology constructs demonstrated higher mean scores, all surpassing 4.0: CK (M = 4.3014; SD = 0.4530), PK (M = 4.3821; SD = 0.5162), and PCK (M = 4.2378; SD = 0.3839). Additionally, the standard deviations for these constructs were lower, indicating strong consensus among respondents regarding their solid comprehension of subject content and teaching strategies. In contrast, the technology-related TPACK domains exhibited lower mean values compared to the non-technology ones: TK (M = 3.4475; SD = 0.9732), TPK (M = 3.9090; SD = 0.7346), and TPACK (M = 3.1137; SD = 1.0420). This suggests a potential need for life sciences teachers to bolster their technological knowledge and pedagogical skills related to technology. Figure 2 provides a graphical representation of the descriptive statistics of the TPACK domains, aiming to offer a more precise visualization and facilitate a comparative analysis of the prominence of the different TPACK components.

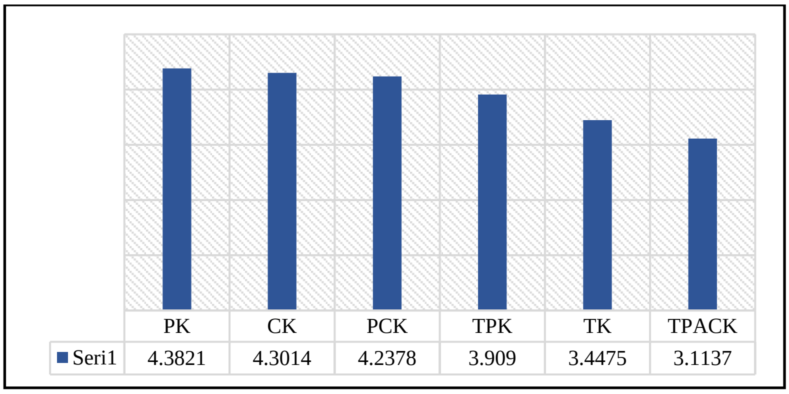

Figure 2. Descriptive Statistics: TPACK Domains (N = 235)

The prominence of PK, CK, and PCK over TPK, TK, and TPACK constructs suggests that life sciences teachers excel more in non-technology constructs while indicating lower confidence in the technology domains. The South African education system’s emphasis on subject specialization at secondary teaching levels, requiring teachers to possess degrees in their subjects, may explain their high CK and PK levels. Additionally, prioritizing pedagogical skills in continuous professional development programmes among in-service teachers might have enhanced their PCK.

Technological Knowledge

The questionnaire consisted of seven items regarding Technological Knowledge (TK), with the corresponding statements and relevant statistical data presented in Table 6.

Table 6. Descriptive Statistics: TK (N = 235)

Statement	Mean	SD	Min	Max
I can learn to use educational technologies easily	3.83	1.017	1.00	5.00
I can teach with the use of different technologies	3.64	0.996	1.00	5.00
I often play around with technology tools	3.40	1.170	1.00	5.00
I know of a lot of different technology tools	3.12	1.210	1.00	5.00
I keep up with important emerging technologies	3.35	1.131	1.00	5.00
I know which technologies would work best for my life sciences teaching	3.35	1.168	1.00	5.00

Overall mean score (3.4475) and standard deviation (0.9732)

Based on the mean ratings presented in Table 6, respondents demonstrated significant competency in TK. Notably, they showed a solid ability to learn technology easily (M = 3.83; SD = 1.017), indicating adaptability and a willingness to explore new technological tools in education. The survey also highlighted respondents' comfort in utilizing various technologies for teaching, reflected in ratings for items such as teaching with different technologies (M = 3.64; SD = 1.1858) and playing around with technology tools (M = 3.40; SD = 1.170). However, familiarity with a wide array of technologies received a lower mean rating (M = 3.12; SD = 1.210), suggesting some respondents may lack confidence in their knowledge of various tools. The significant standard deviation for this item (SD = 1.210) indicates variability in respondents' TK levels, underscoring the need for ongoing skill development. Overall, with a mean rating of (M = 3.4475; SD = 0.9732), these findings indicate a high level of TK among respondents, positioning them well to meet the technological demands of contemporary teaching practices.

Content Knowledge

The questionnaire required the respondents to respond to six statements concerning their CK. Table 7 displays the statistics in this regard. The data in Table 7 outlines respondents' perceptions of their CK. Remarkably, the statement "*I am familiar with the life sciences content that CAPS prescribes* received the highest mean rating (M = 4.47; SD = 0.533), indicating a strong familiarity with the CAPS curriculum among respondents. Following closely, "*sufficient knowledge to answer most learners' life sciences questions"* received a mean rating of (M = 4.35; SD = 0.569), reflecting respondents' confidence in addressing learners' inquiries. However, the statement "*I have various ways and strategies of developing my own life sciences understanding"* had the lowest mean rating

(M = 4.13; SD = 0.543), albeit with a relatively low standard deviation (SD = 0.5190), indicating a consensus among respondents regarding their competency in enhancing their understanding. Overall, the findings suggest respondents perceive themselves as highly knowledgeable in life sciences content, with mean scores exceeding four and relatively consistent agreement among respondents. The CK construct received a notably high mean rating (M = 4.3014) and standard deviation (SD = 0.4530), indicating uniformly high CK levels among respondents.

Table 7. Descriptive Statistics: CK (N = 235)

Statement	Mean	SD	Min	Max
I possess sufficient life sciences knowledge to teach the subject	4.29	0.635	2.00	5.00
I can use a scientific way of thinking	4.22	0.622	2.00	5.00
I have many ways and approaches to increasing my own life sciences understanding	4.13	0.543	2.00	5.00
I am familiar with the life sciences content that is prescribed by CAPS	4.47	0.533	3.00	5.00
I understand and can explain the concept of the scientific method	4.34	0.596	2.00	5.00
I have sufficient knowledge to answer most learners' life sciences questions	4.35	0.569	3.00	5.00

*Overall mean score (4.3014) and standard deviation (0.4530)

Pedagogical Knowledge

The respondents were asked to respond to three PK statements, and the results are shown in Table 8.

Table 8. Descriptive Statistics: PK (N = 235)

Statement	Mean	SD	Min	Max
I can assess learners' performance in life sciences, including knowledge of different cognitive levels, degrees of question difficulty, and the concept of a 'reasonable learner.'	4.09	0.599	2.00	5.00
I know how to adapt my teaching depending on what learners understand or do not understand	4.22	0.539	2.00	5.00
I know how to assess learning in multiple ways	4.27	0.498	3.00	5.00
I can adapt my teaching style to different learners	4.21	0.565	2.00	5.00
I can use various teaching approaches in my life sciences class	4.23	0.502	3.00	5.00
I am familiar with common learner understandings and misconceptions of life sciences	4.21	0.560	2.00	5.00
I can organize and maintain class management and control	4.39	0.606	2.00	5.00
I am familiar with the prescribed life sciences textbooks and other learning resources used in most South African classrooms	4.29	0.577	2.00	5.00

*Overall mean score (4.3821) and standard deviation (0.4162)

Table 8 provides an overview of the respondents' PK domain. It is evident from the table that all PK statements received mean ratings above 4, indicating the respondents' confidence in guiding learners towards appropriate learning methods and monitoring their educational progress. Notably, the statement *I know how to organize and maintain class management and control* received the highest mean rating (M = 4.39; SD = 0.560), highlighting the crucial role of effective classroom management in successful teaching. Moreover, respondents expressed a strong *familiarity with prescribed life sciences textbooks and other classroom resources* (M = 4.29; SD = 0.577). However, the lowest mean value on the PK scale was associated with the item concerning *assessing learners' performance in life sciences, encompassing knowledge of cognitive levels, question difficulty, and the concept of a 'reasonable learner* (M = 4.09; SD = 0.599). Nonetheless, this finding suggests respondents' confidence in their ability to evaluate learners' performance in life sciences. In summary, respondents reported very high PK levels, with an overall mean value of (SD = 4.3821), and a high level of agreement across all items (SD = 0.4162). Furthermore, the elevated mean scores for PK indicate respondents' belief in their capacity to engage learners with challenging activities, thereby promoting critical thinking.

Pedagogical content Knowledge

The respondents were asked to respond to three PCK statements, and the results are shown in Table 9.

Table 9. Descriptive Statistics: PCK (N = 235)

Statement	Mean	SD	Min	Max
I can teach specific life sciences concepts/topics using specific technologies	3.89	0.906	1.00	5.00
I can select effective teaching approaches to guide learners in thinking and learning about my subject.	3.93	0.765	1.00	5.00

*Overall mean score (4.2378) and standard deviation (0.3839)

The statistical data provided in Table 9 offer insights into the PCK mean ratings and standard deviation values. A detailed examination of the mean ratings for individual items reveals that all values exceeded 3.8, indicating a notable competency in teacher PCK. Particularly striking is the statement "*that I can select effective teaching approaches to guide learners' thinking and learning in my subject"* (M = 3.93; SD = 0.765), which garnered the highest mean score. The following are three items that have similar means: "*I can teach specific life sciences concepts/topics using specific technologies"* (M = 3.89; SD = 0.906). These items all achieved mean scores above 3.8, highlighting the teachers' strong self-reported PCK levels. Overall, the mean score for PCK was notably high (M = 4.2378; SD = 0.3839), indicating that the teachers in this study possessed the necessary knowledge and skills to effectively integrate Pedagogical and Content Knowledge, thereby providing diverse learning opportunities for their students.

Technological Pedagogical Knowledge

The respondents were asked to respond to three TPK statements, and the results are shown in Table 10. The findings presented in Table 10 depict the results of the six individual TPK items. Notably, the item "*I can choose technologies that enhance learners' understanding of a lesson"* (M = 3.22; SD = 1.141) garnered the highest mean value among the various items. Upon closer examination of the individual TPK statements, it becomes evident that the lowest mean rating (M = 2.94; SD = 1.144) was attributed to the item "*I can provide leadership in helping others to coordinate the use of content, technologies, and teaching approaches*". This observation suggests that a considerable number of respondents may either be uncertain or lack confidence in their capacity to mentor others in utilizing technologies for teaching purposes.

Table 10. Descriptive Statistics: Tpk (N = 235)

Statement	**Mean**	**SD**	**Min**	**Max**
I can plan a lesson that incorporates the use of technology.	3.17	1.215	1.00	5.00
I can choose technologies that enhance the teaching approaches for a lesson.	3.22	1.141	1.00	5.00
I can choose technologies that enhance learners' understanding of a lesson.	2.96	1.143	1.00	5.00
I always think critically about how to use technology in my class.	3.13	1.186	1.00	5.00
I can select technologies to use in my classroom that enhance what I teach, how I teach and what learners learn.	3.20	1.127	1.00	5.00
I can provide leadership by helping others coordinate the use of the content, technologies, and teaching approaches.	2.94	1.144	1.00	5.00

*Overall mean score (3.9090) and standard deviation (0.7346)

Technological Pedagogical Content Knowledge

The respondents were asked to respond to three TPACK statements, and the results are shown in Table 11. The results in Table 11 show an overall mean rating for TPACK of (M = 3.1137; SD = 1.0420). The mean values for all TPACK statements ranged between 3.10 to 3.13, indicating moderate TPACK levels. Particularly noteworthy is the fact that the TPACK construct attained the lowest mean score among all six domains, implying concerning levels of TPACK among the teachers in this study. Moreover, the standard deviation values for the TPACK items exceed 1.0, signifying greater variation in respondents' responses. This suggests a notable diversity in perceptions and competencies regarding TPACK among the respondents.

Table 11. Descriptive Statistics: TPACK (N = 235)

Statement	**Mean**	**SD**	**Min**	**Max**
I can adapt and use particular technologies to meet my different learners' learning capabilities.	3.10	1.057	1.00	5.00
I can teach life sciences concepts/topics that appropriately combine the content with technology skills.	3.13	1.015	1.00	5.00
I can choose technologies that enhance the content of a lesson.	3.13	1.006	1.00	5.00

*Overall mean score (3.1137) and standard deviation (1.0420)

Discussion

This paper pioneers an exploration into assessing the Technological Pedagogical Content Knowledge (TPACK) of science teachers in rural and marginalized regions of the Global South, an aspect often overlooked in TPACK discourse but critical for a comprehensive understanding of teacher knowledge. The paper categorizes teachers' TPACK levels across six constructs, delineating them into non-technology-related domains (CK, PK, and PCK) and technology-related domains (TK, TPK, and TPACK), drawing upon the framework proposed by Koehler and Mishra (2006). These findings support earlier research by Jang and Tsai (2013) and Kaplon-Schilis and Lyublinskaya (2020), showing that experienced teachers excel more in non technology domains than in technology ones. This implies a robust grasp of subject content and pedagogy among these educators. One possible reason could be that most in-service teachers who did not receive technology integration training during their initial teacher education have honed their skills in non-technology areas through practical teaching experience. However, contrary to these expectations, research by Irmak and Yilmaz Tüzün (2019) revealed a different pattern among pre-service teachers (PSTs). They showed the highest confidence in PK but the lowest in TK.

Realizing that practising teachers generally exhibit higher levels of PK, CK, and PCK compared to TK, TPK, and TPACK (Koehler & Mishra, 2009; Thohir et al., 2022; Sastria, 2023), our investigation prompts an inquiry into when teachers in rural schools will attain advanced competency in technology-related TPACK domains. Compared to technology-related domains, the comparatively higher mean scores for non-technology domains suggest that rural life sciences teachers possess a firmer grasp of subject content and teaching methodologies than technological expertise. This observation resonates with South Africa's teacher training system, where qualified secondary school teachers are mandated to hold a degree in their respective subject area, and ongoing professional development programs prioritize workshops addressing content gaps and enhancing pedagogical skills, thereby bolstering teachers' competency in CK, PK, and PCK.

Additionally, this study is consistent with the findings of the study by Luo et al. (2023), which identifies TK as the most dominant domain among the three technology-related components. However, integrating TK with CK and PK presents challenges, as evidenced by the lower mean scores for TPK and TPACK. This observation aligns with prior studies suggesting that teachers often grapple with understanding the dynamic interplay and transactional relationships between CK, PK, and TK (Amidi et al., 2024; Choi & Paik, 2021; Jang & Tsai, 2013). Recognizing the ever-evolving nature of technology, which necessitates ongoing updates and adaptations, is essential. Consequently, the dynamic nature of technology may contribute to the delay in developing technology-related knowledge domains compared to more stable domains such as CK and PK. Acknowledging this context underscores the significance of continuous professional development to ensure teachers remain abreast of technological advancements and their effective integration into teaching practices.

Conclusion

The increasing prevalence of technology in rural classrooms, particularly in many developing countries like South Africa, highlights the importance of assessing teachers' competence in effectively utilizing these tools to avoid potential risks such as technology abandonment or inadequate utilization. This study provides descriptive insights into the competency levels of TPACK among rural life sciences teachers. Findings revealed an overall low level of TPACK among teachers in rural schools and indicated an urgent need for enhanced competencies to integrate technologies successfully. Proposed strategies to address this challenge include tailored professional development initiatives and increased technology adoption. Despite teachers demonstrating notable competency in non-technology domains, such as CK, PK, and PCK, a significant discrepancy is observed in technology-related TPACK domains, with lower competency levels noted in TK, TPK, and overall TPACK. This research pioneers an investigation into the specific context of rural and under-resourced schools, laying the groundwork for valuable insights crucial to understanding teachers' TPACK and facilitating successful technology integration in these settings. In conclusion, we affirm that focusing on specific TPACK domains rather than seeking TPACK in a generalized domain can provide deeper insights into the nature of TPACK and better support the development of this knowledge among rural secondary school science teachers.

Implications

Assessing TPACK in South African science education represents an emerging research domain. This study marks a foundational step in determining teachers' TPACK in rural schools, setting the groundwork for further inquiry. Insights gleaned from the TPACK levels of rural school science teachers inform the development of targeted interventions and support mechanisms. Policymakers can adopt these findings to craft initiatives aimed at enhancing teachers' knowledge for effective technology integration in teaching, thereby promoting equitable access to quality education in remote areas. These implications resonate globally, contributing to educational technology integration discussions across diverse learning environments, including rural and marginalized region schools. South African rural schools offer valuable insights for educators, researchers, and policymakers worldwide, fostering collaborative efforts to address challenges and optimize the benefits of technology in teaching. Ultimately, this study enriches the ongoing discourse on the intersection of technology and education, advocating for a more inclusive and responsive approach to advancing learning opportunities for all, not only in South Africa but also in various socio-economic and cultural contexts globally.

Limitations

Like all research, this study of rural secondary school teachers' TPACK has strengths and limitations. While the paper assessed teachers' TPACK, it is essential to acknowledge constraints. One such limitation relates to the timeframe for data collection, which coincided with demanding provincial quarterly meetings for rural science teachers. Because data collection occurred while science teachers were attending meetings at the provincial office, the study encountered challenges in securing comprehensive responses from participating teachers due to time constraints and competing priorities.

Future Research

Future research efforts could build upon the insights gained from this study to expand further understanding of teachers' TPACK in rural secondary schools. Firstly, conducting longitudinal studies could provide valuable insights into the development and evolution of teachers' TPACK over time, offering a deeper understanding of how training and experience influence competency levels. Additionally, exploring the effectiveness of specific professional development interventions tailored to enhance teachers' TPACK could offer practical strategies for improving technology integration in rural classrooms.

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